

HANDBOOK ON INGREDIENTS FOR AQUACULTURE FEEDS

Handbook on Ingredients for Aquaculture Feeds

by

Joachim W. Hertrampf

Dr. sc. agr., Dipl. agr., Dipl.-Ing.

and

Felicitas Piedad-Pascual

Ph.D. Nutr., M.S. Food & Nutr., B.S. Pharm.

ILLUSTRATIONS BY ONG, SIK LEE †



SPRINGER—SCIENCE+BUSINESS MEDIA, B.V.

Library of Congress Catalog-in-Publication data is available.

ISBN 978-1-4020-1527-4 ISBN 978-94-011-4018-8 (eBook)
DOI 10.1007/978-94-011-4018-8

Printed on acid-free paper

All Rights Reserved

© 2000 Springer Science+Business Media Dordrecht

Originally published by Kluwer Academic Publishers in 2000

Softcover reprint of the hardcover 1st edition 2000

No part of the material protected by this copyright notice may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying, recording or by any information storage and retrieval system, without written permission from the copyright owner.

*Only God knows everything,
Man cannot know everything,
But he can learn to know many things.*

CONTENTS

List of Tables	xxiii
List of Figures	xxxix
List of Abbreviations	xliii
Preface	xliv
Acknowledgement	xlix
1 Prologue	1
2 Nutrition of Aquatic Animals at a Glance	4
2.1 Diversity of cultured aquatic animals	4
2.2 Proteins	9
2.3 Carbohydrates	13
2.4 Lipids	16
2.5 Vitamins	19
2.6 Minerals	23
2.7 Other feed supplements	27
2.7.1 Chemo-attractants	27
2.7.2 Antibiotics	29
2.7.3 Antioxidants	31
2.8 Physical properties of feed	33
2.9 References	35
3 Animal fats	43
3.1 Rationale	43
3.2 Manufacture and processing	43
3.3 Tallow	43
3.3.1 Description	43
3.3.2 Chemical and physiological properties	44
3.3.3 Feeding value	46
3.4 Lard	50
3.4.1 Description	50
3.4.2 Chemical and physiological properties	50
3.4.3 Feeding value	50
3.5 Poultry fat	53
3.6 Animal fat	53
3.6.1 Description and properties	53
3.6.2 Feeding value	53
3.7 Quality criteria of animal fats	54

3.8	Recommended inclusion rates	56
3.9	Legal aspects	56
3.10	References	57
4	Bile acid products	60
4.1	Rationale	60
4.2	Manufacture and processing	60
4.3	Chemical and physiological properties	60
4.4	Feeding value	62
4.5	Recommended inclusion rates	62
4.6	Legal aspects	63
4.7	References	63
5	Bleaching earth (used)	65
5.1	Rationale	65
5.2	Processing	65
5.3	Chemical and physiological properties	65
5.4	Feeding value	67
5.5	Recommended inclusion rates	68
5.6	Legal aspects	68
5.7	References	68
6	Blood products	69
6.1	Rationale	69
6.2	Collection and processing	69
6.3	Chemical, physiological and other properties	70
6.4	Feeding value	74
6.4.1	Blood meal	74
6.4.2	Preserved blood	76
6.5	Recommended inclusion rates	76
6.6	Legal aspects	77
6.7	References	78
7	Brewer's grains (de-hydrated)	80
7.1	Rationale	80
7.2	Manufacture and processing	80
7.3	Chemical, physiological and other properties	80
7.4	Feeding value	83
7.5	Recommended inclusion rates	83
7.6	Legal aspects and precautions	84
7.7	References	84
8	Casein (de-hydrated)	86
8.1	Rationale	86
8.2	Manufacture and processing	86

8.3	Chemical, physiological and other properties	86
8.4	Feeding value	90
8.5	Recommended inclusion rates	92
8.6	Legal aspects	92
8.7	References	92
9	Cheese scrap	96
9.1	Rationale	96
9.2	Processing	96
9.3	Chemical and physiological properties	96
9.4	Feeding value	98
9.5	Recommended inclusion rates	98
9.6	Legal aspects and precautions	98
9.7	References	98
10	Cocoa-pod husk meal	100
10.1	Rationale	100
10.2	Manufacture and processing	100
10.3	Chemical, physiological and other properties	100
10.4	Feeding value	102
10.5	Recommended inclusion rates	103
10.6	Legal aspects	103
10.7	References	103
11	Coffee pulp (de-hydrated)	105
11.1	Rationale	105
11.2	Processing	105
11.3	Chemical, physiological and other properties	105
11.4	Feeding value	106
11.5	Recommended inclusion rates	107
11.6	Legal aspects and precaution	107
11.7	References	108
12	Crab Meal	109
12.1	Rationale	109
12.2	Manufacture and processing	109
12.3	Chemical, physiological and other properties	110
12.4	Feeding value	112
12.5	Recommended inclusion rates	113
12.6	Legal aspects and precautions	113
12.7	References	113
13	Distillery by-products	115
13.1	Rationale	115
13.2	Manufacture and processing	115

13.3	Chemical, physiological and other properties	116
13.4	Feeding value	119
13.5	Recommended inclusion rates	121
13.6	Legal aspects	122
13.7	References	122
14	Egg Powder	125
14.1	Rationale	125
14.2	Manufacture and processing	125
14.3	Chemical and physiological properties	126
14.4	Feeding value	129
14.5	Recommended inclusion rates	129
14.6	Legal aspects	129
14.7	References	129
15	Feather Meal	131
15.1	Rationale	131
15.2	Manufacture and processing	132
15.3	Chemical, physiological and other properties	133
15.4	Feeding value	136
15.5	Recommended inclusion rate	139
15.6	Legal aspects	139
15.7	References	140
16	Feed Carotenoids	142
16.1	Rationale	142
16.2	Biochemical, biological and other properties	142
16.3	Carotenoid products	145
16.3.1	Synthetic astaxanthin and canthaxanthin	145
16.3.2	Yeast astaxanthin	149
16.3.3	Algal astaxanthin	150
16.3.4	Astaxanthin from crustacean wastes	151
16.4	Recommended inclusion rates	153
16.5	Legal aspects and precautions	153
16.6	References	154
17	Feed Yeast	157
17.1	Rationale	158
17.2	Inactive yeast	158
17.2.1	Definition and manufacture	158
17.2.2	Chemical, physiological and other properties	159
17.2.3	Feeding value	164
17.2.3.1	Fishes	164
17.2.3.2	Crustaceans	166
17.2.3.3	Molluscs	167

17.2.3.4	Zooplankton	167
17.3	Active yeast	169
17.3.1	Definition and production	169
17.3.2	Chemical and other properties	169
17.3.3	Feeding value	171
17.4	Recommended inclusion rates	172
17.5	Legal aspects	172
17.6	References	172
18	Fish meal	177
18.1	Rationale	177
18.2	Manufacture and processing	178
18.3	Chemical, physiological and other properties	180
18.4	Feeding value	185
18.5	Recommended inclusion rates	187
18.6	Legal aspects	187
18.7	References	188
19	Fish protein concentrate (hydrolysed)	192
19.1	Rationale	192
19.2	Manufacture and processing	192
19.3	Chemical, physiological and other properties	192
19.4	Feeding value	195
19.5	Recommended inclusion rates	197
19.6	Legal aspects	197
19.7	References	197
20	Fish Silage and other marine silages	198
20.1	Rationale	198
20.2	Manufacture and processing	199
20.2.1	Acid silage	199
20.2.2	Alkaline silage	199
20.2.3	Fermented silage	200
20.3	Chemical, physiological and other properties	200
20.3.1	Chemical properties	200
20.3.2	Physiological properties	203
20.3.3	Other properties	204
20.4	Feeding value	205
20.5	Recommended inclusion rates	207
20.6	Legal aspects and precautions	207
20.7	References	208
21	Fish Solubles (de-hydrated)	211
21.1	Rationale	211
21.2	Manufacture and processing	211

21.3	Chemical, physiological and other properties	211
21.4	Feeding value	214
21.5	Recommended inclusion rates	214
21.6	Legal aspects	214
21.7	References	215
22	Immunostimulatory substances	217
22.1	Rationale	217
22.2	Substances with immunostimulatory effect	217
22.3	Glucans	217
22.4	Application response	219
22.5	Doses of administration and legal aspects	219
22.6	References	219
23	Krill meal	221
23.1	Rationale	221
23.2	Manufacture and processing	222
23.3	Chemical, physiological and other properties	222
23.4	Feeding value	224
23.5	Recommended inclusion rates	227
23.6	Legal aspects	227
23.7	References	227
24	Leather meal (hydrolysed)	229
24.1	Rationale	229
24.2	Manufacture and processing	229
24.3	Properties	229
24.4	Feeding value	230
24.5	Legal aspects	231
24.6	References	231
25	Leucaena Leaf Meal	232
25.1	Rationale	232
25.2	Manufacture and processing	232
25.3	Chemical, physiological and other properties	232
25.4	Feeding value	235
25.5	Recommended inclusion rates	238
25.6	Legal aspects	238
25.7	References	238
26	Live Food	241
26.1	Rationale	241
26.2	Feed organisms	241
26.2.1	Phytoplanktons	241
26.2.2	Zooplanktons	243

26.2.3	Micro-crustaceans	243
26.2.4	Other feed organisms	245
26.3	Mass-culture of feed organisms	245
26.4	Chemical, physiological and other properties	246
26.5	Feeding value	250
26.6	Feeding recommendations and precautions	252
26.7	References	253
27	Liver from warm-blooded animals	255
27.1	Rationale	255
27.2	Processing	256
27.3	Chemical, physiological and other properties	256
27.4	Feeding value	258
27.5	Recommended inclusion rates	260
27.6	Legal aspects	260
27.7	References	260
28	Maize Products	262
28.1	Rationale	262
28.2	Manufacture and processing	262
28.3	Maize meal	264
28.3.1	Description	264
28.3.2	Chemical, physiological and other properties	264
28.3.3	Feeding value	267
28.4	Maize starch	268
28.4.1	Description	268
28.4.2	Chemical, physiological and other properties	268
28.4.3	Feeding value	369
28.5	Maize gluten meal and maize gluten feed	270
28.5.1	Description	270
28.5.2	Chemical and physiological properties	270
28.5.3	Feeding value	271
28.6	Maize bran	272
28.6.1	Description	272
28.6.2	Properties	272
28.6.3	Feeding value	273
28.7	Maize germ meal	273
28.8	Dextrin	274
28.8.1	Description	274
28.8.2	Chemical and physiological properties	274
28.8.3	Feeding value	275
28.9	Recommended inclusion rates	276
28.10	Legal aspects	276
28.11	References	277

29	Marine Oils	281
29.1	Rationale	281
29.2	Manufacture and processing	281
29.3	Chemical, physiological and other properties	281
29.4	Feeding value	286
29.5	Recommended inclusion rates	288
29.6	Legals aspect	288
29.7	References	288
30	Meat by-product meals	291
30.1	Rationale	291
30.2	Manufacture and processing	291
30.3	Chemical, physiological and other properties	293
30.4	Feeding value	297
30.5	Recommended inclusion rates	298
30.6	Legal aspects	299
30.7	References	300
31	Mineral feed ingredients	302
31.1	Rationale	302
31.2	Macro mineral ingredients	302
31.3	Trace mineral ingredients	307
31.4	Contaminants in mineral ingredients	308
31.5	Chelated mineral ingredients	310
31.6	Legal aspects	310
31.7	References	312
32	Mollusc products	314
32.1	Rationale	314
32.2	Manufacture and processing	315
32.3	Chemical, physiological and other properties	315
32.4	Feeding value	317
32.5	Recommended application and precautions	319
32.6	References	319
33	Pig bristle meal	322
33.1	Rationale	322
33.2	Processing and properties	322
33.3	Feeding value	322
33.4	Recommended inclusion rates	323
33.5	Legal aspects	324
33.6	References	324

34	Potato protein	325
34.1	Rationale	325
34.2	Manufacture and processing	325
34.3	Chemical, physiological and other properties	326
34.4	Feeding value	328
34.5	Recommended inclusion rates	328
34.6	Legal aspects	328
34.7	References	328
35	Poultry by-product meal	330
35.1	Rationale	330
35.2	Manufacture and processing	330
35.3	Chemical and physiological properties	330
35.4	Feeding value	333
35.5	Recommended Inclusion rates	334
35.6	Legal aspects	335
35.7	References	336
36	Pulses	338
36.1	Rationale	338
36.2	Harvesting and processing	339
36.3	Chemical, physiological and other properties	339
36.4	Feeding value	343
36.5	Recommended inclusion rates	348
36.6	Legal aspects	348
36.7	References	349
37	Rice by-products	351
37.1	Rationale	351
37.2	Milling and processing	352
37.3	Rice bran	353
37.3.1	Description	353
37.3.2	Chemical, physiological and other properties	353
37.3.3	Feeding value	355
37.4	Broken rice and rice polishings	356
37.4.1	Description	356
37.4.2	Chemical, physiological and other properties	357
37.4.3	Feeding value	357
37.5	Rice hulls	358
37.5.1	Description and properties	358
37.5.2	Feeding value	358
37.6	Recommended inclusion rates	358
37.7	Legal aspects	359
37.8	References	360

38	Shrimp meal	364
	38.1 Rationale	364
	38.2 Manufacture and processing	364
	38.3 Chemical, physiological and other properties	364
	38.4 Feeding value	367
	38.5 Recommended inclusion rates	368
	38.6 Legal aspects	368
	38.7 References	369
39	Silkworm pupae meal	372
	39.1 Rationale	372
	39.2 Processing	372
	39.3 Chemical, physiological and other properties	372
	39.4 Feeding value	374
	39.5 Recommended inclusion rates	376
	39.6 Legal aspects	376
	39.7 References	377
40	Snail meal	379
	40.1 Rationale	379
	40.2 Processing	380
	40.3 Chemical, physiological and other properties	380
	40.4 Feeding value	381
	40.5 Recommended inclusion rates and precautions	381
	40.6 References	381
41	Soya lecithin	383
	41.1 Rationale	383
	41.2 Manufacture and processing	383
	41.3 Chemical and physiological properties	384
	41.4 Feeding value	388
	41.5 Recommended inclusion rates	391
	41.6 Legal aspects	392
	41.7 References	393
42	Soya protein products	396
	42.1 Rationale	396
	42.2 Manufacture and processing	396
	42.3 Chemical and physiological properties	397
	42.4 Feeding value	399
	42.5 Recommended inclusion rates	400
	42.6 Legal aspects	401
	42.7 References	401

43	Squid meal	403
43.1	Rationale	403
43.2	Manufacture and processing	403
43.3	Chemical, physiological and other properties	404
43.4	Feeding value	406
43.5	Recommended inclusion rates	408
43.6	Legal aspects	408
43.7	References	409
44	Unidentified growth factors	411
44.1	Rationale	411
44.2	Processing	411
44.3	Chemical and physiological properties	412
44.4	Feeding value	413
44.5	Recommended inclusion rates and legal aspects	413
44.6	References	413
45	Vegetable oils	415
45.1	Rationale	415
45.2	Manufacture and processing	415
45.3	Coconut oil	419
45.3.1	Description	419
45.3.2	Chemical and physiological properties	419
45.3.3	Feeding value	421
45.4	Cotton-seed oil	422
45.4.1	Description	422
45.4.2	Chemical, physiological and other properties	422
45.4.3	Feeding value	422
45.5	Ground-nut oil	423
45.5.1	Description	423
45.5.2	Chemical and physiological properties	423
45.5.3	Feeding Value	423
45.6	Linseed oil	424
45.6.1	Description	424
45.6.2	Chemical, physiological and other properties	424
45.6.3	Feeding value	424
45.7	Maize oil	425
45.7.1	Description	425
45.7.2	Chemical, physiological and other properties	425
45.7.3	Feeding value	426
45.8	Olive oil	428
45.8.1	Description	428
45.8.2	Chemical and physiological properties	428
45.8.3	Feeding value	429
45.9	Palm oil and palm kernel oil	429

45.9.1	Description	429
45.9.2	Chemical and physiological properties	430
45.9.3	Feeding value	430
45.10	Rape-seed oil	431
45.10.1	Description	431
45.10.2	Chemical, physiological and other properties	431
45.10.3	Feeding value	431
45.11	Rice bran oil	432
45.11.1	Description	432
45.11.2	Properties and feeding value	432
45.12	Safflower oil	432
45.12.1	Description	432
45.12.2	Chemical and physiological properties	433
45.12.3	Feeding value	433
45.13	Sesame oil	433
45.13.1	Description	433
45.13.2	Properties	433
45.14	Soybean oil	434
45.14.1	Description	434
45.14.2	Chemical and physiological properties	434
45.14.3	Feeding value	434
45.15	Sunflower oil	437
45.15.1	Description	437
45.15.2	Chemical and physiological properties	437
45.15.3	Feeding value	437
45.16	Recommended inclusion rates	438
45.17	Legal aspects	438
45.18	References	439
46	Vegetable oil meals	445
46.1	Rationale	445
46.2	Manufacture and processing	446
46.3	Coconut meal	446
46.3.1	Description	446
46.3.2	Chemical, physiological and other properties	446
46.3.3	Feeding value	450
46.3.4	Recommended inclusion rates	450
46.4	Cotton-seed meal	450
46.4.1	Description	450
46.4.2	Chemical, physiological and other properties	451
46.4.3	Feeding value	453
46.4.4	Recommended inclusion rates	455
46.5	Ground-nut meal	455
46.5.1	Description	455
46.5.2	Chemical, physiological and other properties	455

46.5.3	Feeding value	458
46.5.4	Recommended inclusion rates	459
46.6	Linseed meal	459
46.6.1	Description	459
46.6.2	Chemical, physiological and other properties	459
46.6.3	Feeding value	462
46.6.4	Recommended inclusion rates	462
46.7	Mustard meal	463
46.7.1	Description	463
46.7.2	Chemical, physiological and other properties	464
46.7.3	Feeding value	465
46.7.4	Recommended inclusion rates	466
46.8	Olive by-products	467
46.8.1	Description	467
46.8.2	Chemical and physiological properties	468
46.8.3	Feeding value	468
46.8.4	Recommended inclusion rates	468
46.9	Palm-kernel meal	468
46.9.1	Description	468
46.9.2	Chemical, physiological and other properties	469
46.9.3	Feeding value	471
46.9.4	Recommended inclusion rates	471
46.10	Rape-seed meal	472
46.10.1	Description	472
46.10.2	Chemical, physiological and other properties	472
46.10.3	Feeding value	475
46.10.4	Recommended inclusion rates	476
46.11	Safflower meal	476
46.11.1	Description	476
46.11.2	Chemical, physiological and other properties	476
46.11.3	Feeding value	478
46.11.4	Recommended inclusion rates	478
46.12	Sesame meal	478
46.12.1	Description	478
46.12.2	Chemical, physiological and other properties	479
46.12.3	Feeding value	481
46.12.4	Recommended inclusion rates	481
46.13	Soybean meals	482
46.13.1	Description	482
46.13.2	Chemical, physiological and other properties	483
46.13.3	Feeding value	488
46.13.4	Recommended inclusion rates	492
46.14	Sunflower meal	493
46.14.1	Description	493
46.14.2	Chemical, physiological and other properties	493

46.14.3	Feeding value	495
46.14.4	Recommended inclusion rates	496
46.15	Legal aspects	496
46.16	References	500
47	Vermi meal	509
47.1	Rationale	509
47.2	Culture of worms	509
47.3	Chemical, physiological and other properties	509
47.4	Feeding value	511
47.5	Recommended inclusion rates and precautions	512
47.6	References	513
48	Vitamin C products	515
48.1	Rationale	515
48.2	Synthesis	515
48.3	Properties	515
48.4	Biological value	519
48.4.1	Fishes	519
48.4.2	Crustaceans	521
48.5	Recommended inclusion rates	521
48.6	Legal aspects	521
48.7	References	522
49	Water hyacinth	525
49.1	Rationale	525
49.2	Processing	525
49.3	Chemical, physiological and other properties	525
49.4	Feeding value	527
49.5	Recommended inclusion rates	529
49.6	Legal aspects	529
49.7	References	529
50	Wheat and wheat by-products	531
50.1	Rationale	531
50.2	Milling process	531
50.3	Chemical, physiological and other properties	532
50.4	Feeding value	536
50.4.1	Wheat grain	536
50.4.2	Wheat flour	536
50.4.3	Wheat bran	537
50.4.4	Other wheat products	538
50.5	Recommended inclusion rates	538
50.6	Legals aspects and precautions	538
50.7	References	540

51	Whey (de-hydrated)	543
51.1	Rationale	543
51.2	Manufacture and processing	543
51.3	Chemical, physiological and other properties	543
51.4	Feeding value	547
51.5	Recommended inclusion rates	548
51.6	Legal aspects	548
51.7	References	549
52	<i>Yucca schidigera</i> extract	551
52.1	Rationale	551
52.2	Manufacture and processing	552
52.3	Chemical properties and mode of action	553
52.4	Feeding value	554
52.5	Recommended inclusion rates and legal aspects	554
52.6	References	555
	List of scientific names of aquatic organisms used in this book	557
	Index	567

LIST OF TABLES

1-01: The species of the zoological marine shrimp <i>Penaeidae</i>	2
2-01: Feeding habits of selected fish species	5
2-02: Length of intestines of some aquatic and terrestrial animals in comparison to the animal's body length	6
2-03: Maximum concentrations of pollutants for optimal growth of tiger prawn (<i>Penaeus monodon</i>)	7
2-04: Parameters for the judgement of dietary protein utilisation by fish	10
2-05: Protein requirement of tilapia (<i>Oreochromis</i> sp) and salmonids in dependence of the age of development	11
2-06: Protein requirement of some crustaceans	12
2-07: Amino acid profile of prawns	12
2-08: Factors for estimating the digestible energy of feed ingredients for aquatic animals	13
2-09: Digestibility of carbohydrates by salmonid fishes	14
2-10: Effect of the water temperature on the apparent digestibility of soybean oil and selected fatty acids by the rainbow trout (<i>Salmo gairdneri</i>)	17
2-11: The effect of the melting point of the dietary fat on the digestibility by the rainbow trout (<i>Salmo gairdneri</i>)	17
2-12: Mean content of fatty acid groups in freshwater and marine fishes (% of total fatty acids)	18
2-13: The effect of dietary lipid on fatty acid composition of channel catfish (<i>Ictalurus punctatus</i>)	18
2-14: The effect of cholesterol on the growth of <i>Penaeus japonicus</i>	19
2-15: Major natural sources of vitamins	20
2-16: Guidelines for the vitamin fortification per kg of formulated fish feed	22
2-17: Guidelines for the vitamin fortification per kg of formulated feed for marine shrimps	23
2-18: Classification of minerals in feed for cultured aquatic animals	24
2-19: Concentration of elements in seawater and freshwater	25
2-20: Macro and trace mineral requirements of fish and shrimp	26
2-21: Taste buds and olfactory cells of man and selected species	28
2-22: Concentration of glycine betaine of various invertebrates	28
2-23: Feed antibiotics approved by the EU	31
2-24: Antioxidants approved for feed by the EU	32
2-25: Antioxidants approved for feed in the U.S.A.	32

2-26: Weight loss of pellets in water as an indicator for the water durability of aquaculture feed	34
2-27: Characteristics of selected pellet binding aids from plants	34
3-01: Fatty acid composition of tallow, lard, poultry fat and animal fat	44
3-02: Response of rainbow trout (<i>Salmo gairdneri</i>) to beef tallow after 10 weeks of feeding	46
3-03: Weight gain and feed efficiency of carp (<i>Cyprinus carpio</i>) fingerlings at various levels of beef tallow	46
3-04: Beef tallow as an energy source in diets for red sea bream (<i>Pagrus major</i>)	47
3-05: Growth indicators of milkfish (<i>Chanos chanos</i>) fingerlings fed tallow and various lipids	48
3-06: The fatty acid profile of the diet for channel catfish (<i>Ictalurus punctatus</i>) is reflected in the fatty acid profile of the whole fish	50
3-07: Growth response of juvenile tiger prawns (<i>Penaeus monodon</i>) to various levels of beef tallow in semi-purified diets	50
3-08: Growth indicators of milkfish (<i>Chanos chanos</i>) fingerlings fed pork lard and various lipids	52
3-09: Growth response of juvenile tiger prawns (<i>Penaeus monodon</i>) to various levels of pork lard in semi-purified diets	52
3-10: Growth performance of rainbow trout (<i>Oncorhynchus mykiss</i>) fed 6.0% chicken fat for 20 weeks	53
3-11: Yellow grease as an energy source in diets for Nile tilapia (<i>Oreochromis nilotica</i>)	54
3-12: Congealing points, melting points, iodine values and saponification values of animal fats	55
3-13: Requirements for animal fat by the German feedstuff law	56
4-01: Composition of gall-bladder bile of cattle, pig and dog	61
4-02: Lipids of the bile of sheep	61
4-03: Composition of the bile of fishes	61
5-01: Chemical and physical properties of acid-activated bleaching earth	66
5-02: Bleaching earth's content of some heavy metals	66
5-03: Residual oil extracted from used bleaching earth	66
5-04: Used bleaching earth (UBE) in diets for rainbow trout (<i>Salmo gairdneri</i>)	67
6-01: Chemical composition of fresh blood and blood meal	70
6-02: Effect of drying procedure of blood meal on the crude protein and amino acid content	71
6-03: Essential amino acid content of the protein of blood meal	71
6-04: Macro and trace minerals and vitamin content of blood meal	72
6-05: Digestibility, and metabolisable and digestible energy	

of differently processed blood meals for rainbow trout (<i>Salmo gairdneri</i>) and chinook salmon (<i>Oncorhynchus tshawytscha</i>)	72
6-06: Effect of the drying temperature in the cylindrical dryer on the protein digestibility of blood meal in pigs	73
6-07: Refrigerated storage of blood and the effect on the bacterial count	73
6-08: Replacement of fish meal by a combination of blood meal and rendered carcass meal in diets for rainbow trout (<i>Salmo gairdneri</i>)	74
6-09: Blood meal replaces fish meal in diets for juvenile tilapia (<i>Oreochromis mossambicus</i>)	75
6-10: Differently processed blood meal as a protein source in diets for <i>Penaeus vannamei</i>	76
6-11: Effect of blood silage in the moist diet for rainbow trout (<i>Salmo gairdneri</i>) and Atlantic salmon (<i>Salmo salar</i>)	77
7-01: Chemical composition of dried brewers' grains	81
7-02: Essential amino acid profile of dried brewers' grains	82
7-03: Mineral and vitamin contents of dried brewers' grains	82
7-04: Metabolisable energy values of dried brewers' grains	83
7-05: Dried brewers' grains in practical fish diets	83
8-01: Chemical composition of casein (dehydrated)	86
8-02: Essential amino acid profile of dehydrated casein	87
8-03: Mineral and vitamin contents of de-hydrated casein	88
8-04: Protein digestibility of casein	89
8-05: Apparent digestibility of casein by penaeid shrimps	89
8-06: Effect of preserved crude casein in moist pellets on performances of rainbow trout (<i>Salmo gairdneri</i>) and Atlantic salmon (<i>Salmo salar</i>)	90
8-07: Casein as the protein source in diets fed for 100 days to rainbow trout (<i>Salmo gairdneri</i>)	91
8-08: Replacement of clam protein by casein and other animal protein sources in diets for <i>Penaeus japonicus</i>	92
9-01: Chemical composition of cheese and cheese scrap	97
9-02: Profile of essential amino acids of cheese and cheese scrap	97
9-03: Macro and trace mineral and vitamin contents of cheese	97
10-01: Chemical composition of heat-processed cocoa-pod husk meal, cocoa pods, cocoa shells and cocoa beans	101
10-02: Apparent digestibility of CPHM in diets for African catfish (<i>Clarias ishieriensis</i>)	102
10-03: Performances by African catfish (<i>Clarias ishieriensis</i>)	103
11-01: Chemical composition of the components of coffee pulp and spent coffee	106
11-02: Essential amino acid content of dried coffee pulp	106

11-03: Effect of dried coffee pulp in the diet for male tilapia (<i>Tilapia aurea</i>) fingerlings	107
12-01: Chemical composition of crab meal, crab protein concentrate and pure crab meal	110
12-02: Essential amino acid profile of crab meal and crab protein concentrate	110
12-03: Mineral and vitamin contents of crab meal and crab protein concentrate	111
12-04: Energy values of crab meal	112
12-05: Response of the brown shrimp (<i>Penaeus californiensis</i>) post-larvae and juveniles fed diets containing crab meal	112
13-01: Chemical composition of distillers' dried products	117
13-02: Essential amino acid profile of distillers' dried products	117
13-03: Macro and trace mineral contents of distillers' dried products	118
13-04: The vitamins of distillers' dried products	118
13-05: Energy values of distillers' dried products	119
13-06: Replacement of fish meal by a fixed level of distillers' dried grains with solubles (DDGS) and soybean meal in diets for juvenile channel catfish (<i>Ictalurus punctatus</i>)	120
13-07: Effect of increasing levels of distillers' dried grains with solubles (DDGS) on dressing percentage and body composition of channel catfish (<i>Ictalurus punctatus</i>)	121
13-08: Effect of distillers' dried grains with solubles (DDGS) as an ingredient in diets for the freshwater prawn <i>Macrobrachium rosenbergii</i>	121
13-09: Specification for distillers' feeds by the German feedstuff legislation	122
14-01: Constituents of eggs of some fowl species	125
14-02: Chemical composition of spray-dried egg products	127
14-03: Principal egg-white protein in the domestic fowl	127
14-04: Essential amino acid content of whole egg powder	127
14-05: Mineral and vitamin contents of whole egg powder	128
15-01: Chemical composition and the profile of essential amino acid of the individual parts of the feather	132
15-02: Chemical composition of feather meal	133
15-03: Essential amino acid profile of hydrolysed feather meal and untreated feathers	134
15-04: Mineral and vitamin contents of hydrolysed feather meal	134
15-05: Energy values of hydrolysed feather meal	135
15-06: Digestibility of hydrolysed feather meal	135
15-07: Replacement of fish meal by feather meal and poultry by-product meal in diets for rainbow trout (<i>Salmo gairdneri</i>)	137
15-08: Feather meal and feather meal/blood meal as a substitute for fish meal in diets for tilapia (<i>Tilapia mossambicus</i>)	138

15-09: Feather meal replaces maize gluten meal in diets for catfish (<i>Ictalurus punctatus</i>)	138
15-10: Nutritional standards of feather meal required by German feedstuff law and NRA	139
16-01: Xanthophyll content of plant materials and astaxanthin content of animal products used in aquatic feed	143
16-02: Acute toxicity of carotenoids	144
16-03: Specification of synthetic carotenoids	146
16-04: Relation between egg mortality and egg astaxanthin content in rainbow trout (<i>Salmo gairdneri</i>)	147
16-05: Distribution of astaxanthin in shrimp	147
16-06: Survival and weight gain of kuruma prawns (<i>Penaeus japonicus</i>) fed diets containing various pigment sources at different levels	148
16-07: Pigmentation efficacy of astaxanthin in tiger prawns (<i>Penaeus monodon</i>)	149
16-08: Chemical composition of <i>Phaffia rhodizyma</i> compared to that of brewer's yeast	149
16-09: Deposition of pigmenters in rainbow trout (<i>Oncorhynchus mykiss</i>) flesh fed for 100 days with algal astaxanthin	150
16-10: Guidelines for the application of carotenoids to aquaculture feeds	153
16-11: Pigmenters approved by the EU-Authorities for the use in feeds for aquatic animals	154
17-01: Properties of inactive yeasts	158
17-02: Mean chemical composition of different types of inactive, dry yeasts	160
17-03: Essential amino acid profile of different types of inactive, dry yeasts	160
17-04: Macro and trace mineral content of different types of inactive, dry yeasts	161
17-05: Vitamin content of different types of inactive, dry yeasts	161
17-06: Properties of baker's yeast	162
17-07: Energy values of different inactive, dry yeasts in rainbow trout (<i>Salmo gairdneri</i>)	162
17-08: Apparent digestibility of inactive, dry yeasts by various fish species	163
17-09: Effect of <i>Saccharomyces</i> sp. treatment on the apparent digestibility by rainbow trouts (<i>Salmo gairdneri</i>)	163
17-10: Differently treated dry baker's yeast (<i>Saccharomyces cerevisiae</i>) in the diet for the lake trout (<i>Savelinus namaycush</i>)	164
17-11: Performances of rainbow trout (<i>Salmo gairdneri</i>) on diets with alkane yeast and fish meal as the sole protein source	165
17-12: The effect of lactic yeast (<i>Kluyveromyces fragilis</i>) on performances of tiger prawn (<i>Penaeus monodon</i>)	167
17-13: Response of bivalves on algae and torula yeast and combinations thereof	167
17-14: Assimilation efficiency of the algae <i>Isochrysis galbana</i> and torula yeast for the American oyster (<i>Crassostrea virginica</i>) and the hard clam (<i>Mercenaria mercenaria</i>)	168

17-15: Different preparations of baker's yeast on performances of the rotifer <i>Brachionus plicatilis</i>	168
17-16: Essential amino acid profile of yeast culture	170
17-17: Mineral and vitamin contents of yeast culture	170
18-01: Types of fish meals by some fish meal exporting countries	178
18-02: Chemical composition of fish meal	180
18-03: Essential amino acid profile of fish meal	181
18-04: Important fatty acids in lipids of fish meal	182
18-05: Macro and micro mineral contents of some typical fish meals	182
18-06: Vitamin content of some typical fish meals	183
18-07: Metabolisable and digestible energy content of fish meals in aquatic and terrestrial animals	183
18-08: Apparent digestibility of fish meals in various fish species	184
18-09: Response of rainbow trout (<i>Salmo gairdneri</i>) fingerlings on feeding diets with tilapia or herring meal	186
18-10: Growth response of milkfish fry fed white fish meal and/or maize gluten meal	186
18-11: Quality requirements of fish meals according to German feedstuff legislation	188
19-01: Chemical composition of hydrolysed fish protein concentrate (HFPC) in comparison to soybean meal (from de-hulled beans) and herring meal	193
19-02: Essential amino acid profile of hydrolysed fish protein concentrate (HFPC)	194
19-03: Mineral and vitamin contents of hydrolysed fish protein concentrate (HFPC)	194
19-04: Energy content of hydrolysed fish protein concentrate (HFPC) determined in salmonids	194
19-05: The effect of starter feed containing various marine protein sources on the development of first feeding Atlantic salmon (<i>Salmo salar</i>)	195
19-06: Effect of hydrolysed fish protein concentrate (HFPC) in juvenile chinook salmon (<i>Oncorhynchus tshawytscha</i>)	195
19-07: Feeding tiger prawn (<i>Penaeus monodon</i>) juveniles with hydrolysed fish protein concentrate (HFPC) for 60 days	196
19-08: Legal requirements for hydrolysed fish protein concentrate (HFPC)	197
20-01: Chemical composition of fish silage	200
20-02: Essential amino acid profile of fish silage	201
20-03: Chemical composition of shrimp head and squid viscera silage compared to the fresh material	202
20-04: Essential amino acid profiles of shrimp head silage and shrimp head meal	202
20-05: Apparent digestibility of fish silage	203

20-06: Apparent digestibility of essential amino acids of fish silage	204
20-07: Dogfish (<i>Squalus acanthias</i>) offal silage as feed for Atlantic salmon (<i>Salmo salar</i>)	205
20-08: The influence of storage time of saithe (<i>Pollachius virens</i>) offal silage on performance of Atlantic salmon (<i>Salmo salar</i>)	206
20-09: Increasing levels of lactic acid tilapia silage in diets for juvenile Nile tilapia (<i>Oreochromis niloticus</i>) in replacement for herring meal	206
20-10: Increasing levels of fish silage from a blend of sardine (<i>Sardina pilchardus</i>) and whiting (<i>Merlangius merlangius</i>) on the development of European eel (<i>Anguilla anguilla</i>) fingerlings	207
21-01: Chemical composition (%) of de-hydrated fish solubles and condensed fish solubles	212
21-02: Essential amino acid profile of dehydrated fish solubles	213
21-03: Macro and trace minerals and vitamin contents of de-hydrated fish solubles	213
21-04: Fish solubles in diets for tiger prawn (<i>Penaeus monodon</i>)	214
21-05: Legal requirements for fish solubles in the Federal Republic of Germany	215
22-01: β -glucan content of grains	218
23-01: Chemical composition of krill meal	222
23-02: Essential amino acid profile of krill meal	222
23-03: Fluoride content of feed containing krill meal and fluoride content of rainbow trout (<i>Salmo gairdneri</i>) fed with that feed	223
23-04: Replacing 50% of animal protein by krill meal in the diet for rainbow trout (<i>Salmo gairdneri</i>)	224
23-05: Total replacement of animal protein by krill meal in diets for rainbow trout (<i>Salmo gairdneri</i>)	224
23-06: Replacement of 50% and 100% of animal protein by krill meal in the diet for rainbow trout (<i>Salmo gairdneri</i>)	225
23-07: Replacement of all animal protein by krill meal in the diet for carp (<i>Cyprinus carpio</i>)	225
23-08: Krill meal as the only protein source in replacement for fish meal in diets for channel catfish (<i>Ictalurus punctatus</i>)	226
23-09: The effect of partial replacement of shrimp meal by krill meal in diets for juvenile tiger prawn (<i>Penaeus monodon</i>)	226
24-01: Chemical composition (% in dry matter) of leather scrap meal and leather waste meal	230
24-02: Essential amino acid profile of leather meal	230
25-01: Mimosine content of leucaena leaf meals processed by various methods	232
25-02: Chemical composition of leucaena leaf meal	233
25-03: Essential amino acid profile of leucaena leaves	233

25-04: Macro and micro mineral contents of leucaena leaves	234
25-05: Pigment content of leucaena meal from various countries	234
25-06: Growth responses and feed utilisation efficiencies of Nile tilapia (<i>Oreochromis niloticus</i>) fingerlings fed various levels of leucaena leaf meal for 70 days	236
25-07: Responses of milkfish (<i>Chanos chanos</i>) fed leucaena leaves	237
25-08: Leucaena leaf meal as a protein source in diets for tiger prawns (<i>Penaeus monodon</i>)	237
26-01: Chemical composition of live food	246
26-02: Essential amino acid profile of selected live food	247
26-03: Fatty acid profile of live food	247
26-04: Macro and trace mineral contents of live food	248
26-05: Vitamin content of the brine shrimp (<i>Artemia</i>) as compared to minimum dietary requirement of salmonids	248
26-06: Gross energy content of live food	249
26-07: Apparent protein digestibility, protein efficiency ratio and net protein utilization of live food	249
26-08: Biological response of some cultured aquatic animals to different geographical strains of artemia	251
26-09: Growth response of juvenile blue print oysters (<i>Crassostrea virginica</i>) to various algal species	251
26-10: Estimated daily consumption of rotifers (<i>Brachionus plicatilis</i>) by red sea bream (<i>Pagrus major</i>) larvae during the first month of culture	252
27-01: Chemical composition of liver meal and livers of various animals	256
27-02: Essential amino acid profile of mammal liver	257
27-03: Mineral and vitamin contents of liver meal	257
27-04: Survival and growth of common carp (<i>Cyprinus carpio</i>) larvae fed freeze-dried pork and beef liver	258
27-05: Growth of a hybrid bighead carp (<i>Aristichthys nobilis</i>) x silver carp (<i>Hypophthalmichthys molitrix</i>) larvae fed for two weeks pork liver, zooplankton and crumbled feed	259
27-06: Growth responses of juvenile freshwater prawn (<i>Macrobrachium rosenbergii</i>) to various supplemental levels of frozen beef liver	259
28-01: Products from dry milling and wet milling of maize	263
28-02: Chemical composition of maize products	264
28-03: Essential amino acid profile of maize products	264
28-04: Macro and trace mineral contents of maize products	265
28-05: The vitamins of maize products	265
28-06: Energy values of maize products	266
28-07: Apparent digestibility of maize meal	267
28-08: Effect of maize meal on protein and carbohydrate digestibility by rainbow trout (<i>Oncorhynchus mykiss</i>)	268

28-09: The effect of native (raw) and gelatinised (cooked) maize starch on growth and feed conversion of rainbow trout (<i>Salmo gairdneri</i>)	269
28-10: Digestibility of maize gluten meal and maize gluten feed in rainbow trout (<i>Salmo gairdneri</i>)	271
28-11: Maize gluten versus wheat gluten as protein source in diets for rainbow trout (<i>Salmo gairdneri</i>)	272
28-12: Performance response of milkfish (<i>Chanos chanos</i>) fry fed maize gluten meal at various levels	272
28-13: Chemical composition of maize germs and maize germ meal	273
28-14: Relationship between the dextrin level of the diet and the dextrin digestibility	274
28-15: Recommended inclusion rates for maize products in aquaculture feeds	276
28-16: Quality requirements for maize products by the German feedstuff law	276
29-01: Variation of the fatty acid composition of selected fish species	282
29-02: n-3 fatty acid content of selected fishes	283
29-03: Mean vitamin A and D contents of selected fish liver oils	284
29-04: Guideline specifications of crude fish oil	284
29-05: Apparent digestibility of fish oil by rainbow trout (<i>Salmo gairdneri</i>) in relation to water temperature	285
29-06: Response of different oils on growth and carcass composition of carp (<i>Cyprinus carpio</i>)	286
29-07: The effect of pollack liver oil and beef tallow + n-3 HUFA on the development of red sea bream (<i>Pagrus major</i>)	287
30-01: Lowest and highest nutrient contents of meat by-product meals	293
30-02: Chemical composition of meat by-product meals	293
30-03: Quality consistency of meat and bone meal within and between rendering plants in Denmark	293
30-04: Crude protein and crude fat contents of meat meal of different rendering plants	294
30-05: Essential amino acid profile of meat by-product meals	294
30-06: Macro and trace mineral content of meat meal and meat and bone meal	295
30-07: With increasing ash content of meat and bone meal the content of macro minerals increases and level of micro minerals declines	295
30-08: The vitamins of meat meal and meat and bone meal	296
30-09: Energy values of meat by-product meals per kg	296
30-10: Apparent digestibility of meat by-product meals	297
30-11: Replacement of fish meal by meat meal in diets for rainbow trout (<i>Salmo gairdneri</i>)	298
30-12: Meat and bone meal replaces partially or completely fish meal in diets for tilapia (<i>Oreochromis mossambicus</i>)	298
30-13: Quality requirements for meat by-product meals by the German feedstuff legislation	299

31-01: Variability of phosphorus content in meat and bone meal	302
31-02: Bio-availability of calcium in calcium supplements in pigs	303
31-03: Chemical composition of rock phosphates	303
31-04: Chemical composition of phosphate compounds	304
31-05: The relative biological value of calcium phosphates, tested in broilers	305
31-06: Absorption of dietary phosphates by selected fish species	306
31-07: Chemically pure magnesium and sodium compounds	307
31-08: Common technical trace mineral compounds (%) for aquaculture feeds	308
31-09: Official guidelines for contaminants in individual mineral ingredients in U.S.A.	309
31-10: Contamination levels with highly toxic, toxic, moderately toxic and slightly toxic elements of commercial/technical mineral ingredients for animal feed	309
31-11: Requirements of permitted mineral compounds for animal feeds according to German feedstuff legislation	311
32-01: Chemical composition of mussel meat	315
32-02: Essential amino acid profile of mussel meat	316
32-03: Mineral and vitamin contents of mussel meat	316
32-04: Mean survival, spawning, fecundity and hatching rate of ablated tiger prawn (<i>Penaeus monodon</i>) broodstock fed various diets with various feeding regimes	318
32-05: Performances of tiger prawn (<i>Penaeus monodon</i>) post-larvae fed frozen brown mussel meat and shrimp meal	318
33-01: Essential amino acid profile of raw and hydrolysed pig bristles	323
33-02: Pig bristle meal (hydrolysed) as a protein source in diets for rainbow trout (<i>Salmo gairdneri</i>)	323
34-01: Chemical composition of potato-protein and some other protein sources	326
34-02: Mean mineral content of potato-protein	327
35-01: Chemical composition of poultry by-product meal and "whole poultry meal"	331
35-02: Essential amino acid profile of poultry by-product meal	331
35-03: Mineral and vitamin contents of poultry by-product meal	332
35-04: Energy values of poultry by-product meal	332
35-05: Apparent digestibility of poultry by-product meal in salmonids	333
35-06: Response of coho salmon (<i>Oncorhynchus kisutch</i>) on diets containing increasing levels of poultry by-product meal and declining levels of herring meal	333
35-07: Replacement of fish meal with poultry by-product meal in diets for fry and fingerlings rainbow trouts (<i>Salmo gairdneri</i>)	334
35-08: Quality criteria for poultry by-product meal as required by German feedstuff legislation	335

36-01: Chemical composition of selected pulses	339
36-02: Essential amino acid profile of various pulses	340
36-03: Macro and trace mineral contents of selected pulses	340
36-04: The vitamins of selected pulses	340
36-05: The energy contents of pulses	341
36-06: Digestibility of selected pulses	342
36-07: Performance of tilapia (<i>Oreochromis niloticus</i>) fry on diets containing green gram (<i>Phaseolus aureus</i>)	343
36-08: Various treatments of faba beans (<i>Vigna catiang</i>) and their effects on the chemical composition	344
36-09: Responses of rainbow trout (<i>Oncorhynchus mykiss</i>) feeding untreated and treated faba beans and sweet lupines, respectively	344
36-10: Growth performance of carp (Israeli strain Dor-70) fed diets with lupin meal	346
36-11: Effects of 25% sesbania seed (<i>Sesbania grandiflora</i>), differently treated as replacement for fish meal in diets fed to tilapia (<i>Oreochromis mossambicus</i>)	347
36-12: Minimum/maximum requirements for pulses by the German feedstuff law	348
37-01: Chemical composition of rice by-products	353
37-02: Essential amino acid profile of rice by-products	353
37-03: Macro and trace mineral contents of rice by-products	354
37-04: Vitamin content of rice by-products	354
37-05: Digestibility of rice bran	355
37-06: Maximum inclusion rate of rice by-products in practical aquaculture diets	358
37-07: Minimum/maximum requirements for rice by-products by the German feedstuff law	360
37-08: Specifications for rice bran in Thailand	360
38-01: Chemical composition of shrimp meals	365
38-02: Chemical composition of shrim head meals differently processed	365
38-03: Essential amino acid profile of shrim meals	365
38-04: Fatty acids of total fat in shrimp meal as compared to wild tiger prawn (<i>Penaeus monodon</i>) muscle	366
38-05: Mineral and vitamin contents of shrimp meal	366
38-06: Digestible energy of shrimp meal of selected origins	366
38-07: Apparent digestibility of shrimp meals	367
38-08: Growth response of tiger prawn (<i>Penaeus monodon</i>)	368
39-01: Chemical composition of silkworm pupae meal (in dry matter)	373
39-02: Essential amino acid profile of silkworm pupae meal	373
39-03: Mineral and vitamin contents of silkworm pupae meal	373
39-04: Apparent digestibility of silkworm pupae meal	374

39-05: De-oiled silkworm pupae meal replaces fish meal at increasing levels in diets for common carp (<i>Cyprinus carpio</i>)	375
39-06: Non-defatted silkworm pupae meal replaces fish meal in diets for catla-rohu hybrids	375
39-07: Fish meal replacement by silkworm pupae meal in diets for the catfish <i>Heteropneustis fossilis</i>	376
40-01: Chemical composition of snail meal	380
40-02: Essential amino acid profile of snail meal	380
41-01: Composition of soybean oil “sludge” and crude lecithin	385
41-02: Fatty acid content of soya lecithin	385
41-03: Macro and trace mineral contents of soya lecithin	385
41-04: Mean composition of soya lecithins	386
41-05: Definition of Lecithin by the European Union (EU)	387
41-06: Recommendations for the phospholipid requirement of fishes	392
41-07: Recommendations for the phospholipid requirement of shrimps	392
42-01: Chemical composition of soya protein products	397
42-02: Essential amino acid content of soya protein products	398
42-03: Biological evaluation of soya protein products in rats	398
42-04: Response of yellowtail (<i>Seriola quinqueradiata</i>) on replacement of brown fish meal by soya protein concentrate	400
42-05: Minimum quality requirements for soya protein products as stipulated by international and national bodies	401
43-01: Chemical composition of squid products	404
43-02: Essential amino acid profile of squid meal and squid liver meal	405
43-03: Fatty acid and cholesterol contents of squid by-products	405
43-04: Squid meal and other protein feedstuffs in diets for post-larvae tiger prawn (<i>Penaeus monodon</i>)	406
43-05: Squid meal replaces fish protein concentrate in diets for juvenile tiger prawn (<i>Penaeus monodon</i>)	408
44-01: Mean chemical composition and essential amino acids of UGF	412
44-02: Mineral and vitamin contents of UGF	412
45-01: Fatty acid profile of vegetable oils	418
45-02: Quality characteristics of vegetable oils	419
45-03: Energy values of vegetable oils	420
45-04: Digestibility of vegetable oils	421
45-05: The response of tiger prawns (<i>Penaeus monodon</i>) to various levels of coconut oil in the diet for juveniles	422
45-06: Effect on growth of carp (<i>Cyprinus carpio</i>) fed linseed and fish oils for 133 days	424
45-07: Maize oil as dietary fat source of juvenile rainbow trout	

<i>(Salmo gairdneri)</i>	426
45-08: Vegetable oils and menhaden oil in diets for the juvenile sunshine bass (<i>Morone chrysops x Morone saxatilis</i>)	427
45-09: Specification of crude palm oil and crude palm kernel oil by the "Palm Oil Refiners Association of Malaysia"	430
45-10: Colour strength in muscle of Atlantic salmon (<i>Salmo salar</i>) after feeding different dietary oils	432
45-11: Ratio of n-3:n-6 fatty acids in heart phospholipids and some HUFAs of muscles' total lipids of Atlantic salmon (<i>Salmo salar</i>)	435
45-12: Growth response of milkfish (<i>Chanos chanos</i>) fingerlings fed with various oils and fats	435
45-13: Effect of soybean oil on growth parameters of sea bass (<i>Lates calcarifer</i>) fry	436
45-14: Responses of tiger prawn (<i>Penaeus monodon</i>) to various levels of soybean oil	436
45-15: Effect of increasing dietary fat levels on performances of rainbow trout (<i>Salmo gairdneri</i>)	437
45-16: Quality requirements by the German feedstuff legislation for feed grade vegetable oils	439
46-01: Chemical composition of vegetable oil meals and expellers	447
46-02: Essential amino acid profile of coconut meal and coconut expeller	448
46-03: Mineral and vitamin contents of coconut meal and coconut expeller	449
46-04: Energy values of coconut meal and coconut expellers	449
46-05: Relationship between the residual oil content and the digestible energy value of coconut by-products with pigs	449
46-06: Digestibility of coconut meal and coconut expeller	451
46-07: Essential amino acid profile of decorticated cotton-seed products	451
46-08: Mineral and vitamin contents of decorticated cotton-seed meal and cotton-seed expeller	452
46-09: Energy values of cotton-seed meal	452
46-10: Digestibility of cotton-seed meal	452
46-11: The replacement of soybean meal by cotton-seed meal in diets for channel catfish (<i>Ictalurus punctatus</i>)	454
46-12: Effect of cotton-seed meal in diets for northern white shrimp (<i>Penaeus setiferus</i>) and white leg shrimp (<i>Penaeus vannamei</i>) of different sizes	454
46-13: Essential amino acid profile, true amino acid availability and the chemical score of ground-nut meal for channel catfish (<i>Ictalurus punctatus</i>)	456
46-14: Mineral and vitamin contents of ground-nut products	456
46-15: Energy values of ground-nut meal	457
46-16: Digestibility of ground-nut meal	457
46-17: The effect of ground-nut meal in diets for red swamp crayfish (<i>Procambarus clarkii</i>)	458

46-18: Essential amino acid profile and apparent and true amino acid digestibility of linseed meal for carp	460
46-19: Mineral and vitamin contents of linseed meal and linseed expeller	460
46-20: Energy values of linseed meal	461
46-21: Digestibility of linseed meal	461
46-22: Growth and feed utilisation of linseed meal by common carp (<i>Cyprinus carpio</i>)	462
46-23: Essential amino acid profile of mustard meal and apparent and true amino acid digestibility of mustard expeller for common carp (<i>Cyprinus carpio</i>)	464
46-24: Glucosinolate content of mustard products	465
46-25: Response of common carp (<i>Cyprinus carpio</i>) fry fed mustard expeller	466
46-26: Energy values of olive pulp with rabbits	468
46-27: Essential amino acid profile of palm-kernel meal and palm-kernel expeller	470
46-28: Macro and trace mineral contents of palm-kernel meal and palm-kernel expeller	470
46-29: Energy values of palm-kernel meal and palm-kernel expeller	470
46-30: Digestibility of palm-kernel meal and palm-kernel expeller	471
46-31: Growth and feed utilisation of Nile tilapia (<i>Oreochromis niloticus</i>) fed diets with palm-kernel meal	471
46-32: Essential amino acid profile of rape-seed products and true amino acid availability of canola meal for Atlantic salmon (<i>Salmo salar</i>)	473
46-33: Mineral and vitamin contents of rape-seed meal and rape-seed expeller	473
46-34: Energy values of rape-seed meal	474
46-35: Digestibility of rape-seed meal	474
46-36: Effect of feeding canola meal to hybrid tilapia (<i>Oreochromis mossambicus</i> x <i>Oreochromis aureus</i>)	475
46-37: Essential amino acid profile of safflower products	477
46-38: Mineral and vitamin contents of safflower meal	477
46-39: Energy values of safflower meal	477
46-40: Essential amino acid profile and apparent and true digestibilities of sesame meal for common carp (<i>Cyprinus carpio</i>)	479
46-41: Mineral and vitamin contents of sesame meal	479
46-42: Energy values of sesame meal	480
46-43: Digestibility of sesame meal	480
46-44: Feeding value of sesame expeller in common carp (<i>Cyprinus carpio</i>)	481
46-45: Essential amino acid profile of soybean products	483
46-46: Macro and trace mineral content of soybean meals	484
46-47: The vitamins of soybean meals	484
46-48: Energy values of soybean meal	485
46-49: Digestibility of soybean meals	485
46-50: Digestibility of soybean meal	486
46-51: Effect of duration of heating of soybean meal on urease activity, trypsin inhibitor content and feeding value (broilers)	487

46-52: Responses of tiger prawn (<i>Penaeus monodon</i>) juveniles to diets containing soybean meal	490
46-53: Increasing levels of soybean meal as partial or complete replacement of fish meal in diets for banana shrimps (<i>Penaeus merguensis</i>)	491
46-54: Guideline for the use of soybean meal, soybean expeller, de-hulled soybean meal and full-fat soybean meal in diets for aquatic animals	493
46-55: Essential amino acid profile of sunflower products	494
46-56: Mineral and vitamin contents of sunflower meal and sunflower seeds	494
46-57: Energy values of sunflower meal	495
46-58: Digestibility of sunflower meal	495
46-59: Increasing levels of sunflower meal in diets for rainbow trout (<i>Oncorhynchus mykiss</i>)	496
46-60: Minimum/maximum requirements by the German feedstuff law for meal from solvent extraction and cakes from screw pressing of vegetable oil seeds	497
46-61: Undesirable substances in by-products of vegetable oil seeds processing, according to German feedstuff legislation	499
47-01: Chemical composition of various worm meals	510
47-02: Essential amino acid profile of vermi meals	510
47-03: Macro and trace mineral content of freeze dried vermi meal (<i>Eudrilus eugeniae</i>)	510
47-04: Digestibility of vermi meal	511
47-05: Response of rainbow trout (<i>Salmo gairdneri</i>) fed diets for 84 days with various inclusion levels of freeze dried <i>Eisenia foetida</i>	512
47-06: The effect of vermims in the diets for tiger prawns (<i>Penaeus monodon</i>)	513
48-01: The effect of pelletising temperature and feed's moisture content on the stability of Vitamin C	517
48-02: Storage stability of L-ascorbyl phosphate in pelletised and extruded aquaculture feed	518
48-03: Retention of ascorbic acid preparations from pelletised and extruded salmonid feeds, immersed in seawater	519
48-04: Bioavailability of ascorbic acid coated with hydrogenated soybean oil and crystalline ascorbic acid in fish diets	519
48-05: Effect of increasing levels of ascorbic acid from Na-L-ascorbyl-2-monophosphate	520
48-06: Vitamin C products having the GRAS status of F.D.A.	521
49-01: Chemical composition of water hyacinth (<i>Eichhornia crassipes</i>)	526
49-02: Apparent protein digestibility of water hyacinth	526
49-03: Growth of Nile tilapia (<i>Oreochromis niloticus</i>) fed various amounts of dried water hyacinth	528
49-04: Growth of nile tilapis (<i>Oreochromis niloticus</i>) fed composted water hyacinth	528

49-05: Growth response of Indian major carp (<i>Labeo rohita</i>) fed diets containing water hyacinth	529
50-01: Chemical composition of wheat and wheat products	532
50-02: Essential amino acid profile of wheat and wheat products	532
50-03: Mineral content of wheat and wheat products	533
50-04: The vitamins of wheat and wheat products	533
50-05: Energy values of wheat and wheat products per kg	534
50-06: Digestibility (%) of wheat and wheat products	535
50-07: Growth of Atlantic salmon (<i>Salmo salar</i>) fed differently processed wheat	536
50-08: Growth and feed utilization of the European eel (<i>Anguilla anguilla</i>) fed various levels of wheat flour and protein	537
50-09: Various levels of wheat middlings in diets for juvenile red drum (<i>Sciaenops ocellatus</i>)	539
50-10: Recommended inclusion rates for wheat and wheat products in diets for cultured aquatic animals	539
50-11: Minimum requirements of wheat and wheat by-products in accordance with the Feedstuff Legislation of the Federal Republic of Germany	539
51-01: The influence of the type of coagulation of cow milk on the chemical composition of whey powder	544
51-02: Profile of essential amino acid of whey powder	545
51-03: Mineral and vitamin contents of whey powder	545
51-04: Energy values of whey powder	546
51-05: The effect of spray-drying and drum-drying on the protein digestibility and the biological value of whey powder	546
51-06: Digestibility of whey powder	546
51-07: Biological values of whey powder	546
51-08: Whey powder in diets for rainbow trout (<i>Salmo gairdneri</i>)	547
51-09: Quality requirements for whey products according to German feedstuffs legislation	548
52-01: Specification and chemical composition of commercial <i>Yucca schidigera</i> products	553

LIST OF FIGURES

2-01: Diagram of taxonomic classification of fish.	4
2-02: Diagram of classification of <i>Shrimp</i> spp.	7
2-03: The digestive system of shrimps.	8
2-04: The alimentary system of bivalves.	9
2-05: Classification of carbohydrates (saccharides)	14
2-06: The digestibility of the organic matter of wheat and wheat by-products in carp (<i>Cyprinus carpio</i>) is affected by the crude fibre content of these feed ingredients.	15
2-07: The effect of increasing added inositol levels on the growth of the kuruma prawn (<i>Penaeus japonicus</i>)	21
2-08: Interrelationship between macro and trace minerals in animal metabolism.	24
2-09: Illustration of a taste bud.	27
2-10: The effectiveness of selected gram-positive and gram-negative antibiotics against various microbes.	30
3-01: Relationship between water temperature and apparent digestibility of beef tallow and pork lard in diets for rainbow trout (<i>Salmo gairdneri</i>) and carp (<i>Cyprinus carpio</i>).	45
3-02: Relationship between the level of total dietary fat and the total body and liver fat of the yellowtail (<i>Seriola quinqueradiata</i>) after feeding increasing levels of beef tallow.	49
6-01: The quantity of collected cattle blood in relation to the bleeding time.	69
7-01: Diagram of the processing of dried brewers' grains.	81
8-01: Composition of the nitrogen fraction of milk.	87
8-02: Seasonal variation of casein's amino acids.	88
10-01: Flow diagram in the processing of cocoa beans.	101
12-01: Flow diagram for processing of crab protein concentrate.	109
13-01: Diagram of the processing of distillers' dried feeds.	116
13-02: Variation of the crude protein content of distillers' dried products.	117

14-01: Diagram of processing whole egg powder.	126
15-01: The parts of the poultry feather.	131
15-02; The effect of increasing processing pressure on the pepsin digestibility of continuously and batch processed hydrolysed feather meal.	136
16-01: Factors that influence pigmentation in crustaceans.	148
16-02: Astaxanthin levels in the oil phase from various crustaceans meals.	151
16-03: Percentage of fish with good to excellent colour after 120 days of feeding 3.0, 6.0 and 9.0 mg carotenoids.	152
17-01: Microscopic photos of spray-dried brewer's yeast and molasses yeast.	157
17-02: Replacement of fish meal by alkane yeast with and without l-methionine in diets for coho salmon (<i>Oncorhynchus kisutch</i>).	165
17-03: Development of the body weight of yellowtail (<i>Seriola quinqueradiata</i>) after feeding lactic yeast.	166
18-01: Flow diagram in the processing of fish meal.	179
19-01: Diagram of the production of Hydrolysed Fish Protein Concentrate (HFPC).	193
19-02: Relative growth rate of tiger prawn (<i>Penaeus monodon</i>) juveniles fed with increasing levels of HFPC.	196
20-01: Diagram of batch production of acid fish silage.	198
21-01: Flow diagram of the processing of de-hydrated fish solubles.	212
22-01: Structural formula of β -1,3-1,6-glucan (simplified).	218
23-01: Atlantic krill (<i>Euphausia superba</i>).	221
25-01: The effect on growth and feed conversion of increasing levels of leucaena protein in feeds for the Indian rohu carp (<i>Labeo rohita</i>).	236
26-01: Physical movements of a larvae for catching the prey <i>Brachionus plicatilis</i> .	242
26-02; The micro-crustacea <i>Daphnia Pulex</i> .	244
27-01: The liver of the pig and cattle.	255
28-01: Production diagram of wet milling of maize.	263
28-02: Weight development of chinook salmon (<i>Oncorhynchus tshawytscha</i>) fed diets containing 20% glucose or dextrin.	275

29-01: Flow diagram of the degumming and refining process of fish oil.	282
29-02: The relation between melting point of hydrogenated fish oil and its digestibility by the carp (<i>Cyprinus carpio</i>).	285
30-01: Processing diagram of meat by-product meals.	292
31-01: Schematic production process of calcium phosphates.	304
32-01: Shape of mussels.	314
34-01: Approximate amounts of potato processing products.	325
34-02: Essential amino acids of potato-protein compared with some important protein sources.	327
36-01: Growth of juvenile tiger prawn (<i>Penaeus monodon</i>) fed undehulled and dehulled cow peas (<i>Vigna catianga</i>) diets	345
36-02: Growth of tilapia (<i>Oreochromis mossambicus</i>) fed 25% treated (various treatments) and untreated seed meal of jack beans (<i>Canavalia ensiformis</i>)	347
37-01: Structure of the rice grain.	351
37-02: Flow diagram of rice milling process.	352
40-01: Land (lung) snails. Edible snail (<i>Helix pomatia</i>) (left) and common field (red) slug <i>Agriolimax reticulatus</i> (right).	379
41-01: Diagram of processing of crude soybean oil to lecithin products used in the feeding of aquatic animals.	384
41-02: Polar lipids and their classification.	386
41-03: Performances of rainbow trout (<i>Oncorhynchus mykiss</i>) fed a herring meal basal diet and supplemental soya lecithin.	388
41-04: Weight gain of kuruma prawns (<i>Penaeus japonicus</i>) receiving diets with and without lecithin.	390
41-05: Daily growth rates of Atlantic salmon (<i>Salmo salar</i>) fingerlings by trial periods after feeding phospholipids (de-oiled lecithin) and choline chloride.	391
42-01: Diagram of soya protein products.	396
42-02: Diagram of the production of soya protein hydrolysate.	399
43-01: The common squid (<i>Loligo vulgaris</i>).	403
43-02: Response on liveweight of brown shrimp (<i>Penaeus aztecus</i>) juveniles when fed diets containing squid meal.	407

45-01: Bunches of oil palm (<i>Elaeis guineensis</i>) fruits.	416
45-02: Diagram of vegetable oil extraction.	417
45-03: Development of channel catfish (<i>Ictalurus punctatus</i>) fed on maize oil and menhaden oil.	427
45-04: Specific growth rate (SGR) of rainbow trout (<i>Oncorhynchus mykiss</i>) fed sunflower oil compared to fish oil.	438
46-01: Growth response of catfish (<i>Clarias batrachus</i>) fry to a combination of linseed expeller (38%) and fish meal (26%) compared with fish meal only.	463
46-02: Diagram of olive oil processing.	467
46-03: Products obtained from the processing of crude palm kernels.	469
46-04: Growth response of Indian major carp (<i>Labeo rohita</i>) fry to various levels of sesame expeller.	482
46-05: The effect of different levels of soybean meal de-hulled, soybean meal and full-fat soybean meal on the weight gain of Atlantic salmon (<i>Salmo salar</i>).	488
46-06: Production results of different levels of soybean meal in diets for tiger prawn (<i>Penaeus monodon</i>) reared at various stocking rates.	491
47-01: The red Earthworm (genus: <i>Lumbricus</i> ; class: <i>Oligochaeta</i>) can be 20 to 35 cm long and can live for as long as 10 years.	509
48-01: "Broken back syndrome" of Coho salmon (<i>Oncorhynchus kisutch</i>) (scoliosis [above], normal development [middle], lordosis [below]).	516
48-02: Structural formula of L-ascorbic acid (left) and its oxidised form de-hydro-ascorbic acid (right).	516
49-01: Weekly weight gain of common carp (<i>Cyrprinus carpio</i>) fed composted and non-composted water hyacinth.	527
50-01: Water durability of feed pellets containing 5.0% wheat gluten and wheat flour and extruded rice, respectively	535
51-01: From whole milk to whey powder.	544
52-01: The environmental nitrogen cycle of aquatic animals.	551
52-02: <i>Yucca schidigera</i> plants.	552

LIST OF ABBREVIATIONS

ANPU	=	Apparent net protein utilization
APD	=	Apparent protein digestibility
BV	=	Biological value
°C	=	Degree centigrade
CIC	=	Commonwealth of Independent Countries (former USSR)
CPHM	=	Cocoa-pod husk meal
CPM	=	California Pellet Mill
DDG	=	Distillers dried grains
DM	=	Dry matter
EAAI	=	Essential amino acid index
EC	=	European Community
EFA	=	Essential fatty acids
EU	=	European Union
FAA	=	Free amino acids
FCR	=	Feed conversion rate
FFA	=	Free fatty acids
FAO	=	Food and Agricultural Organisation of the United Nations, Rome/Italy
g	=	Gramme
GRAS	=	Generally recognized as safe
HFPC	=	Hydrolysed fish protein concentrate
HUFA	=	Highly unsaturated fatty acid
i.m.	=	Intra-muscular
IU	=	International unit
kcal	=	Kilocalorie
kg	=	Kilogramme
l	=	Litre
LTF	=	Low thermal fish meal
mcg	=	Microgramme
mg	=	Milligramme
MJ	=	Megajoule
mm ³	=	Millilitre
MT	=	Metric tonne
NPU	=	Net protein utilisation
NRC	=	National Research Council (U.S.A.)
PER	=	Protein efficiency ratio
ppb	=	Parts per billion
ppm	=	Parts per million

ppt	=	Parts per trillion
PUFA	=	Polyunsaturated fatty acid
RNA	=	Ribonucleic acid
SGR	=	Specific growth rate
UBE	=	Used bleaching earth
UGF	=	Unidentified growth factors
WHO	=	World Health Organisation of the United Nations, Geneva/Switzerland

PREFACE

Current growth in global aquaculture is paralleled by an equally significant increase in companies involved in aquafeed manufacture. Latest information has identified over 1,200 such companies, not including those organizations in production of a variety of other materials, i.e., vitamins, minerals, and therapeutics, all used in varying degrees in proper feed formulation. Aquaculture industries raising particular economically valued species, i.e., penaeid shrimps and salmonids, are making major demands on feed ingredients, while relatively new industries, such as tilapia farming, portend a significant acceleration in demand for properly formulated aquafeeds by the end of the present decade and into the next century.

As requirements for aquafeeds increases, shortages are anticipated in various ingredients, especially widely used proteinaceous resources such as fish meal. A variety of other proteinaceous commodities are being considered as partial or complete replacement for fish meal, especially use of plant protein sources such as soybean meal. In the past five years, vegetable protein meal production has increased 10% while fish meal production has dropped over 50%, since 1989, largely attributed to overfishing and serious decline in wild stock. Throughout fisheries processing industries, traditional concepts as “waste” have given way to more prudent approaches, emphasizing total by-product recovery. Feed costs are a major consideration in aquaculture where in some groups, i.e., salmonids, high protein-containing feeds using quality fish meal, can account for as much as 40 to 60% of production costs. About 67% of the actual feed cost can be attributed to the fish meal protein fraction. Clearly, this is an untenable situation as global aquaculture increases in size and diversity of commercial species. Considerations such as cost and availability of commonly utilized aquafeed ingredients also must be recognized as new formulation practices develop. In all likelihood, these will differ from conventional procedures with movement in usage of non-traditional feed ingredients. Currently, aquafeed least-cost formulations mainly are geared to those traditional procedures used in livestock feeding and not designed especially to meet the needs of rapidly growing aquaculture industry.

Innovative approaches must explore the wide variety of processing by-products potentially available as nutritionally valuable ingredients in specific aquafeeds. This must be correlated with the availability of such ingredients, especially plant and animal proteins, in individual countries and the dictates of economic pressures. Competing feedstock (ingredient) demand by major livestock industries is another factor in proper allocation of feed ingredients. Regardless, the final processed aquafeed must meet specific physical standards, such as water stability and palatability, as well as satisfying the nutritional needs of the aquatic species being cultivated. Ultimately, diet selection and use of alternative proteins will relate to the intensity of the cultivation practice. While high cost “nutrient dense” complete pelleted diets may be feasible in intensive

operations, greater flexibility is possible in terms of ingredient substitution in less extensive operations where natural feeding processes may occur.

As new non-traditional diets are formulated, many using the various ingredients enumerated in this book, studies will be needed to ascertain their digestibility and composite nutritional value of the formulation to the particular targeted species. Ancillary attention also must be given to palatability of the diet and its effectiveness in achieving an economically sound conversion rate. Of paramount importance is the effect of individual ingredients on the physical stability of the final pellet and its compostie texture, facilitating optimal ingestion. For instance, shrimp feeds need both good water stability and rehydration properties which directly affect texture and optimal ingestion. Similarly, hard inflexible small dietary particles for first-feeding stages of fish may be rejected. Finally, the effect of a particular ingredient on final sensory properties of the aquatic species must be given consideration to insure maximum consumer acceptability of the processed product. For instance, excessive dietary levels of corn gluten meal and alfalfa meal impart an undesirable yellowish color to catfish flesh due to concentrations of xanthophylls, especially high in corn gluten meals. Conversely, with shrimp, especially such commercial species as *Penaeus monodon* and *Penaeus japonicus*, inclusion of ingredients (i.e., shrimp meal) rich in carotenoids (especially astaxanthin), is needed to impart proper pigmentation to the crustacean exoskeleton.

The efforts of the authors to make available a thorough compilation of feed ingredients, together with relevant performance data where possible, is a worthwhile contribution to global aquaculture. Paradoxically, major anticipated growth in aquaculture is projected to occur in those countries where traditional feed ingredients are lacking or totally unavailable. Thus the information contained here has truly practical value, and unquestionably will be utilized by aquaculturists. Various of the ingredients listed, i.e., soybean meal, fish meal, crab meal, shrimp meal, and other animal and plant by-products already have acceptance in various degree in aquaculture feeds. What is needed are new formulations that reflect reductions in feed costs and especially more prudent use of available commodities. Nowhere else has such a compilation of relevant ingredient data been attempted, and the authors are to be commended for their initial efforts. Certainly, the database will be significantly expanded as experimental results indicate nutritional value and dietary feasibility of the various ingredients presented. Others will be added as food processing industries endeavor to recover by products that have real economic value, rather than that of a waste product to be discarded.

Newly developed ingredients for aquafeeds are appearing in the international marketplace. One example is that of the carotenoid (astaxanthin) containing yeast *Phaffia rhodozyma*, currently being used as an effective pigmenting agent in salmonid and other aquatic diets. Technological developments are being explored to enhance usage of plant and animal feedstuffs in aquafeeds. Examples include, among others, such approaches as development of genetically engineered soybean with increased levels of the essential amino acids methionine and lysine, as well as possible removal of bone from meat and bone meal, thereby reducing calcium levels with a concurrent increase in the protein content. Hydrolyzed protein products, including fish protein concentrates from by-catch and processing water are being commercialized along with hydrolyzed proteins from blood, egg, poultry and liver products.

The stated objectives of this book, “to contribute to a better understanding of commonly used aquaculture feed ingredients and to find some useful information on some potential feedstuffs for aquaculture diets”, clearly are valid ones in terms of needs of present day aquaculture. Hopefully, this worthwhile endeavor will serve as a catalyst for further compilation and ultimate critical analysis of basic and applied information on a wide range of specific ingredients for use in commercial aquaculture.

Dr. Samuel P. Meyers
Professor
Departments of Food Science/
Oceanography & Coastal Science
Louisiana State University
Baton Rouge, LA 70803/USA

ACKNOWLEDGEMENT

The authors gratefully acknowledge Cynthia Animas, Amelia Arisola, Carolina Unggui, Luisa Pacino, Jeremiah Buendia, Oscar Gulmatico and Norma Teruel for their patience and unfaltering help throughout the preparation of the manuscript for this book. Furthermore, the authors sincerely appreciate the illustrations that the late Ong Sik Lee did. Unfortunately, he passed away before this book was printed.

1. PROLOGUE

Aquaculture has had a rapid, global development during the recent 30 years particularly, fish and crustacean culture. Today about 30 species of shrimps and more than 300 finfish species are commercially cultivated world-wide. However, aquaculture does not only include fishes and crustaceans. Culture of aquatic organisms also includes not only the commercial production of molluscs, seaweed, sea cucumber and sea urchin, but also turtles, frogs and reptiles. On the other hand, aquaculture is not new. The Chinese are known to have farmed ponds filled with carp more than 2000 years ago.

The profit oriented commercial farming of aquatic organisms in controlled water and environment is known as aquaculture, and is a specific sector of agricultural production with the objective of producing animal protein for human consumption. For instance, the culture of Atlantic salmon (*Salmo salar*) in Norway, the world's largest producer, has its roots in basic research work with terrestrial farm animals. The late internationally recognised geneticist in animal breeding, *Harald Skervold*, a professor emeritus of the Norwegian Agricultural University, in the sixties, used the salmon for genetic research because reproduction rate is tremendous for enhancing genetical progress compared to the possibilities offered by terrestrial animals.

But commercial aquaculture is not always sunny. The industry is very young, and still works on many presumptions with regard to reproduction, husbandry and specifically nutrition. Some of the problems that cause difficulties in commercial aquaculture are the diversity and enormous number of species with their specific requirements. A very typical example for the diversity of aquatic animals is the zoological marine shrimp family *Penaeidae* which is comprised of 81 different species in 13 genera (Table 1-01). While only few species are used in terrestrial production of farm animals, culture of aquatic organisms includes a wide variety of species, each of them having different habits and various physiological and nutritional needs.

Lack of knowledge and understanding of the behaviour of aquatic animals, associated with a too pronounced attitude for profit-making and short-sighted management that does not consider environmental hazards are major reasons for failures in commercial aquaculture. These attitudes have developed into a kind of "aquacultural nomadism" which means that, when a certain area has been deserted by irresponsible commercial aquaculture, the operation moves on to another, still virgin area, continuing the destructive activities to the environment.

There are also other reasons for the uncertainty of the industry which results in instability. Research work in aquaculture genetics is still at an early stage. Without adequate genetical selection land farm animal production would not have attained today's standards of high performances. So far aquaculture research work has had little regard for hereditary disposition and the environment (including feeding) both of which are necessary for good yield. Unfortunately, feed utilisation cannot be greatly manipulated genetically

because the hereditary coefficient for feed conversion is low as established in terrestrial farm animals.

Table 1-01: The species of the zoological marine shrimp *Penaeidae*¹

<u>Genus</u>	<u>Genus</u>	<u>Genus</u>	<u>Genus</u>
<u><i>Penaeus</i></u>	<u><i>Metapenaeus</i></u>	<u><i>Parapenaeopsis</i></u>	<u><i>Xiphopenaeus</i></u>
<i>P. aztecus aztecus</i>	<i>M. affinis</i>	<i>P. arafurica</i>	<i>X. kroyeri</i>
<i>P. aztecus subtilis</i>	<i>M. benettae</i>	<i>P. cornuta</i>	<i>X. riveti</i>
<i>P. brasiliensis</i>	<i>M. brevicornis</i>	<i>P. hardwickii</i>	<u>Genus</u>
<i>P. brevirostris</i>	<i>M. burkenroadi</i>	<i>P. hungerfordi</i>	<u><i>Eusicyonia</i></u>
<i>P. caeruleus</i>	<i>M. dalli</i>	<i>P. sculptilis</i>	<i>E. cristata</i>
<i>P. californiensis</i>	<i>M. demani</i>	<i>P. tenella</i>	<i>E. lancifer japonica</i>
<i>P. canaliculatus</i>	<i>M. eboracensis</i>	<i>P. venusta</i>	
<i>P. carinatus</i>	<i>M. endeavouri</i>	<u>Genus</u>	<u>Genus</u>
<i>P. duorarum duoraum</i>	<i>M. ensis</i>	<u><i>Trachypenaeus</i></u>	<u><i>Sicyonia</i></u>
<i>P. esculentus</i>	<i>M. incisipes</i>	<i>T. anchoralis</i>	<i>S. brevirostris</i>
<i>P. fluviatilis</i>	<i>M. insolitus</i>	<i>T. byrdi</i>	<i>S. dorsalis</i>
<i>P. indicus</i>	<i>M. intermedius</i>	<i>T. curvirostris</i>	<u>Genus</u>
<i>P. japonicus</i>	<i>M. joyneri</i>	<i>T. faoea</i>	<u><i>Protrachpene</i></u>
<i>P. latisulcatus</i>	<i>M. macleayi</i>	<i>T. fulvus</i>	<i>P. precipua</i>
<i>P. longistylus</i>	<i>M. mastersii</i>	<i>T. gonospinifer</i>	<u>Genus</u>
<i>P. maccullochi</i>	<i>M. monoceros</i>	<i>T. granulosus</i>	<u><i>Atypopenaeus</i></u>
<i>P. merguensis</i>	<u>Genus</u>	<u>Genus</u>	<i>A. formosus</i>
<i>P. monodon</i>	<u><i>Metapenaeopsis</i></u>	<u><i>Solenocera</i></u>	<u>Genus</u>
<i>P. occidentalis</i>	<i>M. barbatus</i>	<i>S. alticarinata</i>	<u><i>Parapenaeus</i></u>
<i>P. orientalis</i>	<i>M. borradailei</i>	<i>S. depressa</i>	<i>P. australiensis</i>
<i>P. penicillatus</i>	<i>M. crassissima</i>	<i>S. subnuda</i>	
<i>P. plebejus</i>	<i>M. lamellata</i>	<u>Genus</u>	
<i>P. schmitti</i>	<i>M. mogiensis</i>	<u><i>Hymenopenaeus</i></u>	
<i>P. semisulcatus</i>	<i>M. novae-guineae</i>	<i>H. mulleri</i>	
<i>P. setiferus</i>	<i>M. palmensis</i>	<i>H. robustus</i>	
<i>P. stylirostris</i>	<i>M. rosea</i>	<i>H. sibogae</i>	
<i>P. vannamei</i>	<i>M. sinuosa</i>		

¹ Source: *Motoh, H. (1977): SEAFDEC, Techn. Report No 2.*

Another misconception and cause for failure in commercial aquaculture is the use of experimental results from one species to another. For example, the kuruma prawn (*Penaeus japonicus*) has the lowest production volume because of its relatively slow growth but the most substantial research work, such as on shrimp feeding experiments, has been done in this species, and results are transferred to other cultivated shrimp species regardless of their feeding behaviour and physiological differences. Similar observations exist for fishes, like salmonids and to a lesser extent channel catfish. When compared with

terrestrial animal production this is tantamount to using experiences from pig production for broiler raising.

There is a remarkable general knowledge of physiology, nutrition and feeding of aquatic organisms, considering the relatively short period in which research work has been carried out. However, with regard to the specific knowledge on nutrition and feeding of most commercially cultivated aquatic species, the global map of aquaculture nutrition and feeding has still many “white spots”.

This “Handbook on Ingredients for Aquaculture Feeds” aims to contribute to a better understanding of the feed components that affect the nutrition and feeding of aquatic animals, mainly fishes and crustaceans. Oftentimes, little consideration is given to the chemical and physiological properties and the feeding value of the individual constituent in formulating commercial aquaculture feed. The use of each feed component has its “pros” and “cons”. Due to this concern the feeding value of a feedstuff might be over or under assessed and necessary restrictions are neglected.

Furthermore, this book will not only contribute to a better understanding of commonly used aquaculture feed ingredients but also give some useful information on some potential feedstuffs for aquaculture diets.

Various agricultural waste products have been included in the hope that they may be found useful, economically feasible and will help in the production of “friendly” feeds not only at the farm level but also in commercial feed manufacturing.

Some remarks have to be made in order to understand the set-up of the handbook. At the start it was planned to sub-divide the contents into protein and energy feedstuffs as well as into “traditional” and “non-conventional” feedstuffs. However, since there are many overlaps, it was found inconvenient to sub-divide into protein and energy feedstuffs. Furthermore, the border-line between traditional and non-conventional feedstuffs is very fluid and the definition of a non-conventional feedstuff is rather complex and debatable.

Many feedstuffs used in aquaculture feeds are actually non-conventional. They are often by- and waste products from the manufacture of foodstuffs for human consumption but may have a superior feeding value for aquatic animals. Due to all these difficulties it was decided to describe the feedstuffs in alphabetical order.

Data referring to terrestrial farm animals were used whenever there was a lack of information from aquatic animals. The data should only serve as an indication that the feedstuff, without any obligation to use them, may be useful for aquaculture feeds.

Last but not least, this presentation does not claim to be a complete review of all possible feedstuffs which could be included into an aquaculture feed.

Hamburg/Germany and Iloilo/The Philippines
December 1999

Joachim W. Hertrampf
Felicitas Piedad-Pascual

2. NUTRITION OF AQUATIC ANIMALS AT A GLANCE

Farming of aquatic animals requires comprehensive knowledge and appreciation of nutrition, feedstuffs, feeds and feeding practices. Compared with the nutrition of terrestrial farm animals, nutrition of aquatic organisms is relatively new. Like terrestrial farm animals the aquatic counterparts require protein, lipids, carbohydrates, vitamins, minerals and other feed additives for meeting the physiological needs of growth and reproduction. However, there are immense differences between terrestrial and aquatic farm animals.

Due to the abundant diversity of cultured aquatic animals their nutritional requirements vary widely.

2.1 Diversity of Cultured Aquatic Animals

For successful farming of aquatic animals the environmental and biological characteristics of the large number of species have to be fully understood.

Fishes

Temperature and salinity of the water are major environmental characteristics in fish culture. Fishes are poikilothermal organisms which normally adapt their body temperature to the environmental temperature⁽¹³¹⁾. Fishes are subdivided into “warmwater” and “cold-water” fishes. Warmwater fishes have an optimum growing water temperature of 25°C to 30°C⁽¹⁰²⁾, and 20°C and below is the preferred temperatures of coldwater Fishes⁽¹⁰¹⁾.

Coldwater and warmwater species can be both, freshwater and marine fishes (Figure 2-01). The migration habit from oceans to streams and vice versa of some species such as salmonids and eels is successfully used in brackishwater fish culture by careful control of water salinity.

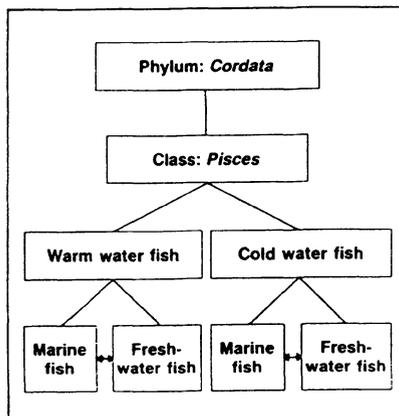


Figure 2-01. Diagram of taxonomic classification of fish⁽⁵⁸⁾.

Water pollution is a serious problem in aquaculture. It is, therefore, suggested that resistance to pollutants should be added to the environmental characteristics of fishes⁽¹¹⁾.

Four attributes determine the biological characteristics of fish⁽¹¹⁾:

- Reproductive habits,
- Requirements of the eggs and larvae,
- Adaptability to crowding,
- Feeding habits.

Fishes can be classified according to the type of food they prefer under natural conditions⁽⁹⁹⁾. The four main categories are (Table 2-01):

- Herbivores,
- Detritus feeders,
- Omnivores,
- Carnivores.

Table 2-01: Feeding habits of selected fish species⁽⁵⁸⁾

<u>1. Herbivores</u>	
Carp:	
• Big head carp	<i>Aristichthys nobilis</i>
• Grass carp	<i>Ctenopharyngodon idellus</i>
• Javanese carp	<i>Puntius gonionotus</i>
• Silver carp	<i>Hypthalmichthys molitrix</i>
Gourami	<i>Osphronemus gourami</i>
Milkfish	<i>Chanos chanos</i>
Perch	<i>Perca</i> spp.
Rabbit fish	<i>Siganus guttatus</i>
Tilapia	<i>Tilapia</i> spp./ <i>Oreochromis</i> spp.
Siamese gourami	<i>Trichogaster pectoralis</i>
<u>2. Detritus feeders</u>	
Mud carp	<i>Cirrhinus molitorella</i>
<u>3. Omnivores</u>	
Channel catfish	<i>Ictalurus punctatus</i>
Common carp	<i>Cyprinus carpio</i>
Grey mullet	<i>Mugil cephalus</i>
<u>4. Carnivores</u>	
Black carp	<i>Mylopharyngodon piceus</i>
Catfish	<i>Clarias batrachus</i>
Grouper	<i>Epinephelus</i> spp.
Marble goby	<i>Oxyelotris marmoratus</i>
Salmon:	
• Atlantic salmon	<i>Salmo salar</i>
• Pacific salmon	<i>Oncorhynchus</i> spp.
Seabass	<i>Lates calcarifer</i>
Trout:	
• Brown trout	<i>Salmo trutta</i>
• Rainbow trout	<i>Salmo gairdneri/Oncorhynchus mykiss</i>

The feeding habit of fish is reflected in the digestive anatomy. The gut-length of fishes is short and the ratio of body length and gut-length is narrow (Table 2-02). The chyme, therefore, stays in the gut only for a short time⁽⁵¹⁾. For this reason fish feed must have a high digestibility. A typical carnivorous fish has a short gut with an extendible stomach for large prey. In the longitudinal axis the stomach can be extended by 30 to 35% and the diameter can increase by 75%⁽¹³¹⁾.

Table 2-02: Length of intestines of some aquatic and terrestrial animals in comparison to the animal's body length⁽⁵¹⁾

Species	Length of the intestine is ... times longer than the body
Trout	1.0 to 1.5
Carp	2.0 to 2.5
Dog / cat	5.0
Horse	12.0
Pig	15.0
Cattle	20.0
Sheep	30.0

Omnivores which tend to eat animal food still have a large stomach but a longer intestine than carnivores. Omnivores such as the common carp (*Cyprinus carpio*), preferring a plant diet, have pharyngeal teeth, no stomach and a long intestine. The gut of herbivorous fish, particularly those which consume phytoplankton is the longest and the most complex type⁽⁹⁹⁾.

Detritus feeders are efficient. They feed mainly on dead organic matter at the bottom of the pond and are "cleaners". In the "transitional stage" the food habit may vary, not only between species but also according to the age of the animals and environmental changes.

Crustaceans

Shrimps are decapod crustaceans of the suborder *Natantia* used mainly for farming. The term "shrimp" and "prawn" are often used interchangeably. Commercially, shrimp refers to the small species while prawn applies to the larger species. The name "shrimp" is used also in connection with various species of the families *Pandalidae*, *Peneidae* and *Palaemonidae*. It particularly refers to the family *Crangonidae*^(11, 105).

The environmental characteristics of shrimps are similar to those of fishes (Figure 2-02). Most important for aquaculture are marine warmwater shrimps. Marine coldwater shrimps are normally small in size. By nature all cultured shrimp species have in the wild the habit of entering shallow coastal waters, when very young. There they settle to the bottom where they grow rapidly for several weeks until they return to the sea⁽¹¹⁾.

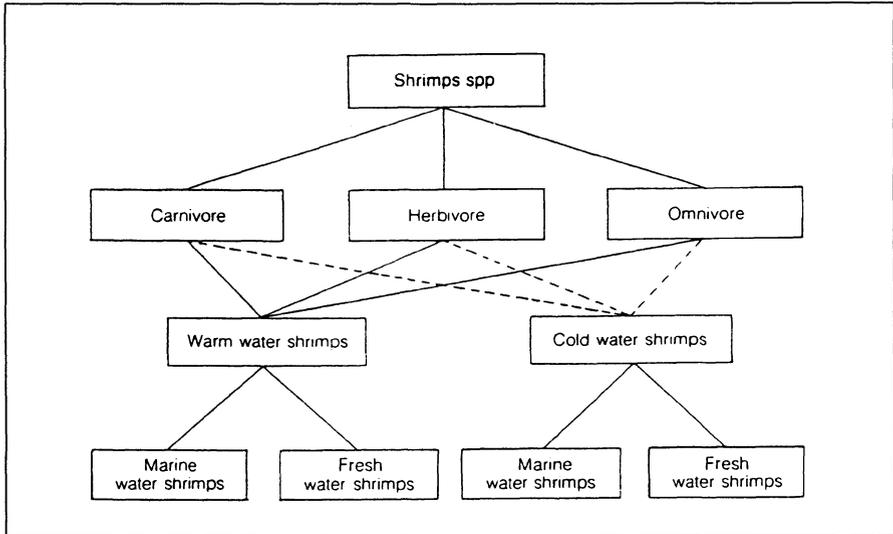


Figure 2-02. Diagram of classification of *Shrimp* spp.⁽⁵⁷⁾.

In shrimp culture water quality is essential. Optimal conditions are⁽³⁰⁾:

- Water temperature: 28 to 33°C
- Salinity: 15 to 25 ppt
- pH: 8.0 to 8.5
- Oxygen: 3.7 ppm (min.)

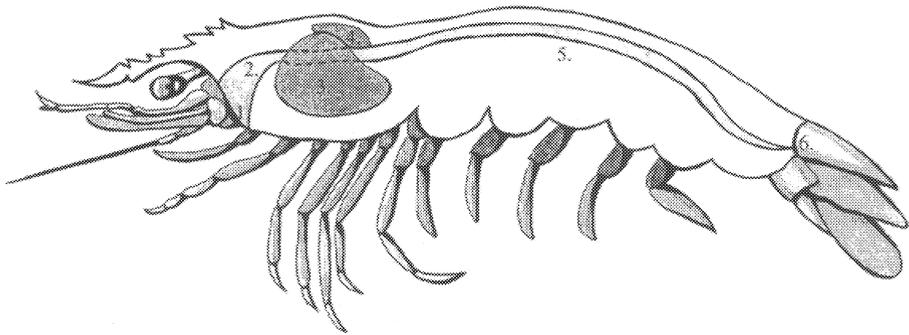
The maximum concentrations for pollutants is shown in Table 2-03.

Table 2-03: Maximum concentrations of pollutants for optimal growth of tiger prawn (*Penaeus monodon*)⁽³⁰⁾

1. <u>Heavy metals:</u>	Mercury	0.0025	ppm
	Copper	0.1	ppm
	Cadmium	0.15	ppm
	Zinc	0.25	ppm
2. <u>Surfactants:</u>	Dunall OSE	0.1	ppm
	BP 110	0.2	ppm
	Seagreen	0.5	ppm
	3. <u>Pesticides:</u>	Malathion	0.0004
	Parathion	0.001	ppb
	Rotenone	0.008	ppb
	Azodrin	0.01	ppb
	Endosulfan	0.01	ppb
	Paraquat	0.01	ppb
	Butachlor	1.0	ppb
4. <u>Others:</u>	H ₂ S	0.033	ppm
	NH ₃	0.1	ppm

Shrimps are classified as carnivores, herbivores and omnivores. The penaeid gut is straight with three main sections: Fore-gut, mid-gut and hind-gut (Figure 2-03)⁽⁹¹⁾. Digestion in penaeid species is a combination of mechanical and chemical processes⁽¹⁴⁹⁾. The hepatopancreas plays a central role in the metabolic processes. It has similar functions to that of the liver in vertebrates. Its enzyme-secretion system is comparable to that of the vertebrate pancreas⁽³⁰⁾.

During the life cycle certain penaeid species change from being herbivorous to carnivorous. However, this transition is only of interest with regard to the protein content of the diet.



- | | | |
|---------------|-------------------|--------------|
| 1. Oesophagus | 3. Hepatopancreas | 5. Intestine |
| 2. Stomach | 4. Heart | 6. Anus |

Figure 2-03. The digestive system of shrimps.

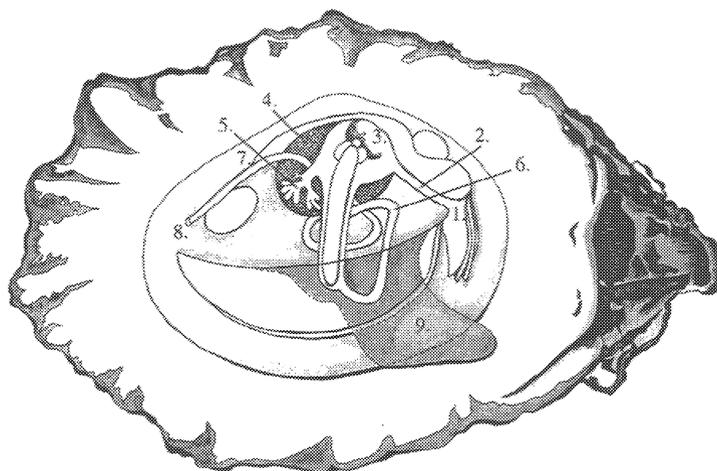
Molluscs

Oysters, mussels, clams and scallops belong to the phylum *Mollusca* and are of the class *Lamellibranchiata* or *Bivalvia*. The latter name derives from the two shells which enclose the animal. There are over 7,000 species of bivalves that live in a wide variety of habitats. Only a small portion of all these species are of aquacultural interest⁽¹¹⁸⁾.

Brackishwater and seawater are the primary habitats of farmed molluscs. Bivalves remain in general cemented in one location with the exception of the terrified scallops and the gastropod abalone (*Haliotis* spp.)^(2, 47).

Molluscs species in the wild are primarily herbivores. Carnivorous bivalves are of no direct interest for aquaculture⁽¹²¹⁾. The digestive system of bivalves is the most complex in the animal kingdom. Five basic stomach types have been described of which three are found in cultured bivalves (Figure 2-04)⁽¹¹⁷⁾. Not less than 21 different digestive enzymes have been found in the bivalve stomach⁽¹²¹⁾. Some bivalves are completely gutless such as *Solemya reidi*⁽¹²²⁾.

The natural diet of marine bivalves is “biphasic”, including both particulate and dissolved components⁽¹³²⁾. The diet of abalone changes during the different phases of their development⁽⁴⁷⁾. However, the feeding behaviour of bivalves differs from species to species. But all of them have in common the tendency to eat only when certain conditions are present, such as tidal flow, the vigorous movement of the surrounding water and the presence of food^(47, 121).



- | | | |
|---------------|--------------------------|-----------|
| 1. Mouth | 4. Digestive diverticula | 7. Rectum |
| 2. Oesophagus | 5. Digestie tabule | 8. Anus |
| 3. Dorsalhood | 6. Midgut | 9. Foot |

Figure 2-04. The alimentary system of bivalves.

Bivalves have the ability to take up dissolved organic material from the water as demonstrated by the uptake of free amino acids (FAA)⁽¹³²⁾. Bacteria associated with bivalves are eaten as food and may contribute to the nutrition of these bivalves. They provide soluble molecules for absorption by the gills or gut, or as contributors to digestion⁽¹²¹⁾. At the same time marine bivalves compete effectively with bacteria normally present in their habitat for available dissolved organic matter⁽¹³²⁾.

The biosynthesis of mollusc shell is a specific mechanism. Shell formation is a complex process which is not completely understood but it is heavily dependent on the chemical composition of the water and influenced by the nutritional quality of the assimilated food⁽¹²⁹⁾.

The slow development of formulated diets for farmed molluscs has been mainly due to the fact that their nutritional requirements have not yet been established. Mollusc nutrition is far behind that of other farmed aquatic animals⁽²¹⁾.

2.2 Proteins

Proteins are a large class of nitrogenous substances of a complex union of amino acids and containing carbon (50.0%), oxygen (22.0%), hydrogen (0.7%) and other elements such as sulphur, phosphorus, iron and iodine⁽¹³¹⁾. Nitrogen (N) (16.0%) is the most important element of protein. The crude protein content of a feed ingredient is generally obtained by multiplying the nitrogen content with the factor 6.25.

However, not all nitrogen of a feed ingredient refers to protein. Nitrogen can be a component of proteins, proteides and non-protein nitrogen. Protein consists of only polypeptides while proteides are composed of at least one protein and another compound which is a non-protein, e.g. phospho-proteides = protein + phosphoric acid. Compounds which contain nitrogen but not in the form of amines ($-\text{NH}_2$) do not have any nutritional value for aquatic animals⁽⁵¹⁾.

The basic units of protein are amino acids. There are some twenty major amino acids. The ten essential amino acids cannot be synthesised by the organism and have to be provided for in the feed for aquatic animals. For complete utilisation of the dietary protein the amino acids have to be balanced. Excess of dietary protein/amino acids is not only costly but also requires energy for deamination. Amino acids are not only the building blocks of protein but are also involved in growth, maintenance of body tissue and energy for the well-being of the animal^(40, 85, 109).

Fishes

In the digestive tract of the fish the dietary protein is split into free amino acids and short peptide chains by enzymes and absorbed by the gut-wall. In the blood, protein appears in the form of amino acids⁽⁵⁵⁾. Utilisation of dietary protein depends on its digestibility which is affected by a number of factors⁽¹¹⁰⁾. Certain parameters are used for determining the protein utilisation by the fish (Table 2-04). They are at the same time an indicator for the quality of the dietary protein⁽¹³¹⁾.

Table 2-04: Parameters for the judgement of dietary protein utilisation by fish

Abbr. Name of parameter	Formula
PER Protein efficiency ratio	$\text{PER} = \frac{\text{Weight gain (g)}}{\text{Protein ingestion (g)}}$
PPV Productive protein value	$\text{PPV} = \frac{\text{Weight gain (g)}}{\text{Protein ingestion (g)}} \times 100$
BV Biological value	$\text{BV} = \frac{\text{N-retention} + \text{endogene N} + \text{N-losses in the digestive tract}}{\text{Feed-N}} \times 100$
NPU Net protein utilisation	$\text{NPU} = \frac{(\text{B} - \text{B}_o) - (\text{B}_k - \text{B}_o)^1}{\text{N-ingestion}}$
EAA Essential amino acid index	EAA = Geometrical average of the 10 essential amino acids

¹ B = Body-N after ingestion of feed protein

B_o = Body-N at start of trial

B_k = Body-N after protein-free nutrition

The fish body contains 65 to 75% protein⁽¹⁵⁸⁾. Its protein requirement, therefore, is about two to three times higher than that of mammals and converts protein much better than crustaceans⁽¹⁰⁹⁾.

Fishes do not have an absolute protein requirement⁽⁸⁸⁾. It is influenced by the species, age of the animals and the water temperature. Fishes cultured in tropical climate have a lower protein requirement (25 to 30%) than those cultured in moderate climate (30 to 40%)^(40, 109, 162).

Fish fry has the highest protein requirement which declines with growth (Table 2-05)^(10, 52). A linear relationship between dietary protein requirement and specific growth rate (SGR) exists⁽¹³⁸⁾. Warmwater fish have a faster SGR than temperate fish⁽¹⁰⁹⁾.

Table 2-05: Protein requirement of tilapia (*Oreochromis sp*) and salmonids is dependent on the age of development

Tilapia ⁽¹⁰⁾		Salmonids ⁽⁵²⁾		
Liveweight g	Protein-requirement %	Stage of development	Protein-requirement %	
until	1.0	35.0 to 50.0	Fry	50.0
	1.0 to 5.0	30.0 to 40.0	Fingerling	40.0
	5.0 to 25.0	25.0 to 30.0	Grow-out	35.0
more than	25.0	20.0 to 25.0		

Crustaceans

The principles of providing crustaceans with dietary protein are similar to those for fishes. In addition to species, food-habits, age and water temperature, the source of protein and energy level of the diet as well as stocking rate affects the protein requirement of crustaceans^(71, 88). For intensive shrimp culture commercial feed should contain not more than 35% protein while that for semi-intensive shrimp culture ranges between 20 to 35%⁽⁸⁸⁾. The protein requirement of commonly cultured crustaceans is in Table 2-06.

Usually protein from animal sources give better growth and survival than plant proteins. Marine crustaceans require relatively high levels of animal protein, particularly of marine origin. Freshwater prawns are better utilisers of plant proteins than marine shrimps.

A guideline for the amino acid requirement of crustaceans is the amino acid composition of the whole shrimp (Table 2-07)^(71, 109). The utilisation of synthetic amino acids by crustaceans is not yet fully established⁽¹⁰⁹⁾. Diets based exclusively on synthetic amino acids were poorly utilised⁽¹¹⁰⁾.

Table 2-06: Protein requirement (%) of some crustaceans^(88, 109)

<i>Penaeus aztecus</i>	Northern brown shrimp	25 - 45
<i>Penaeus indicus</i>	Indian white prawn	36 - 63
<i>Penaeus japonicus</i>	Kuruma prawn	35 - 60
<i>Penaeus merguensis</i>	Banana prawn	34 - 50
<i>Penaeus monodon</i>	Tiger prawn	40 - 50
<i>Penaeus setiferus</i>	Northern white shrimp	28 - 32
<i>Penaeus stylirostris</i>	Blue shrimp	30 - 35
<i>Penaeus vannamei</i>	White leg shrimp	30 - 35
<i>Palaemon serratus</i>	Pink shrimp/common prawn	30
<i>Macrobrachium rosenbergii</i>	Giant river prawn	25 - 45
<i>Macrobrachium nobilis</i>	Fresh water prawn	30
<i>Homarus americanus</i>	American lobster	11 - 60

Molluscs

Very little is known on protein requirement of molluscs. Most of the diets, if not all, used in larval rearing are natural food such as micro-algae of varied species. The protein efficiency is related to the presence of essential amino acids in the same proportion as in the tissue. The nutrient content of artificial diets tested were based on the composition of *Isochrysis galbana* and contained egg albumin, yeast, salmon sperm and crystalline amino acids⁽¹⁵⁶⁾.

Table 2-07: Amino acid profile of prawns (g/16 g N)⁽²⁷⁾

Amino acid	Tiger prawn	Indian prawn	Kuruma prawn
	<i>Penaeus monodon</i>	<i>Penaeus indicus</i>	<i>Penaeus japonicus</i>
Arginine	9.16	9.94	8.16
Histidine	1.52	1.91	2.40
Isoleucine	3.86	4.01	4.58
Leucine	8.04	7.24	8.04
Lysine	6.83	6.62	8.46
Methionine	2.01	1.82	2.90
Phenylalanine	4.02	4.01	4.83
Tyrosine	3.05	2.93	4.20
Valine	3.70	3.09	4.44

The ten essential amino acids and in addition proline and tyrosine were found to be essential for *Mytilus californianus*⁽¹⁵⁶⁾. The utilisation of bacteria protein by molluscs is still being deliberated. The ability of the usage most probably varies between species^(13, 121). Abalone feed should not contain less than 30% protein⁽⁴⁷⁾.

2.3 Carbohydrates

Carbohydrates or saccharides are generally composed of carbon, hydrogen and oxygen. They are aliphatic mono-oxopolyhydroxy-compounds with the basic formula $C_x(H_2O)_y$. Saccharides are energy nutrients for all fauna and flora organisms. They are reservoirs and fuel and are the frame for plants. Globally carbohydrates form the major volume of all biological material⁽¹⁴⁶⁾. Carbohydrates are classified as mono-, oligo- and polysaccharides (Figure 2-05). Monosaccharides are the basic compound for forming oligosaccharides and polysaccharides⁽¹³¹⁾.

The major carbohydrates of feed ingredients for aquatic animals are oligo- and polysaccharides (starch, cellulose, pectin). Starch from plants is a macro-molecule and composed of 2,000 to 8,000 β -glucose-units^(131, 99). The animal starch is glycogen, which primarily is deposited in the liver^(99, 57).

In general, in the digestive tract polysaccharides are split into monosaccharides by enzymatic hydrolysis for absorption. The enzyme for splitting cellulose - cellulases - is only produced by micro-organisms^(131, 146). The indigestible lignin is the fibrous material of the cell-wall⁽⁹⁹⁾ which obstructs the utilisation of the carbohydrates of the cell-wall by the bacteria.

Table 2-08: Factors for estimating the digestible energy of feed ingredients for aquatic animals⁽¹⁰¹⁾

Nutrient	Gross energy kcal/kg	Digestible energy kcal/kg
Carbohydrates (non-legumes)	4.1	3.0
Carbohydrates (legumes)	4.1	2.0
Proteins (animals)	5.5	4.25
Proteins (plants)	5.5	3.8
Fats	9.1	8.0

Remark: No calorific value has been attributed to fibre in this method of calculation

Carbohydrates are determined indirectly. They are the difference between the sum of moisture, crude protein, crude fat, ash and crude fibre content and 100 and is named the "nitrogen-free extract" (N-free extract). It does not encompass cellulose, lignin and pentosanes which are included in the crude fibre content^(48, 57, 131).

Gross energy, digestible energy and metabolisable energy are instruments for the determination of the energy value of feed ingredients. Metabolisable energy is difficult to determine with aquatic animals and the digestible energy from experiments are not readily available. However, the digestible energy can be calculated based on factors shown in Table 2-08⁽⁹⁹⁾. Other techniques are also used for estimating the digestible energy. To calculate the digestible energy, the factors have to be multiplied with the nutrients (based on dry matter) of the individual feed ingredients. The sum of these is the digestible energy.

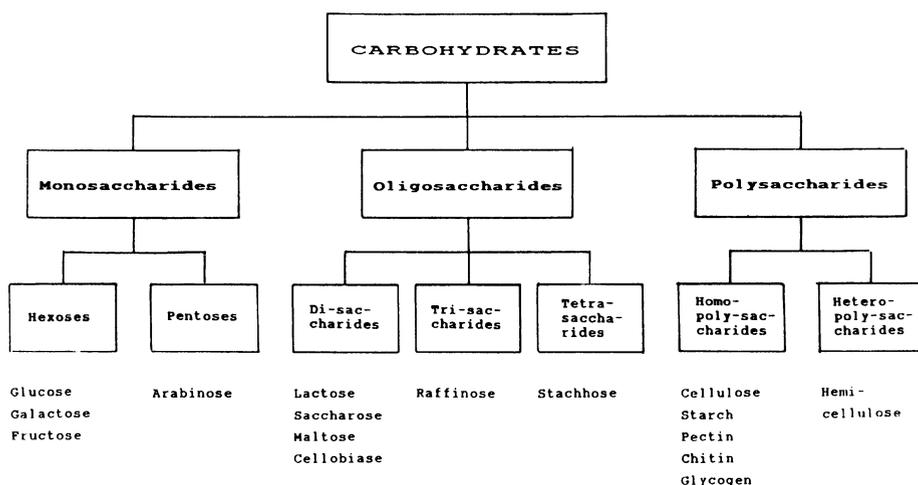


Figure 2-05. Classification of carbohydrates (saccharides)

Fishes

The digestion of carbohydrates by the fish is affected by their feeding habits, the secretion of the stomach juice, the availability of carbohydrate enzymes and the anatomy of the digestive tract. In general, carnivorous fish such as salmonids digest carbohydrates less efficiently than omnivorous and herbivorous fish^(55, 99, 131). Rainbow trout cannot digest purified cellulose and hemi-cellulose⁽¹⁴⁾. Water temperature has no effect on carbohydrate digestibility⁽⁶¹⁾.

The carbohydrate digestibility by salmonids is affected by the size of the carbohydrate molecule and its level in the diet (Table 2-09)^(114, 131). The poor ability to utilise carbohydrates applies also to the carnivorous yellowtail (*Seriola quinqueradiata*) and striped jack (*Caranx delicatissimus*)^(128, 143, 144).

Table 2-09: Digestibility (%) of carbohydrates by salmonid fishes⁽¹³¹⁾

Carbohydrate	Brook trout (<i>Salvelinus fontinalis</i>)	Rainbow trout (<i>Salmo gairdneri</i>)
Glucose	99	79 - 90
Maltose	92	
Saccharose		73
Lactose	60	
Dextrin		77 - 80
Starch (cooked)	57	52 - 70
Starch (raw)	38	20 - 24
α-cellulose		10 - 14

Due to high enzyme activity certain carp species such as common carp (*Cyprinus carpio*) and grass carp (*Ctenopharyngodon idella*) utilise carbohydrates well^(126, 128) while fry of the bighead carp (*Aristichthys nobilis*) respond negatively⁽¹⁴⁸⁾. Various catfish species use carbohydrates even at levels of almost 50%^(67, 90, 99). The African tilapia (*Sarotherodon melanotheron*) utilised dietary carbohydrates satisfactorily⁽⁹⁷⁾.

The crude fibre utilisation by fish is uncertain⁽¹³¹⁾. In carp it was found that with increasing levels of crude fibre the digestibility of the organic matter declined (Figure 2-06)⁽¹²⁶⁾.

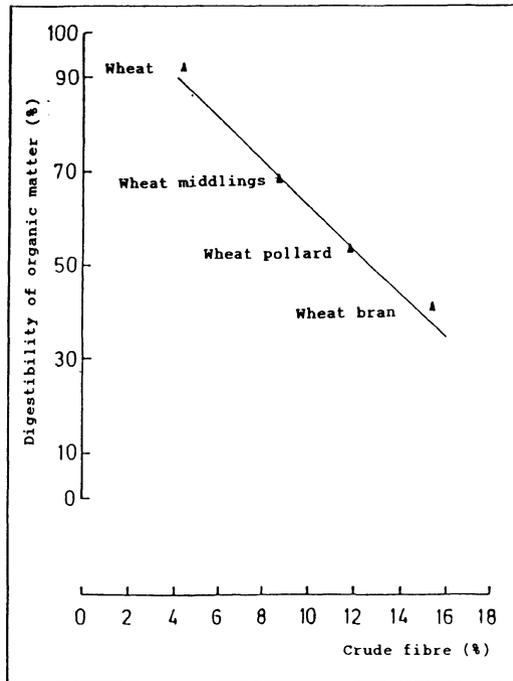


Figure 2-06. The digestibility of the organic matter of wheat and wheat by-products in carp (*Cyprinus carpio*) is affected by the crude fibre content of these feed ingredients⁽¹²⁶⁾.

Crustaceans

In crustaceans carbohydrates are important as an energy source for chitin synthesis and synthesis of non-essential fatty acid⁽¹¹⁰⁾. In addition carbohydrates have a protein sparing effect⁽²⁰⁾. However, there are differences in the utilisation of the various carbohydrate sources. Monosaccharides such as glucose, galactose and fructose inhibit the growth of the brown shrimp (*Penaeus aztecus*), pink shrimp (*Penaeus duorarum*) and kuruma prawn (*Penaeus japonicus*)^(69, 99, 110). On the other hand disaccharides like sucrose, maltose and trehalose, and polysaccharides such as dextrin and starch have a high nutritive value as carbohydrate sources^(26, 69). Crustaceans are incapable of digesting oligosaccharides from seeds of legumes and pulses due to the absence of specific enzymes^(28, 110).

Chitin is a linear polysaccharide with the formula $(C_6H_{13}O_5)_n$ and the major component of the exoskeleton of crustaceans. Due to moulting this has to be steadily replaced. It is synthesised from glucose via glucosamine, a precursor of chitin⁽⁶⁹⁾.

Although dietary crude fibre may stimulate the microbial gut flora⁽⁴⁶⁾, its level in commercial diets should be less than 5.0%⁽¹¹⁰⁾.

Molluscs

Little information is available on the value of carbohydrates in mollusc culture. In abalone farming carbohydrates are considered as an inexpensive energy source⁽⁴⁷⁾.

In studies on gastropod nutrition carbohydrates were included in diets at rather high levels⁽²¹⁾.

2.4 Lipids

Lipids are fatty acid esters of glycerol and are the primary means by which animals store energy. Aquatic animals are able to metabolise lipids readily, particularly when deprived of food. Dietary lipids have two major functions. They are sources of energy and fatty acids. Dietary lipids also give palatability to the feed and serve as a vehicle for the absorption of fat-soluble vitamins and sterols and in addition play a very important role in the structure of biological membranes such as phospholipids and sterol esters^(30, 43).

The protein-sparing property of dietary lipids has been demonstrated in rainbow trout (*Salmo gairdneri*). With increasing fat content of the diet, the protein retention increased^(60, 141). The requirement of fish ranges from 5.0 to 18.0% fat depending on the fish species⁽¹¹⁰⁾, but diets for the Atlantic salmon (*Salmo salar*) may contain fat levels as high as 25.0%.

Lipids with high content of unsaturated fatty acids particularly polyunsaturated fatty acids (PUFA) are very liable to oxidation. Metabolites of lipid oxidation may react with other nutrients and reduce their availability. Malonaldehyde, a product of fat oxidation can be toxic to fish⁽²²⁾.

Fishes

Fishes have to be provided with exogenous lipids. Triglycerides are the major energy source for metabolism in fish muscle. The fatty acids of the lipids are oxidised in the cell mitochondria⁽⁵⁵⁾.

Chain-length and the saturation of the the fatty acids affects the digestibility of lipids. The higher the content of long-chained, saturated fatty acids, the lower the digestibility. The fat digestibility also is affected by water temperature and the melting point of dietary lipids (Table 2-10 and 2-11)⁽⁹⁾. Fishes can synthesise *de novo* fatty acids from acetate as a precursor⁽²²⁾, with the exception of the three essential fatty acids “linolenic acid” (18:3n-3); “linoleic acid” (18:2n-6) and “arachidonic acid” (20:4n-6). They have to be provided in the feed.

Table 2-10: Effect of the water temperature on the apparent digestibility (%) of soybean oil and selected fatty acids by the rainbow trout (*Salmo gairdneri*)⁽⁹⁾

		Water temperature	
		3°C	11°C
Soybean oil		87.9	89.2
Stearic acid	C18:0	77.4	79.5
Oleic acid	C18:1	87.2	87.8
Linoleic acid	C18:2	96.6	97.3
Linolenic acid	C18:3	100.0	100.0

Fish lipids contain high levels of unsaturated fatty acids. However, environmental factors such as freshwater and seawater (Table 2-12); migration from the ocean to streams and vice versa; salinity; water temperature, depth of the water (pressure) and also the fatty acid composition of the dietary fat influence the fatty acid composition of the fish (Table 2-13)^(22, 55, 87, 107, 108, 134, 139).

PUFA are the dominating fatty acids in the fish. The dietary requirement of essential fatty acids is in the range of 0.5 to 1.5%^(10, 24, 110, 140, 142, 152, 161). But an oversupply of Omega-3 HUFA (highly unsaturated fatty acids) in trout feed depresses performances of the animals. The symptoms of an oversupply are similar to those of fatty acid deficiencies⁽¹³¹⁾.

Signs of deficiency symptoms of essential fatty acids are described by NRC⁽¹⁰¹⁾.

Table 2-11: The effect of the melting point of the dietary fat on the digestibility (%) by the rainbow trout (*Salmo gairdneri*)⁽⁹⁾

Fish oil (untreated and hydrogenated)		Water temperature	
		3°C	11°C
Melting point	10°C	85.8	84.8
Melting point	21°C	74.6	75.2
Melting point	33°C	68.8	69.5
Melting point	41°C	46.4	49.0

Table 2-12: Mean content of fatty acid groups in freshwater and marine fishes (% of total fatty acids)⁽²²⁾

Fatty acid group	Freshwater fishes	Marine fishes
Saturated	23.3	25.7
Monoenoic	41.6	42.7
n-6	6.0	3.6
n-3	23.4	23.3
Ratio n-6:n-3	0.34	0.15

Table 2-13: The effect of dietary lipid on fatty acid composition of channel catfish (*Ictalurus punctatus*)⁽¹³⁴⁾

Total fatty acids	Fatty acid composition of diet ¹		Carcass fatty acid composition ¹		Liver fatty acid composition ¹	
	Beef tallow	Menhaden meal	Beef tallow	Menhaden meal	Beef tallow	Menhaden meal
HUFA	3.8	41.9	10.5	42.1	17.6	48.4
n-6	-	3.3	4.3	5.4	5.1	4.3
n-3	3.8	38.4	5.0	34.6	5.04	3.8

¹ of total fatty acids

Crustaceans

Crustaceans have to be provided with exogenous lipids. The requirement is lower than for fish. Recommendations are in the range of 4.0 to 10.0% for marine shrimps and 3.0 to 6.0% for freshwater shrimps⁽¹¹⁰⁾. In juvenile kuruma prawn (*Penaeus japonicus*) the n-3-series of fatty acids is more effective than the n-6-series⁽⁷²⁾.

The reproductive performances of shrimp broodstock is insufficient when there is lack of essential fatty acids (EFA)^(95, 96). In the presence of phospholipids larval *Penaeus japonicus* required less PUFA than juveniles⁽⁷⁵⁾. The requirement is estimated to be 1.0 to 1.6%⁽¹¹⁰⁾.

Crustaceans have a dietary requirement for sterols because they are incapable of synthesising *de novo* sterols from acetate and mevalonic acid⁽²³⁾. Dietary cholesterol is the most effective. Very likely sterols other than cholesterol have to be converted to cholesterol in the body^(76, 147). Diet supplementation with 0.25 to 1.0% cholesterol meets the requirements of crustaceans (Table 2-14)^(23, 32, 110, 111).

Molluscs

The nutritional value of lipids and fatty acids for bivalves has been established by a number of experiments. Lipids are particularly important for larval growth and

development of oysters⁽¹⁵⁶⁾. However, the quantitative deposition of lipids in the body is unknown. It is assumed that triglycerides have a consistent fatty acid pattern throughout the bivalve body⁽²⁾. Changes in the fatty acid composition have been observed during the development of bivalves⁽²⁹⁾.

Phytoplanktons are regarded as the principal food sources for bivalve larvae. However, some algae appear to be more nutritious than others. Some algal food may be deficient in 20:5n-3 and 22:6n-3 fatty acids as observed in a trial in the juvenile Pacific oyster (*Crassostrea gigas*)⁽¹⁵⁶⁾. Supplementation of the algal diet with encapsulated 22:6n-3 fatty acids improved the growth of the Pacific oyster⁽⁸³⁾.

Not more than 5.0% fat should be used in formulated feed for abalone (*Haliotis* spp.). The added fat for coldwater abalone should have a low melting point⁽⁴⁷⁾. In formulated diets for the blue print oyster (*Crassostrea virginica*) 12.0% oyster lipid extract was successfully used⁽⁸³⁾

Table 2-14: The effect of cholesterol on the growth of *Penaeus japonicus*
(Test period: 30 days, temp.: 26 to 27°C)⁽⁴¹⁾

Cholesterol fortification %	Weight gain	
	g	%
0	0.74	100.0
0.7	1.10	148.6
1.4	1.20	162.2
2.1	1.45	195.9

2.5 Vitamins

Vitamins are organic nutrients, essential to man and animals. Insufficient dietary supply results in deficiency symptoms. Scurvy is the oldest known vitamin deficiency, described as early as 400 B.C. by *Hippocrates*. Rickets in children and the deadly beri-beri disease are caused by vitamin deficiencies.

In this century most of the vitamins were discovered in feeding experiments with rats and mice⁽⁶⁾. Although vitamins occur naturally all of them can be synthesised by chemical or microbiological processes on an industrial scale⁽⁵⁶⁾.

True Vitamins

The characteristic of a true vitamin is the co-enzyme function^(30, 33, 101). There are 14 vitamins which are classified as fat-soluble and water soluble vitamins (Table 2-15). Vitamins are involved in many biological functions of the organism. They are important for good health and high performance. Some Vitamins have a precursor which is converted in the body from a pro-vitamin into a true vitamin, e.g. β -carotene is the precursor of Vitamin A.

Table 2-15: Major natural sources of vitamins⁽⁹⁹⁾

Vitamin	Other name for Vitamin	Source
1. Fat-soluble Vitamins		
Vitamin A	Retinol	Fish oils
Vitamin D ₃	Calciferol	Fish oils
Vitamin E	Tocopherol	Vegetable oils
Vitamin K ₃	Menadion	Leaf meals, alfalfa
2. Water-soluble Vitamins		
Vitamin B ₁	Thiamin	Legumes, brans, yeast
Vitamin B ₂	Riboflavin	Yeast, liver, milk, soya beans
Vitamin B ₆	Pyridoxine	Yeast, cereals, liver
Vitamin B ₁₂	Cyanocobalamin	Fish meal, fish viscera, slaughterhouse wastes
Vitamin C	Ascorbic acid	Fresh fish tissue, insects
Biotin	Vitamin H	Liver, yeast, milk products
Folic acid	Pteroylglutamic acid	Yeast, fish tissue, fish viscera, leaf meal
Nicotinic acid	Vitamin PP	Yeast, legumes, forage
Pantothenic acid	Vitamin B ₃	Yeast, brans, animal offal, fish tissue
Choline	Vitamin B ₄	Wheat germ, legumes

Apart from the traditional functions of true vitamins “additional effects” have been described such as enhancing immunity of the organism by Vitamin A and the detoxifying effect of Vitamin E when there is an over-supply of selenium⁽⁵⁶⁾.

Generally, fat-soluble vitamins and Vitamin C are less stable than water-soluble vitamins. The stability of vitamins are affected by moisture, oxidation, reduction, trace minerals, heat, light, pressure, pH and the storage time^(34, 56).

Information on the bio-availability of vitamins are scarce. In aquatic animals only the bio-availability of synthetic Vitamin C has been studied⁽³¹⁾. The bio-availability of inherent vitamins of raw materials is rather variable⁽¹⁵¹⁾.

Substances without Vitamin Status

The term vitamin has been applied to many chemical substances that do not meet the criteria for vitamin status since they do not have a co-enzyme function. Without being dietary essentials, they exhibit biological activity⁽³³⁾. Cultured aquatic animals are in need of some of them, e.g. inositol.

Fishes

For fish farmers the most obvious signs of vitamin deficiencies are growth retardation and increased mortality. However, in most cases vitamin deficiency symptoms are due to insufficient availability of more than one vitamin⁽⁵⁵⁾.

Fat-soluble vitamins, particularly Vitamin A, can be deposited in the liver while water soluble vitamins are hardly deposited in the organism. Deficiencies of water-soluble vitamins, therefore, occur much faster⁽⁷⁹⁾. The utilisation of Pro-vitamin A by fish depends on the water temperature (should not be lower than 12° to 14°C)⁽¹¹⁶⁾. Only α -tocopherol can be used efficiently as Vitamin E by fish. The utilisation of all other tocopherols is much lower⁽¹⁵⁴⁾.

In fish nutrition Vitamin B₁ deficiency is most common, particularly when raw fish is fed. Raw fish contains the enzyme thiaminase which can destroy thiamin (Vitamin B₁)⁽⁹⁹⁾. Tryptophan cannot be effectively utilised by salmonids without nicotinic acid which serves as a precursor⁽¹¹⁵⁾. Choline, although classified as an essential vitamin, can be synthesised by the body in the presence of a methyl-donor (e.g. methionine), folic acid and Vitamin B₁₂^(25, 159, 163). Choline may also be replaced by phospholipids (see chapter 41)⁽¹³⁵⁾. The “fatty liver syndrome” (e.g. in carp (*Cyprinus carpio*) is the most severe choline deficiency sign⁽¹⁶³⁾,

Crustaceans

Just like in fishes the primary sign of vitamin deficiency in crustaceans are poor growth and high mortality rate. The need for providing kuruma prawn (*Penaeus japonicus*) with choline and inositol has been demonstrated. Beyond 2,000 mg/kg diet no additional growth was observed (Figure 2-07)^(56, 74).

Freshwater prawns most probably obtain a portion of their vitamin requirements from the nutrients of the pond^(8, 16, 17, 137).

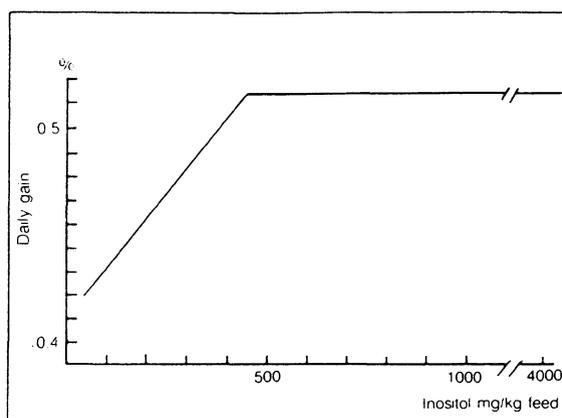


Figure 2-07. The effect of increasing added inositol levels on the growth of the kuruma prawn (*Penaeus japonicus*)⁽⁷¹⁾.

Molluscs

Molluscs need vitamins as any other animal, however, their needs are not yet quantitatively established. Since cultured molluscs are basically fed on natural food (algae), their vitamin requirements may be met^(47, 110, 156). Bacteria associated with molluscs such as in bivalves, may also supply vitamins^(13, 121). Formulated feed also contain high levels of yeast which is a good source of the B-Vitamins⁽⁴⁴⁾.

Vitamin Requirements

Vitamin requirements have been categorized and defined as the:

- Minimum vitamin requirement;
- Optimum vitamin requirement;
- Suboptimal scope.

The vitamin level between minimum and optimum requirements is the suboptimal scope. Supplying suboptimal amount is more or less practiced in vitamin fortification of aquaculture feed⁽⁵⁶⁾.

Many factors affect the quantitative requirement of vitamins by fish. Coldwater fish have a higher vitamin requirement than warmwater fish^(56, 136). Stress situations such as high salinity or poor water quality require higher vitamin fortification. Since crustaceans are slow eaters, their diet requires higher vitamin levels to counteract the loss of water-soluble vitamins through leaching.

A guide for the fortification of aquaculture feed with vitamins are in Tables 2-16 and 2-17.

Table 2-16: Guidelines for the vitamin fortification per kg of formulated fish feed⁽¹³¹⁾

Vitamin		Rainbow trout	Common carp	Channel catfish
Vitamin A	IU	5,000 -20,000	4,000 -20,000	-
Vitamin D ₃	IU	2,000 - 3,000	2,000	500 - 4,000
Vitamin E	mg	100 - 500	100 - 500	-
Vitamin K ₃	mg	10 - 20	3	-
Vitamin B ₁	mg	10 - 20	10	1
Vitamin B ₂	mg	10 - 20	5 - 10	10
Vitamin B ₆	mg	10 - 20	5 - 10	2 - 3
Vitamin B ₁₂	mcg	20 - 50	-	-
Vitamin C	mg	200 - 400	50 - 100	50 - 200
Pantothenic acid	mg	50 - 100	30 - 90	250 ¹
Nicotinic acid	mg	50 - 100	20 - 50	20
Biotin	mg	1 - 2	1	1
Folic acid	mg	5 - 10	-	-
Cholin	mg	500 - 1,000	1,000 - 2,000	-
Inositol	mg	300 - 500	400 - 500	-

¹ for fry

Table 2-17: Guidelines for the vitamin fortification per kg of formulated feed for marine shrimps^(4, 62, 136)

Vitamin A	IU	4,000	- 100,000
Vitamin D ₃	IU	1,000	- 5,000
Vitamin E	mg	100	- 300
Vitamin K ₃	mg	5.0	- 100
Vitamin B ₁	mg	30	- 120
Vitamin B ₂	mg	20	- 70
Vitamin B ₆	mg	50	- 120
Vitamin B ₁₂	mcg	20	- 100
Vitamin C	mg	1,000	- 5,000
Pantothenic acid	mg	75	- 220
Nicotinic acid	mg	150	- 330
Biotin	mg	0.5	- 1.5
Folic acid	mg	5.0	- 15
Cholin	mg	400	- 2,400
Inositol	mg	300	- 4,000

Vitamin Toxicity

Too little as well as too high vitamin supply can be harmful to animals. Tolerance levels are not the same for each vitamin and may range from two times to 1,000 times that of the requirement⁽³⁵⁾. The toxicity of vitamins is classified as follows:

- Vitamins with high toxic potential (Vitamin A - Vitamin D - Choline);
- Vitamins with moderate toxic potential (Vitamin B₂ - nicotinic acid - pantothenic acid);
- Vitamins with low toxic potential (Vitamin E - Vitamin K₃ - Vitamin C - Vitamin B₁ - Vitamin B₆ - Vitamin B₁₂ - biotin - folic acid).

Signs of excess vitamin supply (hypervitaminosis) have been observed in fish⁽¹³⁶⁾. However, rainbow trout tolerated without adverse effect 900,000 IU Vitamin A/kg feed and 1.4 million IU Vitamin D₃/kg feed⁽⁶¹⁾.

2.6 Minerals

Minerals are essential nutrients for aquatic animals. For optimum performances they must be provided in proper amounts and in biologically available form. In contrast to terrestrial animals, aquatic animals can absorb part of the required minerals from the water through their gills or even through their entire body surface^(55, 56).

Minerals are not only required for the formation of bones, scales, teeth and exoskeletons, but are also needed in many physiological processes and functions⁽¹¹³⁾. The mineral content of the whole body depends on the age of the animal and the mineral supply. Both essential and almost all non-essential minerals are found in the animal body⁽⁴²⁾ but the general opinion that marine aquatic animals are highly contaminated with heavy metals, has been proven to be incorrect⁽¹⁰⁶⁾.

Mineral absorption is affected by the aquatic species and certain environmental factors such as mineral content of the water, water temperature and pH of the water⁽⁵⁵⁾.

There are 23 minerals, classified as macro and micro (trace) minerals, which are essential to aquatic animals (Table 2-18)⁽¹³⁶⁾. Minerals required at levels of more than 100 mg/kg diet (basis: dry matter) are macro elements. All others are micro (trace) minerals⁽¹³¹⁾. An intensive interrelationship between the minerals exists in the organism (Figure 2-08) and their functions are rather complex⁽³⁹⁾.

Table 2-18: Classification of minerals in feed for cultured aquatic animals⁽¹³⁶⁾

Macro minerals		Trace minerals		Trace minerals ¹	
Calcium	Ca	Aluminium	Al	Arsenic	As
Chloride	Cl	Cobalt	Co	Chromium	Cr
Phosphorus	P	Copper	Cu	Nickel	Ni
Potassium	K	Fluorine	F	Silicon	Si
Magnesium	Mg	Iodine	I	Tin	Sn
Sodium	Na	Iron	Fe	Vanadium	V
Sulfur	S	Manganese	Mn		
		Molybdenum	MO		
		Selenium	Se		
		Zinc	Zn		

¹ Biological function still uncertain

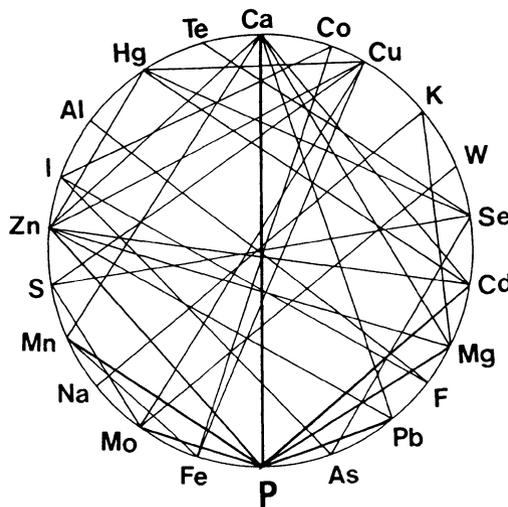


Figure 2-08. Interrelationship between macro and trace minerals in animal metabolism⁽⁵⁶⁾.

Bio-availability of Minerals

The bio-availability of minerals, as affected by a number of factors, is comparable to the digestibility of nutrients of organic origin^(56, 82). However, the determination of the bio-availability of minerals is not yet standardised⁽⁵⁶⁾. The bio-availability of calcium carbonate (CaCO_2), tested in carp (*Cyprinus carpio*) is very low (27%)⁽⁹⁸⁾ and that of mono-sodium phosphate (Na_2HPO_4), tested in rainbow trout (*Oncorhynchus mykiss*) is high (90 to 95%)⁽¹²⁴⁾.

Most phytate-phosphorus of plant seeds is not only poorly available but also binds calcium (Ca) as well as magnesium (Mg) and Zinc (Zn)^(42, 89).

Fishes

Calcium (Ca) and phosphorus (P) are the dominant inorganic components in the whole fish, e.g. rainbow trouts contain 0.43% Ca and 0.41% P⁽⁵⁰⁾. The Ca:P-ratio in the feed, therefore should be 1.0:1.0 to 1.2. About 90% of Ca and 80% of P are found in the bones. The remaining percentages are vital for metabolism⁽⁵⁵⁾.

While the absorption of Ca from water is high and makes fish less dependent on dietary Ca⁽⁵⁵⁾, the P-uptake from water is low⁽¹¹²⁾ since the P-content of the water is also low (Table 2-19)⁽¹⁸⁾. However, the Ca absorption from water is related to the available P to the fish⁽⁵⁵⁾. Dietary magnesium (Mg) is essential because water has a low Mg content⁽¹³¹⁾. On the other hand, most probably the sodium (Na), potassium (K) and chloride (Cl) requirement can be satisfied by the water⁽⁸⁹⁾.

Table 2-19: Concentration (mg/l) of elements in seawater and freshwater⁽¹⁸⁾

Element		Freshwater	Seawater
Calcium	Ca	42.0	400
Chloride	Cl	6.0	19,000
Copper	Cu	-	0.003 - 0.5
Iron	Fe	0.005	0.01
Magnesium	Mg	11.0	1,340
Manganese	Mn	-	0.02
Phosphorus	P	0.005	0.02
Potassium	K	2.0	380
Silicon	Si	-	3.0
Sodium	Na	8.0	10,500
Zinc	Zn	0.005	0.01

The knowledge on trace minerals for fish is scarce⁽¹³¹⁾. They are needed for a number of chemical processes in the metabolism (formation and synthesis of certain proteins, enzymes, vitamins, hormones)⁽⁷⁹⁾. The biological functions of molybdenum (Mo), chromium (Cr), arsenic (As), nickel (Ni), vanadium (V) and tin (Sn) are uncertain, e.g. chromium still is considered as an undesirable substance^(42, 157). Table 2-20 provides guidelines on the mineral requirement of fish.

Crustaceans

The basics of mineral functions and requirements for crustaceans are similar to that for fish. Like fish, marine crustaceans are able to absorb minerals from the aquatic environment⁽¹¹³⁾. The more intensive the shrimp culture is, the less the physiological mineral requirement can be met by the water⁽⁸¹⁾. Freshwater shrimps drink little or no water.

Due to the frequent moulting of crustaceans large quantities of minerals are lost and have to be replaced. Prior to ecdysis, minerals must be removed from the old exoskeleton to soften it. Only a certain portion of the minerals can be stored in tissues^(70, 81).

Oversupply of minerals might be just as harmful as deficiencies as indicated by experiments under laboratory conditions⁽⁷³⁾. Guidelines for the macro and trace mineral requirement are in Table 2-20.

Molluscs

Mineral requirements for molluscs have not been defined and are difficult to define. Molluscs drink water and utilise the inorganic and organic materials in their aquatic environment. However, it seems that adding minerals to formulated feed improves growth^(7, 45, 47).

Table 2-20: Macro and trace mineral requirements of fish⁽⁵⁵⁾ and shrimp^(38, 45, 113, 136)

		Fish	Shrimp
1. Macro minerals			
Calcium	%	0.5	0.5 - 1.25
Phosphorus	%	0.7	1.0 - 2.0
Magnesium	%	0.05	0.1 - 0.3
Sodium	%	0.1 - 0.3	0.2 - 0.6
Potassium	%	0.1 - 0.3	0.7 - 0.9
Sulfur	%	0.3 - 0.5	-
Chlorine	%	0.1 - 0.5	-
<hr style="border-top: 1px dashed black;"/>			
2. Trace minerals			
Iron	mg/kg	50 - 100	70 - 300
Copper	mg/kg	1,000 - 4,000	10 - 35
Manganese	mg/kg	20 - 50	20 - 45
Cobalt	mg/kg	5 - 10	5 - 10
Zinc	mg/kg	30 - 100	90 - 110
Iodine	mg/kg	100 - 300	30
Selenium	mg/kg		0.1 - 0.2

2.7 Other Feed Supplements

2.7.1 Chemo-attractants

Gustation and Olfaction

Food attraction and feeding stimulation are significant considerations in the formulation and ultimate acceptance of aquatic feeds. An otherwise nutritionally balanced diet may be ineffective or marginal in its performance due to the absence or presence of a minimal concentration of ingredients that elicit a positive stimulatory response in a particular aquatic species⁽⁹³⁾. At the stage salmonids begin exogenous feeding, as much as 50% of the population may die of starvation in the presence of commercial feed, due to the poor acceptance of the feed⁽⁸⁶⁾.

The pattern of food search behaviour is induced by the taste (gustation) and the smell (olfaction). The sense of taste and the sense of smell are both chemical senses⁽⁷⁸⁾. The taste is the “sense at close range” while the smell is the “sense at a distance”. Receptors of the taste are the taste buds which are chemo-receptors (Figure 2-09)⁽⁷⁹⁾. The total number of taste buds varies from species to species (Table 2-21).

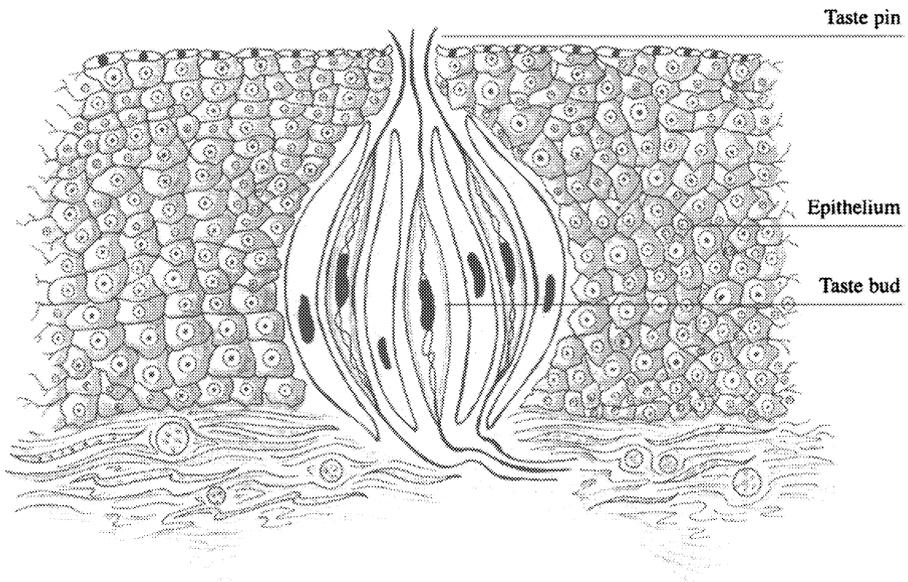


Figure 2-09. Illustration of a taste bud (re-designed from: 79, 160).

Table 2-21: Taste buds and olfactory cells of man and selected species^(79, 100, 160)

Species	Taste buds Nos.	Olfactory cells Million
Chicken	25	10 - 20
Duck	200	10 - 20
Man	9,000 - 10,000	10 - 20
Sheep	10,000	125 - 225
Pig	5,000 - 15,000	125 - 225
Goat	15,000	125 - 225
Cattle	25,000 - 35,000	125 - 225

In aquatic animals the sense of taste is more important than the sense of smell. The latter only plays a certain role in some few species. Taste buds not only can be found in the mouth but also in the lips. They also may cover the head as well as the whole body including the tail⁽⁷⁸⁾. For the rainbow trout (*Salmo gairdneri*) sense of taste and sense of smell are independent of each other⁽¹³³⁾. Fishes can have an olfactory ability 250 times better than that of man⁽⁷⁹⁾.

Table 2-22: Concentration of glycine betaine of various invertebrates⁽⁸⁰⁾

Species	mg/100 g raw muscle
1. Crustaceans	
Crab	357 - 711
Shrimp	251 - 961
Krill	106
2. Molluscs	
Octopus	1,434
Squid	619 - 928
Clam	679 - 727
Oyster	805
Mussel	964

Phagostimulatory Substances

To make the search for food by cultured aquatic animals more efficient, formulated feed is fortified with phagostimulatory substances, also named chemo-attractants. They provide the proper “signals” that allow aquatic animals to recognise the pellet as a potential

food source. To activate the feeding behaviour of aquatic animals is quite complex. The search for food by fish consists of three phases⁽⁶⁸⁾:

- Arousal to or awareness of food stimulus;
- Search to locate feed stimulus;
- Consummation to assess acceptability.

Certain synthetic amino acids have been shown to accelerate the search for food and its ingestion⁽¹⁵⁰⁾. An important activator of feeding behaviour is glycine⁽⁹³⁾. Mixtures of amino acids have proven to be more effective than individual amino acids⁽³⁾. Essential amino acids like lysine may have no or only limited chemo-attractant effect⁽⁹²⁾

The lipid fraction of the feed also may have chemo-attractant properties. Phospholipids and their derivatives were found to be attractive for yellowtail (*Seriola quinqueradiata*) and abalone (*Haliotis* spp.)^(47, 53).

Besides synthetic amino acids natural materials such as waste and by-products from processing of aquatic animals are also used as chemo-attractants. Post mortem deterioration releases free amino acids and nucleotides⁽¹⁴⁶⁾. Glycine betaine is found in relatively large concentrations in various marine invertebrates (Table 2-22). The acceptance preference for certain chemo-attractants differ between aquaculture species⁽¹¹⁰⁾.

Effective attractants which stimulate the gustatory (taste) and olfactory (smell) senses of aquatic animals are:

- Fish solubles,
- Mussel flesh (meat),
- Mussel extractive (*Mytilus edulis*),
- Short-necked clam (*Tapes* spp.),
- Shrimp meal,
- Shrimp waste,
- Squid meal,
- Tuna viscera powder.

For herbivorous molluscs, algae and seaweed are attractive. The chemo-attractability is due to the content of free amino acids. The higher the content of free amino acids, the more is the algae and seaweed species, respectively, preferred⁽¹⁵⁾.

2.7.2 Antibiotics

Performance Promotion

Antibiotics are bacteriostatic or bactericidal substances in the metabolism of a wide range of micro-organisms. They are primarily effective against bacterial infections⁽¹⁴⁵⁾ but not for viral infections, as often claimed. Antibiotics were used for the first time in 1949 as an antibacterial performance promoter^(77, 125).

Antibiotics are somewhat selective in their antibacterial actions. They are, therefore, divided into effectiveness against “gram¹-negative bacteria” and “gram-positive bacteria”. For instance, streptomycin is mainly effective against gram-negative bacteria while penicillin is most effective against gram-positive organisms. Antibiotics such as chlortetracycline and oxytetracycline have a wider range of activity and are effective against both (Figure 2-10). While the latter are called “broad-spectrum” antibiotics, the former are “narrow-spectrum” antibiotics⁽¹³⁰⁾.

¹ The Danish bacteriologist *Hans Christoph Joachim Gram* (1853-1938) developed the dye-process for the differentiation of similar appearing bacteria.

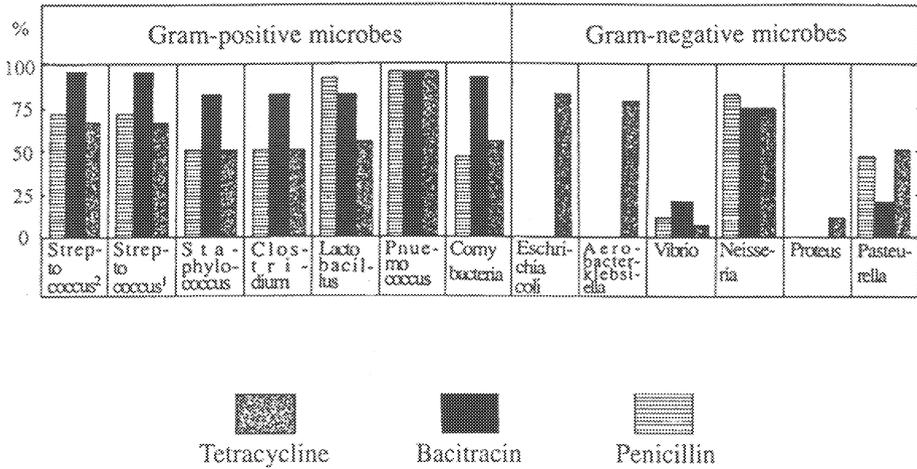


Figure 2-10. The effectiveness of selected gram-positive and gram-negative antibiotics against various microbes (1 non-hemolytic; 2 hemolytic) (65).

After almost 50 years of application the mode of action of antibiotics as performance promoters is not yet fully understood. A number of theories have been considered but a definite answer has not been obtained.

The use of antibiotics as performance promoter is limited in many countries. An antibiotic which should be approved by the EU as a performance promoter has to meet the following essential criteria:

- The antibiotic is not to be used for human and veterinary medicine;
- After feeding of an antibiotic there are no residues in the animal that is produced;
- There should be no development of any kind of resistance against pathogenic germs.

Only few antibiotics meet these requirements. The number of feed antibiotics approved by the EU is very short (Table 2-23)⁽¹⁵⁷⁾ and will be re-considered due to popular objections.

The performance promoting effect of antibiotics in mammals and poultry is well known. Relevant trials in cultured fish were less successful. It is presumed that, contrary to warm-blooded animals, fish do not have a permanent bacterial flora in the intestine because the empty gut of the healthy fish is more or less sterile^(11, 120). In cultured aquatic animals signs of resistance to pathogenic bacteria have been observed after feeding diets containing antibiotics^(11, 47).

Prevention and Cure

A wide range of antibiotics are important for the prevention and treatment of diseases of aquatic animals. However, this is no longer a nutritional matter. The application, therefore, has to be supervised by veterinarians or fish pathologists. After application of the antibiotic, withdrawal periods have to be observed so that the consumable parts of the aquatic animals are free of residues. Due to this concern some countries have enforced strict regulations^(66, 133).

Table 2-23: Feed antibiotics approved by the EU⁽¹⁵⁷⁾

Antibiotic	Chemical formula	EU-No.
Avilamycin	$C_{57-62}H_{82-90}Cl_{1-2}O_{31-32}$	E 717
Avoparcin	$C_{53}H_6O_{30}N_6Cl_3$	E 715
Flavophospholipol	$C_{70}H_{124}O_{40}N_6P$	E 712
Monensin-sodium	$C_{16}H_{61}O_{11}Na$	E 714
Salinomycin-sodium	$C_{42}H_{69}O_{11}Na$	E 716
Spiramycin	I. $C_{43}H_{74}O_{14}N_2$ } II. $C_{45}H_{76}O_{15}N_2$ } Base III. $C_{46}N_{78}O_{15}N_2$ }	E 710
Tylosin-phosphate	$C_{46}H_{77}NO_{17}$	E 713
Virginiamycin	I. $C_{28}H_{35}O_7N_3$ II. $C_{43}H_{49}O_{10}N_7$	E 711
Zinc Bacitracin	$C_{66}H_{103}O_{16}N_{17}SZn$	E 700

Very recently, approval of some of the above have been withdrawn.

2.7.3 Antioxidants

Autoxidation and Chemical Reactions

Feed and feedstuffs readily undergo oxidation when exposed to air. The oxidation reaction is irreversible and results in chemical changes causing losses in nutrients and a reduction in the shelf-life of feed and feedstuffs. This oxidation reaction is referred to as “autoxidation” or “rancidity”.

A wide range of feedstuffs and other organic substances used in animal feeds easily undergo autoxidation. Predominantly, substances which have unsaturated carbon (C) atoms (double bonds) in their molecular structure are very susceptible to autoxidation. Ingredients commonly affected by autoxidation are fats, oils, vitamins and pigments. Rancidity causes palatability problems in feed, loss in vitamin potency and colour strength of pigments. Proteins and carbohydrates are not prone to autoxidation because they do not contain the oxygen labile double bonds.

Autoxidation is a chain reaction and occur in three phases⁽¹⁾. It can be prevented by chelation of metallic ions that are responsible for catalysing the initiation phase of autoxidation and by scavenging of free radicals by antioxidants which serve as electron donors⁽¹⁴⁶⁾. Substances that prevent autoxidation are classified as:

- Natural antioxidants;
- Synthetic antioxidants.

Some chelating agents are citric acid, tartaric acid, phosphoric acid and their salts. The efficacy of antioxidative substances may be synergistic and also be affected by the substrate itself⁽¹⁴⁶⁾. Antioxidants do not last for ever. Due to their antioxidative reactions they deplete themselves.

Antioxidants used as feed additives have to be safe for man and animals. In many countries the application of antioxidants has to be approved by the competent authorities (Tables 2-24, 2-25).

Table 2-24: Antioxidants approved for feed by the EU⁽¹⁵⁷⁾

Antioxidant	Chemical formula	EU-No.
L-Ascorbic acid	$C_6H_8O_6$	E 300
Butylated hydroxyanisole (BHA)	$C_{11}H_{16}O_2$	E 320
Butylated hydroxytoluene (BHT)	$C_{15}H_{24}O$	E 321
Ethoxyquin	$C_{14}H_{19}ON$	E 324
Calcium-L-ascorbate	$C_{12}H_{14}O_{12}Ca \cdot 2H_2O$	E 302
5,6-Diacetyl-ascorbic acid	$C_{10}H_{12}O_8$	E 303
Dodecyl gallate	$C_{19}H_{30}O_5$	E 312
Sodium-L-ascorbate	$C_6H_7O_6Na$	E 301
Octyl gallate	$C_{15}H_{22}O_5$	E 311
Propyl gallate	$C_{10}H_{12}O_5$	E 310
Synthetic alphatocopherol	$C_{29}H_{50}O_2$	E 307
Synthetic deltatocopherol	$C_{27}H_{46}O_2$	E 309
Synthetic gammatocopherol	$C_{28}H_{48}O_2$	E 308
Natural extract with high content of tocopherols	-	E 306

Table 2-25: Antioxidants approved for feed in the U.S.A.⁽¹⁾

Antioxidant	Classification under food regulations
Ascorbic acid	582.3013
Ascorbyl palmitate	582.3149
Butylated hydroxyanisole (BHA)	582.3169
Butylated hydroxytoluene (BHT)	582.3173
Calcium ascorbate	582.3189
Dilauryl thiodipropionate	582.3280
Distearyl thiodipropionate	582.3280
Ethoxyquin	573.380
Propyl gallate	582.3660
Resin guaiaic (same as guaiac gum)	582.3336
Thiodipropionic acid	582.3109

Damaging Effects of Oxidation

Major physiological and pathological damaging effects of feeding oxidised fat and oils are:

- Dark colouration,
- Anemia,
- Lethargy,
- Brown-yellowish pigmented livers,
- Abnormal kidneys,
- Gill clubbing.

The products of lipid oxidation may react with other nutrients, e.g. protein and vitamins, and reduce the available dietary levels. Oxidation products may also be toxic⁽²²⁾, e.g. malonaldehyde is toxic to rats^(37, 119). Higher levels of Vitamin E and selenium in the diet may detoxify oxidised dietary fat^(103, 104).

Feeding oxidised fat to fish, particularly salmonids, resulted in depressed performances, higher mortality rates and other physiological damages^(12, 36, 49, 63, 123). The so called “Sekoke disease” of the common carp (*Cyprinus carpio*) is caused by oxidised fat^(54, 153, 155).

2.8 Physical Properties of Feed

Feed pellets have to be eaten and should not fall apart before they are ingested by the aquatic animals. The water durability of aquaculture feed, therefore, is important. Manufacturers of aquaculture feed have to consider the eating habit of the aquatic animals when processing feed. The slower the animal eats, the more water-durable the pellets should be.

Generally, carnivorous fishes are fast eaters, while crustaceans are slow eaters. For aquatic animals that eat floating feeds, water durability of the feed is of less importance than for bottom feeders.

Most major raw materials used for aquaculture feed formulations have poor pelletising ability and, therefore, feed made from them have an unsatisfactory water durability. The pellet stability and water durability of the feed can be substantially improved by extrusion, expansion and addition of a binding agent to the mash prior to pelletising.

The parameters that may be used for determining pellet quality of aquaculture feed are:

- Abrasion,
- Hardness,
- Water durability.

Testing of the water durability of pellets is not yet uniform. A practical parameter for testing the effectiveness of a pellet binding agent is the weight loss of the pellets in water. The higher the degree of disintegration of the pellet in a given time, the higher the weight loss and, therefore, the lower the water durability (Table 2-26)⁽¹⁵⁾.

Leaching of water soluble nutrients during the first minutes of immersion is important for ease of finding the feed by the animals⁽⁹⁴⁾. The “leaching rate” can be measured by the visible light absorption after 10, 30 and 60 minutes⁽⁸⁴⁾.

The range of materials that have a pellet binding capacity is very wide, and are classified as⁽⁵⁹⁾:

- Natural minerals,
- Wood-processing by-products,
- Plant products with pellet binding properties,
- Synthetic compounds.

Most materials belong to plant products with pellet binding properties (Table 2-27).

Table 2-26: Weight loss of pellets in water as an indicator for the water durability of aquaculture feed^(1,5)

Pellet binding aid	Inclusion rate %	Weight loss after drying (%)			
		0.5 ¹	1.0	2.0	6.0
PMC ²	0.5	5.9	8.1	10.1	11.0
Guar gum	1.0	5.5	9.7	10.7	12.7
Egg bananas	5.0	4.4	10.2	14.5	17.9
Nam-wa bananas	5.0	6.8	14.1	16.4	19.3
Broken mung beans	15.0	6.2	11.3	12.9	20.7
Mung bean bran	15.0	8.3	11.4	15.5	21.0
Yellow alfa starch	10.0	7.6	18.0	27.2	32.0
Cooked broken rice	25.0	21.7	41.4	44.8	45.7
Alfa starch	10.0	50.3	52.7	59.5	71.4

¹ Hours pellets stayed in water; ² Polymethylolcarbamide

Table 2-27: Characteristics of selected pellet binding aids from plants⁽⁶⁴⁾

Source	Plant/product	Characteristics
Agriculture products and by-products	Wheat gluten, high gluten wheat flour, tapioca flour, rice gluten, maize starch, sago palm starch	Stickiness of the binder depends on the feed processing equipment and operating techniques. Widely used in aquaculture feeds
Glue from seaweeds	Agar-agar, alginate carrageenan	Very sticky, high price. Used particularly for research and experimental diets
Endosperm of beans	Guar gum, locust bean gum	Function has to be harmonised with the pH. Used for specialty feed
Plant secretions	Arabic gum, tragacanth, karaya gum	Very sensitive to pH, therefore not widely used in feeds

There are three parameters that are important for calculating the “Efficiency Index” for selecting the most suitable pellet binding agent⁽⁵⁹⁾. These parameters are:

- Water durability (tested by loss of weight after drying);
- Inclusion rate of the binding agent (as parameter for pellet binder’s contribution to the water pollution, since most of them are only slightly or non-digestible);
- Cost of the pellet binding agent per unit of feed.

The formula for the index is:

$$\text{Efficiency Index} = \frac{(X \times 5) \times (Y \times 2) \times Z}{3 \times W}$$

Whereby:

- X = Water Durability,
- Y = Inclusion rate,
- Z = Cost of pellet binding agent per MT of feed,
- W = Any divisor for reducing the index (otherwise it may be very high),
- 5 and 2 = Factor expressing the importance of criteria,
- 3 = Number of criteria.

The lower the Efficiency Index, the more cost and performance efficient is the pellet binder. In general, low inclusion rates of the pellet binder are not only cost effective but also highly performance efficient with regard to water durability and environmental pollution.

2.9 References

1. AAFCO (1995): Official publication 1995. Ass. of American Feed Control Officials (Publisher), Sacramento, CA/USA.
2. Ackman, R.G. (1982): Fatty acid metabolism of bivalves. Proc. 2nd Int’l Conf. on Aquaculture Nutrition, Biochemistry and Physiological Approaches to Shellfish Nutrition, 27-29 Oct., Rehoboth Beach, Delaware/USA, 358-376.
3. Adron, J.W.; Mackie, A.M.(1978): Studies on the chemical nature of feeding stimulants for rainbow trout, *Salmo gairdneri*. J. Fish Biology, 12., 303.
4. Akiyama, D.M.; Dominy, W.G. (1989): Penaeid shrip nutrition for the commercial feed industry. Texas Shrimp Farming Manual, Vol. 1, Extension Service Texas A&M University, Corpus Christi, Texas/USA.
5. Akiyama, D.M.; Dominy, W.G.; Lawrence, A.L. (1991): Penaeid shrimp nutrition for the commercial feed industry (Revised). Proc. Aquaculture Feed Process. and Nutrition Workshop, Thailand and Indonesia, 19 to 25 Sept. (American Soybean Ass., Singapore).
6. Albers, N.; Behm, G.; Dressler, D.; Klaus, W.; Küther, K.; Lindner, H. (1984): Vitamins in animal nutrition. Arbeitsgem. Wirkstoffe i.d. Tierernährung e.V. (AWT), Bonn/Germany.
7. Ali, S.M. (1982): Effect of natural silt on oyster growth. Proc. 2nd Conf. Aquaculture Nutrition: Biochem. and Physiol. Approaches to Shellfish Nutrition, Rohoboth Beach, Delaware/U.S.A., October, 431.
8. Anderson, R.K.; Parker, P.L.; Lawrence, A. (1987): A ¹³C/¹²C tracer study of the utilization of presented feed by a commercially important shrimp *Penaeus vannamei* in a pond grow-out system. J. World Maricult. Soc., 18., 148-155.

9. *Austreng, E.; Skrede, A.; Eldegard, Å.*, (1979): Effect of dietary fat sources on the digestibility of fat and fatty acids in rainbow trout and mink. *Acta Agric. Scand.*, *29*, 119-126.
10. *Balarin, J.D.; Haller, R.D.* (1982): The intensive culture of tilapia in tanks, raceways and cages. In: *Muir, J.E., Roberts, R.J.* (eds.). Recent advances in aquaculture. Croom Helm Ltd., London/England.
11. *Bardach, J.E.; Ryther, J.H.; McLarney, W.O.* (1972); Aquaculture: The farming and husbandry of freshwater and marine organisms. John Wiley & Sons, New York/USA.
12. *Bell, J.G.; Cowey, C.B.; Adron, S.* (1988): Some effects of Vitamin E and selenium deprivation on tissue enzyme levels and indices of tissue peroxidation in rainbow trout (*Salmo gairdneri*). *Brit. J. Nutrition*, *53*, 149-157.
13. *Berg, C.J., jr.; Alatalo, P.; Cavanaugh, C.M.; Felbeck, H.; Jannasch, H.W.; Somero, G.N.* (1982): Possible chemoautotrophic nutrition in Bahamian bivalves. *Proc. 2nd Int'l Conf. on Aquaculture Nutrition, Biochemistry and Physiological Approaches to Shellfish Nutrition*, 27-29 Oct., Rehoboth Beach, Delaware/USA, 425 (Abstr.).
14. *Bergot, F.* (1981): Etude de l'utilisation digestive d'une cellulose prifiée chez la truite arc-en-ciel (*Salmo gairdneri*) et la carpe (*Cyprinus carpio*). *Repr. Nutr. Dével.*, *21*, 157-167.
15. *Boonyaratpalin, M.* (1984): Binders and pellet stability of prawn diets (Mimeograph).
16. *Boonyaratpalin, M.* (1994): A review of nutrition and feed development efforts in Asean on the Asian sea bass. *Proc. 2nd Fish Nutrition Workshop, Singapore*, 25-27 October, 150-170.
17. *Boonyaratpalin, M.; New, M.B.* (1993): On-farm feed preparation and feeding strategies for marine shrimp and freshwater prawns. *Proc. FAO/AADCP Reg. Expert Consultation on Farm-made aquafeeds*, 14 to 18 December, 1992, Bangkok/Thailand.
18. *Boyd* (1989): Quoted from: *Kurmaly, K.* (1994):
19. *Buranapanidit, J.; Boonyaratpalin, M.; Watanabe, T.; Pechmanee, T.; Yashiro, R.* (1988): Essential fatty acid requirement of juvenile seabass *Lates calcarifer*. *Techn. paper no.3, Nat. Inst. of Coastal Aquaculture, Dept. of Fisheries, Bangkok/Thailand.*
20. *Capuzzo, J.M.* (1982): Crustacean bioenergetics: The role of environmental variables and dietary levels of macronutrients on energetic efficiencies. *Proc. 2nd Int'l Conf. on Aquaculture Nutrition, Biochemistry and Physiological Approaches to Shellfish Nutrition*, 27-29 Oct., Rehoboth Beach, Delaware/USA, 71-86.
21. *Carefoot, T.H.* (1982): Gastropod nutrition. *Proc. 2nd Int'l Conf. on Aquaculture Nutrition, Biochemistry and Physiological Approaches to Shellfish Nutrition*, 27-29 Oct., Rehoboth Beach, Delaware/USA, 321-337.
22. *Castell, J.D.* (1979): Review of lipid requirements of finfish. In: *Finfish nutrition and fish feed technology. Schriften BFF, Hamburg/Germany*, *14/15*, (2), 59-84.
23. *Castell, J.D.; Mason, E.C.; Covey, J.F.* (1975): *J. Fish Research Board Canada*, *38*, 1431-1435.
24. *Castell, J.D.; Sinnhuber, R.D.; Wales, J.H.; Lee, D.J.* (1972): Essential fatty acids in the diet of rainbow trout (*Salmo gairdneri*): Growth, feed conversion and some gross deficiency symptoms. *J. Nutrition*, *102*, 77-86.
25. *Chan, M.M.* (1984): Choline and carnitine. In: *Machlin, I.J.* (1984): *Handbook of vitamins*. Marcel Dekker, Inc., New York and Basel.
26. *Chen, K.J.; Co, W.G.* (1988): Prawn culture. Chuson Printing Press, Pangasinan/The Philippines.
27. *Cherian et al.* (1991): Quoted from: *Paulraj, R.* (1995).
28. *Chow, K.E.; Halver, J.E.* (1980): Carbohydrates. In: *ADCP* (eds.): *Fish feed technology*. FAO, AD/REP/80/11, Rome/Italy.
29. *Chu, F.-L.E.; Webb, K.L.; Hepworth, D.; Barrett, B.; Roberts, M.* (1982): Growth and fatty acid composition of oyster larvae. *Proc. 2nd Int'l Conf. on Aquaculture Nutrition, Biochemistry and Physiological Approaches to Shellfish Nutrition*, 27-29 Oct., Rehoboth Beach, Delaware/USA, 426 (Abstr.).

30. Chuang, J.L. (1990): Nutrient requirements, feeding and culturing practices of *Penaeus monodon*: A review. Publication F.Hoffmann-La Roche Ltd., Basel/Switzerland.
31. Clark, A.; Murthy (1994): Quoted from: J.W.H. (1995).
32. Clark, E.; Lawrence, A. (1988): Quoted from: Chuang, J.L. (1990).
33. Cody, M. (1984): Substances without vitamin status. In: Machlin, I.J. (ed.): Handbook of vitamins. Marcel Dekker, Inc., New York and Basel.
34. Coelho, M.B. (1991): Effects of processing and storage on vitamin stability. Feed International, 12., (12), 39-45.
35. Combs, G.F. jr. (1988): Vitamin tolerance of animals. In: Cornell Nutrition Conf. National Academy Press.
36. Cowey, C.B.; Degener, E.; Tacon, A.G.; Youngson, A.; Bell, J.G. (1984): The effect of Vitamin E and oxidized fish oil on the nutrition of rainbow trout (*Salmo gairdneri*) grown at natural, varying water temperatures. Brit. J. Nutrition, 51., 443-457.
37. Crawford et al. (1965): Quoted from Castell (1979).
38. Davis, D.A. (1990): Dietary mineral requirements of *Penaeus vannamei*: Evaluation of the essentiality for thirteen minerals and the requirements for calcium, phosphorus, copper, iron, zinc and selenium. Ph.D. Dissertation, Texas A&M University/U.S.A.
39. Davis, D.A.; Kurmaly, K. (1993): Advances in mineral nutrition for aquatic species. Proc. VICTAM Asia'93 Conf., October, Bangkok/Thailand.
40. De Silva, S.S. (1985): Performance of *Oreochromis niloticus* L. fry maintained on mixed feeding schedules of different protein content. Aquac. Fish. Management, (16), 331-340.
41. Deshimaru, O.; Kuroki, K. (1974): Studies on purified diet for prawns: II. Optimum contents of cholesterol and glucosamines in the diet. Bull. Jap. Soc. Sci. Fisheries, 45., 363-367.
42. Dressler, D. (1971): Mineralische Elemente in der Tierernährung. Verlag Eugen Ulmer, Stuttgart/Germany.
43. Dupree, H.K.; Huner, J.V. (1984): Third report to the fish farmers. Publ. U.S. Fish and Wildlife Service, Washington, D.C.
44. Epifanio, C.E. (1982): Phytoplankton and yeast as foods for juvenile bivalves. A review of research at the University of Delaware. Proc. 2nd Conf. on Aquaculture Nutrition: Biochem. and Physiol. Approaches to Shellfish Nutrition, Rohoboth Beach, Delaware/U.S.A., October, 292-304.
45. Ewart, J.W. (1982): The growth of juvenile oysters *Crassostrea virginica* (Gmelin) fed algae supplemented with silt or kaolin. Proc. 2nd Conf. on Aquaculture Nutrition: Biochem. and Physiol. Approaches to Shellfish Nutrition, Rohoboth Beach, Delaware/U.S.A., October, 427.
46. Fair, P.H.; Forner, A.r.; Millikin, M.R.; Sick, L.V. (1980): Effects of dietary fiber on growth, assimilation and cellulose activity of the prawn (*Macrobrachium rosenbergii*). Proc. World Maric. Soc., 11., 359-381.
47. Fallu, R. (1991): Abalone Farming. Fishing News Books, Oxford/England.
48. Felwell, R.; Fox, S. (1978): Practical poultry feeding. Faber and Faber, London and Boston.
49. Fowler, L.G.; Wood, E.M. (1969): Effect of type of supplemental dietary fat on chinook salmon fingerlings. Progr. Fish-Culturists, 28., 123-127.
50. Frenzel E.; Pfeffer, E. (1982): Untersuchungen über den Mineralstoff-Bedarf von Regenbogenforellen (*Salmo gairdneri*). Archiv Tierernährg., 32., 1-8.
51. Friesecke, H. (1984): Handbuch der praktischen Fütterung von Rind, Schaf, Pferd, Schwein, Geflügel und Süßwasserfischen. BLV Verlagsges., München/Germany.
52. Halver, J.E. (1980): The vitamins. In: ADCP (eds.): Fish feed technology. FAO, ADCP/REP/80/11, 233-239, Rome/Italy.
53. Harada, K. (1987): Relationship between structure and feeding attraction activity of certain L-amino acids and lecithin in aquatic animals. Bull. Jap. Soc. Sci. Fishery, 53., 2243-2247.

54. Hata, K.; Kaneda, T. (1980): Effect of autoxidized oil on carp. Bull. Jap. Soc. Sci. Fisheries, 46., 997-1000.
55. Hefner, B. (1988): Nutrition of pond fishes. Cambridge University Press, Cambridge/U.K.
56. Hertrampf, J.W. (1985): Feeding phosphates and their biological value. Proc. 6th Australian Poultry and Stock Feed Convention, 22-27 Sept., Melbourne/Australia.
57. Hertrampf, J.W. (1991): Feeding aquatic animals with phospholipids. I. Crustaceans. Lucas Meyer Publication No. 8.
58. Hertrampf, J.W. (1992): Feeding aquatic animals with phospholipids, II. Fishes. Lucas Meyer Publication No. 11.
59. Hertrampf, J.W. (1992): On the water durability of aquaculture feed pellets - A review. Advances in Feed Techn., (7), 18-38.
60. Higuera, M. dela; Murillo, A.; Varela, G.; Zamora, S. (1977): The influence of high dietary fat levels on protein utilization by the trout (*Salmo gairdneri*). Comp. Biochem. Physiology, 56., 37-41.
61. Hilton, J.W. (1982): The effect of pre-fasting diet and water temperature, on liver glycogen and liver weight in rainbow trout (*Salmo gairdneri* Richardson), during fasting. J. Fish Biology, 20., 69-78.
62. Hoffman-La Roche, F. (1987): Recommended vitamin supplementation levels for domestic animals. Hoffman-La Roche A.G, Basel/Switzerland (2nd revised ed.)
63. Hohjoh, T.; Kunazawa, H.; Oosaki, M.; Yonemura, T.; Kashiwa, G. (1967): Effects of oxidized fish oils and added ethoxyquin on the culture of rainbow trout. J. Japan Oil Chemists' Soc., 16., 135-137.
64. Huang, H.J. (1989): Aquaculture feed binders. Proc. P.R. China Aquaculture and Feed Workshop, 17-30 Sept. (Published by ASA, Singapore).
65. Husaas, O.; Hertrampf, J. (1965): Zinc Bacitracin: Eine Orientierung über den antibiotischen Futterzusatz Zinkbacitracin in der Tierernährung (3rd ed.). A/S Apothekernes Laboratorium for Specialpræparater, Oslo/Norway.
66. JWH (1995): Using drugs in aquatic animals. Lecithin Trends 23/95, May (Lucas Meyer Newsletter).
67. Jantrannotai, W.; Sitasit, P.; Raichapakdee, S. (1992): Optimum dietary level of broken rice for growth and performance of hybrid walking catfish. Nat. Inland Fish. Inst., Bangkok/Thailand (Mimeograph).
68. Jones, K. (1991): Food search behavior in fish and the use of chemical lures in commercial and sport fishing. In: Chemoreception in Fishes, Vol. 2.
69. Kanazawa, A. (1982): Penaeid nutrition. Proc. 2nd Int'l Conf. on Aquaculture Nutrition, Biochemistry and Physiological Approaches to Shellfish Nutrition, 27-29 Oct., Rehoboth Beach, Delaware/USA, 87-105.
70. Kanazawa, A. (1985): Nutrition of penaeid prawns and shrimps. In: Taki, Y.; Primavera, J.H.; Llobrera, J.A. (eds.): Proc. 1st Intern. Conf. on the Culture of Penaeid prawn/shrimps, Iloilo City/The Philippines.
71. Kanazawa, A. (1995): Recent developments in shrimp nutrition and feed industry. Paper pres. at Techn. Session of INDAQUA '95, Madras/India, 27-30 January.
72. Kanazawa, A.; Teshima, S.; Endo, M. (1979a): Quoted from: Chuang, J.L. (1990).
73. Kanazawa, A.; Teshima, S.; Sasaki, M. (1984): Requirements of the juvenile prawn for calcium, phosphorus, magnesium, potassium, copper, manganese and iron. Mem. Fac. Fish. (Kagoshima Univ.), 33., 63-71.
74. Kanazawa, A.; Teshima, S.; Tanska, N. (1976): Nutritional requirements of prawn. V. Requirement for choline and inositol. Mem. Fac. Kagoshima University, 25., 47-51.
75. Kanazawa, A.; Teshima, S.; Tokiwa, S. (1979b): Quoted from: Chuang, J.L. (1990).
76. Kanazawa, A.; Tanaka, N.; Teshima, S.; Kashiwada, K. (1971): Bull. Jap. Soc. Sci. Fisheries, 37., 211-215.
77. Knobloch, E.; Cérná-Heyrovská, J. (1979): Fodder biofactors. Elsevier Scientific Publ. Co., Amsterdam/The Netherlands.
78. Koch, W.; Bank, O.; Jens, G. (1976): Fischzucht (4th ed.). Verlag Paul Parey, Hamburg and Berlin/Germany.
79. Kolb E. (1989): Lehrbuch der Physiologie der Haustiere (I and II). VEB Gustav Fischer Verlag,

Jena/Germany.

80. Konosi, S.; Yamagushi, K. (1982): Quoted from: Meyers, S.P. (1986).
81. Kurmaly, K. (1994): Balancing out nutrition. Intern. Milling Flour & Feed, 188., (2), 75-80.
82. Lall, S.P. (1989): The minerals. In: Halver, J.E. (ed.): Fish nutrition. Academic Press, London, 2nd ed.
83. Langdon, C.J. (1982): New techniques and their application to studies of bivalve nutrition. Proc. 2nd Int'l Conf. on Aquaculture Nutrition, Biochemistry and Physiological Approaches to Shellfish Nutrition, 27-29 Oct., Rehoboth Beach, Delaware/USA, 305-320.
84. Lee, J.; Tsay, S.T. (1988): A new binder for aquaculture. Sem. Aquatic Animal Feeds and Nutrition, 9 Dec., Taiwan (Mimeograph).
85. Le Grow, S.M.; Beamish, F.W.H. (1986): Influence of dietary protein and lipid on apparent heat increment of rainbow trout *Salmo gairdneri*. Cand. J. Fish. and Aquatic Sci., 43., 19-25.
86. Lemm, C.A. (1983): Growth and survival of Atlantic salmon fed semi-moist or dry starter diets. Prog. Fish-Culturist, 45., 72.
87. Lewis, R.W. (1962): Temperature and pressure effects on the fatty acids of some marine ectotherms. Comp. Biochem. Physiology, 6., 75-89.
88. Lim, C.; Persey, A. (1988): Practical feeding - penaeid shrimps. In: Lovell, R.T. (ed.): Nutrition and feeding of fish. Van Nostrand Reinhold (publ.), New York/USA.
89. Lovell, R.T. (1989): Nutrition and feeding of fish. Nostrand Reinhold, New York/USA.
90. Luquet, P.; Moreau, Y. (1990): Energy-protein management by some warmwater finfishes. In: Advances in tropical aquaculture. Actes Colloq, No. 9, IFREMER, Paris/France.
91. McLaughlin, P.A. (1983): Quoted from: Chuang, J.L. (1990).
92. Mearns, K.J. (1985): Response of Atlantic salmon (*Salmo gairdneri* L.) Yearlings to individual L-amino acids. Aquaculture, 48., 253.
93. Meyers, S.P. (1986): Attractants, aquatic diet development. Feedstuffs, 58., 29.12.
94. Meyers, S. (1991): Pellet binders for shrimp feed. Feed International, 12., (3), 22-28.
95. Middleditch, B.S.; Missler, S.R.; Hines, H.B.; McVey, J.P.; Brown, A.; Ward, D.G.; Lawrence, A.L. (1980): Quoted from: Chuang, J.L. (1990).
96. Millamena, O.M.; Pudadera, R.A.; Catacutan, M.R. (1984): Effects of diet on reproductive performance of ablated *Penaeus monodon* broodstock. Proc. 1st Int'l Conf on Culture of *Penaeid* prawns/shrimps. Iloilo City/The Philippines, 178 (Abstr.).
97. Moreau, Y. (1992): Utilization of carbohydrates as energy-yielding substrates by the tilapia, *Sarotherodon melanothodon*. 3rd Asian Fisheries Forum, 26-30 Sept., Singapore, 98 (Abstr.).
98. Nakamura, Y.; Yamada, J. (1980): Effects of dietary calcium levels, Ca/P ratios, and calcium components on the calcium absorption rate in carp. Bull. Faculty Fish., Hokkaido Univ., 31., 277-282.
99. New, M.B. (1987): Feed and feeding of fish and shrimps - A manual on the preparation and presentation of compound feeds for shrimps and fish in aquaculture. UNDP/FAO/ADCP/REP/87/26, Rome/Italy.
100. Nørhede-Jensen, S. (1991): Feed quality and aroma of feed. Feed Magazine, (1), 14-18.
101. NRC (1981): Nutrient requirements of coldwater fishes. National Academy Press, Washington, D.C.
102. NRC (1983): Nutrient requirements of warmwater fishes and shellfishes. National Academy Press. Washington, D.C.
103. Oberbach, H.; Hartfiel, W. (1988): Untersuchungen zum Tocopherol- und Selenbedarf von Regenbogenforellen (*Salmo gairdneri*) und pathologische Mangelerscheinungen bei Aufnahme polyensäurereichen Rationen. Fett-Wissenschaft, Technologie, 91., 97-101.
104. Oberbach, H.; Totovic, V.; Hartfiel, W. (1988): Auswirkungen unterschiedlicher oxidiertes Fette im Futter von Regenbogenforellen (*Salmo gairdneri*) auf den Bedarf von Vitamin E und Selen. Fett-Wissenschaft,

- Technologie, 91., 148-153.
105. *OECD* (1984): Multilingual dictionary on fish and fish products. Fishing News Books Ltd.; Farnham/England.
 106. *Oehlenschläger, J.* (1991): Toxische Schwermetalle in Seefischen und anderen Meerestieren. Forschungsreport (ELF), (6), 11-13.
 107. *Ota, T.* (1976): Lipids of Masu salmon. IV. Changes of lipid composition and fatty acid composition in flesh lipids of Masu salmon in the early stage of seawater life. Bull. Fac. Fish. Hokkaido University, 27., (1), 30-36.
 108. *Ota, T.; Atakagi, T.* (1977): A comparative study on the lipid class composition and fatty acid composition of sweet smelt *Plecoglossus altivelis*. Bull. Fac. Fish. Hokkaido University, 28., (1), 47-56.
 109. *Pandian, T.J.* (1989): Protein requirements of fish and prawns cultured in Asia. Proc. Third Asian Fish Nutrition Network Meeting. Asian Fish. Soc. Spec. Publication, Manila/Philippines, No. 4, 11-22.
 110. *Paulraj, R.* (1995): Aquaculture. Marine Prod. Export Dev. Authority, Kochi/India (2nd ed.) (Publisher).
 111. *Petriella, A.M.; Muller, M.I.; Fenucci, J.C.; Saez, M.B.* (1984): Influence of dietary fatty acids and cholesterol on the growth and survival of the Argentine prawns, *Artesia longinares* Bate. Aquaculture, 37., 11-20.
 112. *Phillips, A.M.; Podoliak, H.K.; Dumas, R.F.; Thoesen, R.W.* (1958): Metabolism of dietary phosphorus by brook trout. Fish. Res. Bull., No. 22, Cortland Hatchery Report No. 27, 59-66.
 113. *Piedad-Pascual, F.* (1989): Mineral requirements of penaeids. Aquacop Actes de Colloque, 9., 309-318.
 114. *Pieper, A.; Pfeiffer, E.* (1979): Carbohydrates as possible sources of dietary energy for rainbow trout. Proc. World Symp. on Finfish Nutr. and Fishfeed Techn., Hamburg/Germany, Vol. I, 20-23 June, 209-219.
 115. *Poston, H.A.; Combs, G.F.* (1980): Nutritional implications of tryptophan catabolizing enzyme in several species of trout and salmon. Proc. Soc. Exp. Biol. Medicine, 160., 452-454.
 116. *Poston, H.A.; Riis, R.C.; Rumsey, G.L.; Ketola, H.G.* (1977): The effect of supplemental dietary amino acids, minerals and vitamins on salmonids fed cataractogenic diets. Cornell. Vet., 67., 472-509.
 117. *Purchon, R.D.* (1960): The stomach in the *Eulamellibranchia*: Stomach types IV and V. Proc. Zoological Soc., London, 135., 431-489.
 118. *Quayle, D.B.; Newkirk, G.F.* (1989): Farming bivalve molluscs. Methods for study and development. The World Aquaculture Soc., Baton Rouge, LA/USA.
 119. *Rasheed, A.A.* (1963): Nutritive value of marine oil. I. Menhaden oil at varying oxidation levels with and without antioxidants in rat diets. J.Nutrition, 79., 323-332.
 120. *Rasmussen, C.J.* (1967): Handbog i Ørredopdræt. Rhodos forlag, Copenhagen/Denmark.
 121. *Reid, R.G.B.* (1982): Aspects of bivalve feeding and digestion relevant to aquaculture nutrition. Proc. 2nd Int'l Conf. on Aquaculture Nutrition, Biochemistry and Physiological Approaches to Shellfish Nutrition, 27-29 Oct., Rehoboth Beach, Delaware/USA, 231-251.
 122. *Reid, R.G.B.; Bernhard, F.R.* (1980): Gutless bivalves. Science, 208., 609-610.
 123. *Sakaguchi, H.; Hamaguchi, A.* (1979): Physiological studies on cultured red sea bream. III. Digestibility and changes of chemical constituents in plasma and hepatopankreas after feeding oxidized oil. Bull. Jap. Soc. Sci. Fish, 45., 545-548.
 124. *Sakamoto, S.; Yone, Y.* (1979): Availability of phosphorus compounds as dietary phosphorus sources for red sea bream. J. Fac. Agric, Kyushu Univ., 23., 177-184.
 125. *Schneider, W.* (1977): Futtermittelrechtliche Begriffe. In: *Kling, M.; Wöhlbier, W.*: Handelsfuttermittel. Verlag Eugen Ulmer, Stuttgart/Germany.
 126. *Schwarz, F.F.* (1994): Verdaulichkeit und energertischer Futterwert von Karpfenfuttermitteln. Kraftfutter, (4), 118-121.

127. *Shane, S.M.* (1995): Benefits of antioxidant additives. ASA Techn. Bull., MITA (P) No. 083/12/94, *PO14*. (Singapore).
128. *Shimeno, S.; Hosakawa, H.; Takeda, M.* (1979): The importance of carbohydrate in the diet of a carnivorous fish. Proc. World Symp. on Finfish Nutr. and Fishfeed Techn., Hamburg/Germany, Vol. I, 20-23 June, 127-141.
129. *Sick, L.V.; Siegfried, C.A.* (1982): Effects of the ambient environment on metabolic regulation of shell biosynthesis in marine bivalve molluscs. Proc. 2nd Int'l Conf. on Aquaculture Nutrition, Biochemistry and Physiological Approaches to Shellfish Nutrition, 27-29 Oct., Rehoboth Beach, Delaware/USA, 377-399.
130. *Siegmund, O.H.; McLean, J.W.; Armistead, W.W.; Hagan, W.H.; Hutchings, L.M.; Schnelle, G.B.* (1961): The Merck Veterinary Manual (2nd ed.). Merck and Co., Inc., Rahway, N.J./USA.
131. *Steffens, W.* (1985): Grundlagen der Fischernahrung. VEB Gustav Fischer Verlag, Jena/Germany.
132. *Stephens, G.C.* (1982): Dissolved organic material and the nutrition of marine bivalves. Proc. 2nd Int'l Conf. on Aquaculture Nutrition, Biochemistry and Physiological Approaches to Shellfish Nutrition, 27-29 Oct., Rehoboth Beach, Delaware/USA, 338-357.
133. *Stevenson, J.P.* (1987): Trout farming manual. Fishing News Books Ltd., Farnham/England.
134. *Stickney, R.R.; Andrews, J.W.* (1972): Effects of dietary lipids on growth, food conversion and lipid and fatty acid composition of catfish. J. Nutrition, 102., 249-258.
135. *Storebakken, T.; Berge, G.; Hung, S.S.O.* (1992): Growth effects of dietary phospholipids and choline on Atlantic salmon fingerlings. Trial-Report of 28 Jan.
136. *Tacon, A.G.J.* (1987): The nutrition and feeding of farmed fish and shrimp - A training manual. 2. Nutrient sources and composition. FAO Field Document 5/E, Brasilia/Brazil.
137. *Tacon, A.G.J.* (1988): The nutrition and feeding of farmed fish and shrimp - A training manual. 3. Feeding methods. FAO Field Document 7/E, Brasilia/Brazil.
138. *Tacon, A.G.J.; Cowey, C.B.* (1985): Protein and amino acid requirements. In: *Tytler, P.; Calow, P.* (eds.): Fish energetics: New perspectives. Croom Helm Press, London, 155-184.
139. *Takeuchi, T.; Satoh, S.; Watanabe, T.* (1983): Dietary lipids suitable for the practical feed of *Tilapia nilotica*. Bull. Jap. Soc. Sci. Fish., 49., 1361-1365.
140. *Takeuchi, T.; Watanabe, T.; Nose, T.* (1979): Requirement for essential fatty acids of chum salmon (*Oncorhynchus keta*) in freshwater environment. Bull. Jap. Soc. Sci. Fish., 45., 1319-1223.
141. *Takeuchi, T.; Watanabe, T.; Ogino, C.* (1978): Optimum ratio of protein to lipid in diet for rainbow trout. Bull. Jap. Soc. Sci. Fish., 44., 683-688.
142. *Takeuchi, T.; Arai, S.; Watanabe, T.; Satoh, Y.* (1980): Requirement of eel *Anguilla japonica* for essential fatty acids. Bull. Jap. Soc. Sci. Fish., 46., 345-353.
143. *Takeushi, T.; Shiina, Y.; Watanabe, T.; Sekiya, S.; Imaizumi, K.* (1992): Suitable protein and lipid levels in diet for fingerling of yellowtail. Nippon Suisan Gakkaishi, 58., (7)., 1333-1339.
144. *Takeushi, T.; Arakawa, T.; Shiina, Y.; Satoh, S.; Imaizumi, K.; Sekiya, S.; Watanabe, T.* (1992): Effects of dietary α - and β -starch on growth of juvenile striped jack and yellowtail. Nippon Suisan Gakkaishi, 58., (4)., 701-705.
145. *Tangl, H.* (1959): Die Rolle der Vitamine, Hormone und Antibiotika in der Tierzucht. Akadémia Kiadó, Budapest/Hungary.
146. *Täufel, A.; Ternes, W.; Tunger, L.; Zobel, M.* (1993): Lebensmittel-Lexikon. Behr's Verlag, Hamburg/Germany.
147. *Teshima, S.; Kanazawa, A.* (1986): Nutritive value of sterols for the juvenile prawn. Bull. Jap. Soc. Sci. Fish., 52., (3), 519-524.
148. *Trono-Legiralde, M.T.; Santiago, C.B.; Chui-Chern, Y.C.* (1992): The effects of dietary carbohydrates, lipid and energy on the growth, feed efficiency and tissue composition of bighead carp (*Aristichthys nobilis*) fry.

- 3rd Asian Fish. Forum, 26-30 Sept., Singapore, 99 (Abstr.).
149. Vonk, H.J. (1960): Quoted from: Chuang, J.L. (1990).
150. Ward, N.E. (1991): Chemoattractants for trout and salmon. *Feed Management*, 42., (3), 6-10, 38-39.
151. Ward, N.E. (1995): Commercial vitamin supplementation for poultry. Techn. Bull. American Soybean Ass., Singapore, PO17.
152. Watanabe, T.; Takeuchi, T. (1976): Evaluation of pollack liver oil as a supplement to diets for rainbow trout. *Bull. Jap. Soc. Sci. Fish.*, 42., 893-906.
153. Watanabe, T.; Matsukura, Y.; Hashimoto, Y. (1966): Effect of natural and synthetic antioxidants on the incidence of muscle dystrophy of carp induced by oxidized soury oil. *Bull. Jap. Soc. Sci. Fish.*, 32., 887-891.
154. Watanabe, T.; Takeuchi, T.; Wada, M. (1981): Dietary lipid levels and α -tocopherol requirement of carp. *Bull. Jap. Soc. Sci. Fish.*, 47., 1585-1590.
155. Watanabe, T.; Matsui, M.; Kawabata, T.; Ogino, C. (1977): Effect of alpha-tocopherol deficiency on carp. V. The composition of triglycerides and cholesteryl esters in lipids of young carp. *Bull. Jap. Soc. Sci. Fish.*, 43., 813-817.
156. Webb, K.L.; Chu, F.-L.E. (1982): Phytoplankton as a food source for bivalve larvae. Proc. 2nd Int'l Conf. on Aquaculture Nutrition, Biochemistry and Physiological Approaches to Shellfish Nutrition, 27-29 Oct., Rehoboth Beach, Delaware/USA, 273-291.
157. Weinreich, O.; Koch, V.; Knippel, J. (1994): Futtermittelrechtliche Vorschriften. Buchedition Agrimedia, Hamburg/Germany.
158. Wilson, R.P. (1989): Amino acids and proteins. In: Halver, J.E. (ed.): *Fish Nutrition*. Academic Press, Inc. San Diego/USA, 112-151.
159. Wilson, R.P.; Poe, W.E. (1988): Choline nutrition of fingerling channel catfish. *Aquaculture*, 68., 65-71.
160. Wittke, G. (1972): *Physiologie der Haustiere*. Verlag Paul Parey, Berlin and Hamburg/Germany.
161. Yone, Y.; Fujii, M. (1975): Studies on nutrition of red sea bream. XI. Effect of omega-3 fatty acid supplement in a corn oil diet on growth and feed efficiency. *Bull. Jap. Soc. Sci. Fish.*, 41., (1), 73-77.
162. Yurkowski, M.; Tabachek, J.L. (1979): Proximate amino acid composition of some natural fish foods. Proc. World Symp. on Finfish Nutr. and Fishfeed Techn., Hamburg/Germany, Vol. I, 20-23 June, 435-448.
163. Zeisel, S.H. (1990): Phospholipids and choline deficiency. In Hanin, I.; Pepeu, G. (1990): *Phospholipids*. Plenum Press, New York and London, 219-231.

3. ANIMAL FATS

3.1 Rationale

Fats of land animals are an efficient, low-cost and high energy source for feeding animals. Fats are derived from the fat tissue of animals. A general classification follows⁽⁹⁾:

- Tallow, from cattle and sheep;
- Lard, from pigs, horses and bones;
- Animal fats normally a mixture of different fat sources, particularly poultry fat and fat from fallen animals.

Fat is also classified according to the fat's origin, colour, melting point, the amount of polyunsaturated fatty acids (PUFA), highly unsaturated fatty acid (HUFA), free fatty acids and impurities.

In the past animal fats have been primarily used as raw materials for margarine, making soaps and detergents, candles and stearic acid⁽⁴⁸⁾. Annually approximately 1.25 million MT of rendered fat is being recycled into animal fat in the U.S.A.⁽³²⁾.

3.2 Manufacture and Processing

Rendering is the process of converting fat tissue into the various animal fats. The animal by-products are heated to release the fat from the tissue and to remove the moisture⁽³²⁾. There are two principal methods of rendering⁽³³⁾:

- Animal tissue is placed in an enclosed pressure vessel (cooker) and super-heated steam is injected to provide both heat and agitation. The mixture is cooked at 110° to 120°C for three to six hours and settles into three phases:
 - A top fat layer which is drawn off;
 - An intermediate water layer;
 - A bottom layer, consisting primarily of proteinaceous material (grieves).

This method is no longer widely used and has been replaced by:

- Modern rendering plants that feature a continuous rendering process, and a sophisticated equipment for prevention of air and water pollution.

3.3 Tallow

3.3.1 Description

Tallow is animal fat that is solid above 40°C⁽³⁰⁾. It is white, greyish-white to yellowish from carotenoids when animals graze. It usually comes from cattle or mutton. Rendered

fat from beef fat is commonly known as beef tallow or sometimes “oleo stock” due to its high content of oleic acid (43.5%)⁽⁵⁾.

Tallow is classified as “edible” and “feed” tallow. The “American Fats and Oils Association” subdivides tallow into 12 grades. The free fatty acids and the titre are most important for grading⁽³³⁾. In Europe, there are only three grades: fine tallow, edible tallow and industrial tallow⁽⁴⁹⁾.

3.3.2 Chemical and Physiological Properties

Chemical Properties

Beef tallow is an energy source. It contains high levels of saturated fatty acids (48.2%) and unsaturated fatty acids (46.6%). Only 4.3% are polyunsaturated fatty acids (Table 3-01)⁽⁴⁰⁾. The cholesterol content is 1,000 mg/kg⁽⁴⁹⁾. The mineral and vitamin contents of beef tallow is insignificant.

Table 3-01: Fatty acid composition of tallow, lard, poultry fat and animal fat (%)^(3, 4, 5, 21, 22, 29, 31, 33, 34, 43)

Fatty acid		Tallow		Lard	Poultry fat	Animal fat
		Beef	Mutton			
1. Saturated Acids						
Lauric	12:0	-	-	0.5	-	-
Myristic	14:0	3.2	5.2	1.5	1.1	2.1
Pentadecanoic	15:0	0.5	-	-	-	-
Palmitic	16:0	26.4	23.6	25.7	24.2	20.9
Margaric	17:0	0.9	2.0	0.5	0.3	0.3
Stearic	18:0	19.8	24.5	13.0	6.3	47.6
Arachidic	20:0	0.1	-	-	-	-
Total Saturated Fatty Acids:		49.5	51.9	40.4	32.2	70.0
2. Mono-unsaturated Fatty Acids						
Myristicoleic	14:1	0.6	-	-	0.2	0.3
Pentadecenoic	15:1	0.02	-	-	-	0.2
Palmiticoleic	16:1	3.4	2.5	3.7	6.2	2.6
Heptadecenoic	17:1	0.6	0.5	0.5	0.1	-
Oleic	18:1	41.0	33.3	45.0	39.7	13.7
Eicosenoic	20:1	0.4	-	1.0	0.1	-
Total Unsaturated Fatty Acids:		46.3	39.6	52.6	54.7	16.8
3. Polyunsaturated Fatty Acids						
Linoleic	18:2	2.7	4.4	9.6	19.3	15.3
Linolenic	18:3	0.7	4.0	2.7	1.1	1.0
Arachidonic	20:4	0.4	0.4	-	-	-
Total Polyunsaturated Fatty Acids:		3.8	8.8	12.3	21.5	16.3

Physiological properties

The digestible and metabolisable energy of beef tallow for land animals range between 8,100 to 8,700 kcal/kg and 7,100 to 7,500 kcal/kg, respectively^(9, 26, 28). The digestibility of tallow in land animals depends on the species and age of the animals. Digestibility of tallow is particularly low in young animals due to the high level of saturated fatty acids of tallow and the insufficient secretion of bile acid by young animals⁽²⁷⁾. Similar conditions may be assumed for aquatic animals.

Apparent digestibility of tallow increases in rainbow trout (*Salmo gairdneri*) and in carp (*Cyprinus carpio*) as water temperature increases (Figure 3-01)⁽⁵¹⁾:

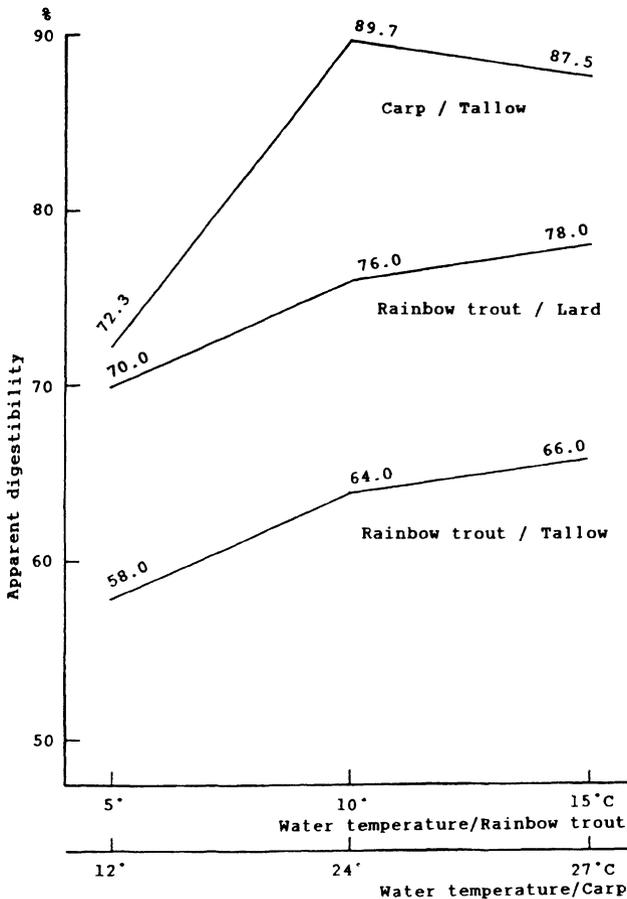


Figure 3-01. Relationship between water temperature and apparent digestibility of beef tallow and pork lard in diets for rainbow trout (*Salmo gairdneri*) and carp (*Cyprinus carpio*)^(data from: 51)

3.3.3 Feeding Value

Fishes

Beef tallow in general, is a good energy source for fish provided that the diet alone contains omega fatty acids^(48, 55). Certain fish species or group of fish species may respond differently on feeding diets containing beef tallow.

Salmonids fed only on beef tallow did not perform well. However, reducing the beef tallow level in the diet by substituting marine oils with high content of PUFA gave superior results by more than doubling weight gain and improving feed conversion (Table 3-02)^(48, 55). Beef tallow in broodstock diets for rainbow trout has no negative effect on reproduction parameters when compared to a commercial high protein broodstock feed⁽⁵⁰⁾.

Table 3-02: Response of rainbow trout (*Salmo gairdneri*) to beef tallow after 10 weeks of feeding⁽⁴⁸⁾

Beef tallow	%	10.0	-	6.0	4.0
Cuttlefish liver oil	%	-	10.0	4.0	6.0

Mean initial weight	g	6.1	6.0	6.1	6.1
Final weight	g	26.0	13.9	24.4	22.9
Weight gain	%	326.2	300.0	275.4	-
Feed conversion	1:	1.16	0.78	1.14	1.08

However, the supplementation of a basic diet with fat from beef spleen caused physiological disorders in chinook salmon (*Oncorhynchus tshawytscha*) fingerlings which were not found in fishes fed with groundnut oil⁽¹¹⁾.

Beef tallow in combination with cuttlefish liver oil in diets for carp resulted in best weight gain and feed conversion⁽⁵⁰⁾. But in semi-purified diet for carp fingerlings, the addition of beef tallow depressed growth in the range of 5.7 to 13.1 (Table 3-03)⁽²⁹⁾.

Table 3-03: Weight gain and feed efficiency of carp (*Cyprinus carpio*) fingerlings at various levels of beef tallow⁽²⁹⁾

Casein-gelatine	%	26	26	26	34	34	34
Feed oil	%	5	5	5	5	5	5
Beef tallow	%	0	4.5	9.5	0	4.5	9.5

Weight gain	%	314	296	273	508	451	448
Feed efficiency	%	96.2	96.6	93.8	115.5	117.2	117.8

It appears that channel catfish (*Ictalurus punctatus*) is not so finicky concerning beef tallow. Compared to soybean oil and fish oil, fish showed matching performance⁽²⁹⁾. In hatchery diets, beef tallow levels of 20 to 49% was superior to 30% menhaden fish oil⁽⁵²⁾. But challenging the immune response of channel catfish (0.7 g weight) with a mixture of beef tallow and zinc was without any success while other oils (maize, linseed, menhaden) strengthened the immunity from the pathogen (*Edwardsiella ictaluri*)^(12, 13).

Fish perform better on diets containing beef tallow alone or in combination with other fat sources compared to fat-free diets, if feeds are not isoenergetic as observed in a number of experiments (Table 3-04). Beef tallow of up to 12% in diets for blue tilapia (*Tilapia aurea*) promoted good performance but levels of more than 12 % depressed performances⁽⁴²⁾.

Table 3-04: Beef tallow as an energy source in diets for red sea bream (*Pagrus major*) (trial period: 42 days)⁽⁴⁷⁾

White fish meal	%	57.0	57.0	57.0	57.0
Beef tallow	%	-	5.0	10.0	5.0
Pollack liver oil	%	-	5.0	5.0	10.0
Crude protein	%	50.8	53.8	54.1	53.7
Crude fat	%	6.2	16.2	20.9	20.7
Digestible energy	kcal/kg	3,150	3,960	4,300	4,250

Initial body weight	g	7.5	7.5	7.5	7.5
Growth rate	%	207	280	267	285
Feed efficiency	%	73.1	93.3	88.6	97.4
PER		1.4	1.7	1.6	1.8

<u>Body composition</u>					
Crude protein	%	18.8	18.1	18.3	18.3
Crude fat	%	8.4	14.1	14.0	14.6

The milkfish (*Chanos chanos*) performed best on a combination of beef tallow and coconut oil (1:1) compared not only to fat-free diet but tallow and other oil sources (Table 3-05)⁽¹⁾. This appears to be unusual since both beef tallow and coconut oil are high in saturated but low in polyunsaturated fatty acids. This is because the milkfish is able to desaturate and elongate saturated fatty acids. However, fish oil was superior to tallow in diets for Atlantic croaker (*Micropogonias undulatus*) and striped mullet (*Mugil cephalus*)⁽²⁵⁾.

Feeding of beef tallow affects the carcass composition. The fat content of the whole fish is directly related to dietary fat as found in milkfish (Table 3-05)⁽¹⁾, red seabream (*Pagrus major*) (Table 3-04)⁽⁴⁷⁾ and yellowtail (*Seriola quinqueradiata*) in the latter with extreme increase of liver lipids at highest fat content of the diet (Figure 3-02)⁽⁴⁶⁾. Less body fat was observed if dietary beef tallow was compared on an isonitrogenous and isoenergetic basis to fish oil in the hybrid striped bass (*Morone chrysops x Morone saxatilis*)⁽¹⁴⁾.

The fatty acid profile of the fish fat is a direct reflection of the dietary fatty acid profile (Table 3-06)^(15, 42). This is particularly pronounced when added fat is high in saturated fatty acids (e.g., beef tallow and coconut oil) (Table 3-05). The fatty acid profile of tallow is also reflected in developing eggs of broodfish fed with tallow⁽¹⁸⁾.

Table 3-05: Growth indicators of milkfish (*Chanos chanos*) fingerlings fed beef tallow and various lipids⁽¹⁾

No fat	%	0	-	-	-	-
Beef tallow	%	-	5.0	5.0	5.0	5.0
Cod liver oil	%	-	5.0	-	-	-
Coconut oil	%	-	-	5.0	-	-
Soybean oil	%	-	-	-	5.0	-
Maize oil	%	-	-	-	-	5.0

Growth rate	%	213.7	385.3	450.5	306.3	345.3
Weight gain	g	2.0	3.7	4.3	2.9	3.3
Feed conversion	1:	3.5	2.4	1.9	3.0	2.5
Survival rate	%	90.0	100.0	100.0	98.0	97.0

Body composition in dry matter:						
- Moisture	%	81.6	73.1	74.6	74.4	74.2
- Crude Protein	%	20.9	66.8	66.5	67.9	67.3
- Crude fat	%	3.6	19.9	19.6	17.6	27.6

Fatty acid composition:						
- n-3	%	2.5	13.3	3.5	5.3	6.7
- n-6	%	8.8	6.7	4.4	22.1	22.7
- Saturated	%	36.4	29.5	48.0	27.4	24.0

Crustaceans

Beef tallow is a poor lipid source for the tiger prawn (*Penaeus monodon*). In a four week feeding trial with tallow fed at increasing levels in semi-purified diets total lipid content was similar at all levels of beef tallow. The fatty acid composition of the prawns reflected that of the dietary lipids and HUFAs were incorporated more into the polar lipid fraction (Table 3-07)⁽⁷⁾.

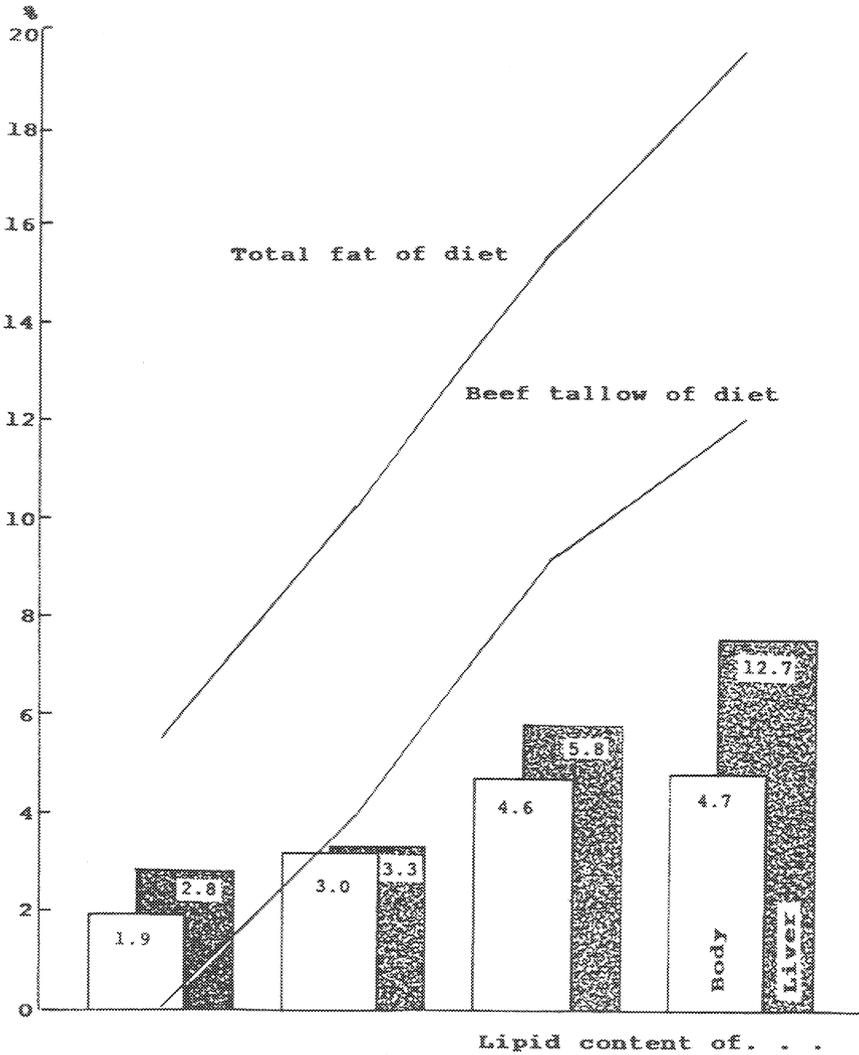


Figure 3-02. Relationship between the level of total dietary fat and the total body and liver fat of the yellowtail (*Seriola quinqueradiata*) after feeding increasing levels of beef tallow (data from: 46)

Table 3-06: The fatty acid profile of the diet for channel catfish (*Ictalurus punctatus*) is reflected in the fatty acid profile of the whole fish⁽⁴²⁾

Fatty acid		Formula	Diet ¹ %	Fish Carcass %
Systematic name	Common name			
Tetradecanoic	Myristic	14:0	2.9	2.1
Hexadecanoic	Palmitic	16:0	18.8	17.1
Hexadecenoic	Palmitoleic	16:1n-7	5.1	6.7
Octadecanoic	Stearic	18:0	10.9	2.8
Octadecenoic	Oleic	18:1n-9	57.5	59.5
Octadecadienoic	Linoleic	18:2n-6	2.1	2.8
Octadecatrienoic	Linolenic	18:3n-3	-	2.2
Eicosatetraenoic	Arachidonic	20:4n-6	-	0.6
Eicosapentaenoic	N/N ²	20:5n-3	-	0.5
Docosatetraenoic	Adrenic	22:4n-6	-	traces
Docosapentaenoic	Behenic	22:5n-3	-	0.7
Docosahexaenoic	N/N	22:6n-3	-	1.4
Others			2.5	3.0

¹Containing 10% beef tallow; ²No trivial name given

Table 3-07: Growth response of juvenile tiger prawns (*Penaeus monodon*) to various levels of beef tallow in semi-purified diets⁽⁷⁾

Beef tallow	%	0	4.0	8.0	12.0
Initial weight	g	0.537	0.628	0.581	0.588
Mean weight gain	%	27.7	10.1	18.3	17.3
Specific growth rate	%/day	0.86	0.27	0.76	0.56
Mean survival	%	66.7	66.7	66.7	77.8
Total body lipid content	%	0.88	1.03	1.06	0.98

3.4 Lard

3.4.1 Description

Lard from pork is white fat with a good taste and odour. The consistency of lard is affected by the composition of the feed fed to pigs⁽⁴⁹⁾. For the quality of lard, the rendering process is hardly influential.

Lard also comes from horses and any type of bones. It has usually a melting point between 20 to 40°C as compared to above 40°C for tallows⁽³⁰⁾.

3.4.2 Chemical and Physiological Properties

Chemical Properties

Most of the fatty acids present in pork fat are saturated fatty acids, although linoleic and linolenic acids are also present. The most important fatty acids are palmitic acid, stearic acid, oleic acid and linoleic acid (Table 3-01). Cholesterol content of lard is 860 mg/kg⁽⁴⁹⁾.

The mineral and vitamin content of lard is insignificant with the exception of Vitamin E (22 mg/kg)⁽⁵¹⁾.

Physiological Properties

The digestible and metabolisable energy tested in land animals range from 8,100 to 9,100 and from 7,900 to 8,900 kcal/kg, respectively^(9, 26, 28).

Like in beef tallow, digestibility of pork lard in young broiler and piglets are lower than in older animals^(8, 39). Apparent digestibility of lard in rainbow trout (*Salmo gairdneri*) increases as temperature increases (Figure 3-01).

3.4.3 Feeding Value

Fishes

Using pork lard in diets for rainbow trout (*Oncorhynchus mykiss*) as the only fat source in comparison to other animal fats and vegetable oils showed no differences in growth and feed conversion⁽¹⁶⁾. The combination of pork lard with vegetable oil or the partial replacement of marine oil (e.g. herring oil) result in good performances by rainbow trout fingerlings^(38, 41, 56).

The combination of pork lard with coconut oil (1:1) in milkfish feeds is superior to combinations with other fat sources.

The pork lard/coconut oil fed fish did not only perform better than the fat-free group but also better than the rest of the fat combinations (Table 3-08)⁽¹⁾.

The dietary fat level and the fatty acid profile is reflected in the carcass composition in the same way it was reflected in fish fed beef tallow. The higher the level of unsaturated fatty acids in the diet, the higher the levels of the same in the carcass (Table 3-08)⁽¹⁾.

Crustaceans

Among dietary lipids (pork lard, anchovy, linseed or maize oils), in diets for Chinese prawn (*Penaeus chinensis*), the lowest fecundity and hatchability were obtained with pork lard. Eggs of prawns fed pork lard contained the lowest n-3 highly unsaturated fatty acid (HUFA) (12.8%), compared to the other sources. Prawns also fed maize and linseed oils had increased egg production over those fed the pork lard diet but there was no significant improvement in hatchability⁽⁵⁴⁾.

Pork lard is a poor energy source for tiger prawn juveniles compared to cod liver oil at various lipid levels⁽⁷⁾. Mean weight gain and specific growth rate, was only better in pork lard at 8.0% and 12% compared to the fat-free diet (Table 3-09).

In the carcass composition of juvenile tiger prawns the fatty acid profile of the tissues reflected that of the dietary lipids⁽⁷⁾.

Table 3-08: Growth indicators of milkfish (*Chanos chanos*) fingerlings fed pork lard and various lipids⁽¹⁾

No fat	%	0	-	-	-
Pork lard	%	-	5.0	5.0	5.0
Coconut oil	%	-	5.0	-	-
Soybean oil	%	-	-	5.0	-
Maize oil	%	-	-	-	5.0

Growth rate	%	213.7	457.9	297.0	347.4
Weight gain	g	2.0	4.4	2.8	3.3
Feed conversion	1:	3.5	1.9	2.6	2.3
Survival rate	%	90.0	100.0	98.0	98.0

Body composition in dry matter:					
- Moisture	%	81.7	72.7	74.8	72.7
- Crude protein	%	70.9	65.6	66.1	66.0
- Crude fat	%	3.6	21.8	18.4	19.7
Fatty acid composition:					
- n-3	%	2.5	6.4	8.2	9.8
- n-6	%	8.8	8.4	27.8	28.2
- Saturated	%	36.4	47.1	28.1	24.6

Table 3-09: Growth response of juvenile tiger prawns (*Penaeus monodon*) to various levels of pork lard in semi-purified diets⁽⁷⁾

Pork lard	%	-	4	-	8	-	12	-
Cod liver oil	%	-	-	4	-	8	-	12

Initial weight	g	0.5	0.6	0.4	0.6	0.7	0.6	0.6
Final weight	g	0.6	0.7	0.8	0.9	1.2	0.83	1.21
Weight gain	%	27.5	13.0	50.8	31.4	63.9	36.6	106.7
SGR	%/day	0.9	0.4	1.5	1.0	1.7	1.1	2.6
Survival rate	%	66.7	61.1	77.7	66.7	83.3	50.0	83.3
Lipid content of the body	%	0.9	1.1	1.1	-	1.4	1.1	1.5

3.5 Poultry Fat

Poultry fat comes mainly from discarded chicken fat and chicken viscera. About 2/3 are unsaturated and polyunsaturated fatty acids (Table 3-01)⁽⁴⁰⁾.

Poultry fat in the diet (6.0%) for rainbow trout and fed for 20 weeks performed as well as the same diet fortified with salmon oil (Table 3-10)⁽¹⁶⁾.

Table 3-10: Growth performance of rainbow trout (*Oncorhynchus mykiss*) fed 6.0% chicken fat for 20 weeks⁽¹⁶⁾

		Poultry fat	Salmon oil
Mean initial weight	g	80.0	80.0
Mean final weight	g	269.1	257.7
Feed efficiency ¹	%	0.88	0.86
Body composition ² :			
Moisture	%	74.39	74.06
Crude protein	%	16.84	16.77
Crude fat	%	6.69	6.98
Lipid extracted from fillet	%	4.27	4.32

¹Dry weight of diet/wet weight gain; ²wet basis

3.6 Animal Fat

3.6.1 Description and Properties

Animal fat or feed grade fat is usually a blend of different fats and may contain poultry fat, lard, low grade tallow (yellow grease) and fat from fallen animals (destruction fat). Animal fat can be highest of all discussed fats in the saturated fatty acids. Palmitic, stearic acid and linoleic acid are rather high (Table 3-01).

3.6.2 Feeding Value

Yellow grease as sole fat source in diets for tilapia (*Oreochromis niloticus*) showed no significant differences in growth rate, feed conversion or level of protein deposition when compared to the diet without added fat (Table 3-11). However, the addition of yellow grease to the diet significantly increased the levels of carcass and viscera fat. It appears that the Nile tilapia is able to store significant quantities of lipids in the carcass and the viscera, but are not able to utilise this energy source to improve growth or feed utilisation⁽¹⁷⁾.

Consumers reject tilapia fed predominantly with raw chicken viscera because its fat gives tilapia flesh a broiler taste⁽³⁶⁾.

Table 3-11: Yellow grease as an energy source in diets for Nile tilapia (*Oreochromis nilotica*)⁽¹⁷⁾

Fish meal	%	6.8	6.6	6.3
Soybean meal (44%)	%	36.1	34.7	33.4
Yellow grease	-	0.0	3.8	7.2
Crude protein	%	34.0	32.9	31.1
Crude fat		5.1	9.1	12.4
Digestible energy	kcal/kg	2,414	2,725	2,820
	MJ/kg	10.1	11.4	11.8

Final body weight	g	189.5	193.3	189.0
Weight gain	g	147.6	152.0	147.0
Feed conversion ¹	1:	0.65	0.64	0.60

Body composition:				
- Crude protein	%	16.6	16.3	16.2
- Fat	%	4.5	5.7	5.9
- Viscera fat	%	10.8	15.4	17.2

¹Wet weight gain (g)/dry weight food offered (g)

3.7 Quality Criteria of Animal Fats

Animal fats used for feeding purposes should fulfill certain quality criteria with regard to^(21, 33):

- Moisture content
- Impurities
- Acid value
- Unsaponifiables
- Saponification value
- Fatty acid profile
- Iodine value
- Peroxide value

Moisture in fat reduces energy value of the fat and favours the growth of micro-organisms. The moisture content should not exceed 1.0%.

The insoluble *impurities* are determined with petrol-ether. Such substances are: N-compounds, carbohydrates, minerals, oxidised fatty acids. These substances cause fast spoilage of the fat by autoxidation and micro-organisms. The maximum content is limited to 1.0%.

The *acid value* is the indicator for “free fatty acids” (FFA) and is an expression of fat freshness. The maximum acid value is 50 but higher values does not mean that the fat is not fit to be used as a feedstuff. A high level of free fatty acids does not seem to affect the feeding value of the fat and did not result in negative performances in salmonids⁽⁶⁾, in calves⁽³¹⁾, in pigs^(10, 19, 37) and in laying hens⁽²⁰⁾.

Unsaponifiables refer to any material of animal fat that will not saponify when mixed with an alkali. High levels of unsaponifiable matter may have a depressing effect on performance of the animal.

The *saponification value* is an estimate of the mean molecular weight of the fatty acids. The higher the saponification value, the lower the mean chain length of the triglycerides. It is measured in mg potassium-hydroxide required for the saponification of 1.0 g fat (Table 3-12).

Table 3-12: Congealing points, melting points, iodine values and saponification values of animal fats

Type of fat	Congealing Point ⁽²¹⁾ °C	Melting point ^(21,51) °C	Iodine value ^(3, 33, 34)	Saponification value ^(3, 33)
Tallow (beef)	30-80	43-49	41-52	195-201
(goat)	-	-	34	199
(mutton)	-	-	41	197
Lard	22-32	28-44	52-74	193-201
Poultry fat	21-27	30-32	80-85	-
Animal fat	-	-	59-79	-

The characteristics of the *fatty acid profile* are classified as follows:

- High level of medium-chain, saturated fatty acids,
- High level of long-chain, poly-unsaturated fatty acids,
- High level of long-chain, single unsaturated fatty acids, (poultry fat)
- High level of long-chain, saturated fatty acids (beef tallow, lard, bone fat).

Other parameters for obtaining information about the fatty acid profile of fats is the congealing point and the melting point (Table 3-12). The melting point is affected by the amount of unsaturated fatty acids and length of the saturated acid chain⁽²⁷⁾.

The *iodine value* is a measure of the chemical saturation of the fat and results are expressed as g iodine absorbed per 1,000 g of fat (Table 3-12).

The *peroxide value* expresses the freshness of fat. It determines the content of peroxide oxygen in lipids. The peroxide value should not exceed 10.

3.8 Recommended Inclusion Rate

Fat has a negative effect on pellet quality (stability, water durability). The desired pellet quality, therefore, is the limiting factor for the use of animal fat. Recommended inclusion rates of fat from land animals for aquaculture feeds are:

- Tallow: 5.0 to 10.0%
- Lard: 5.0 to 10.0%
- Poultry fat: 5.0 to 10.0%
- Animal fat: 5.0 to 10.0%

3.9 Legal Aspects

The EU-Regulation 92/87/EEC of 26 October 1992 does not differentiate between the species from which the fat is derived. Animal fat is listed as No. 9.08 and defined by both the EU directive and the German feedstuff law as “A product from fat of warm-blooded animals”. However, the German law differentiates between “refined animal fat” and “animal fat”. In addition, certain minimum/maximum requirements have to be met (Table 3-13)⁽⁵²⁾.

Table 3-13: Requirements for animal fat by the German feedstuff law⁽⁵²⁾

		Refined fat	Unrefined fat
Moisture	max. %	0.1	0.1
Acid value	max.	-	50
Impurities	max. %	0.1	1.0
Unsaponifiables	max. %	3.0	3.0

A supplement to EU-Regulations (instruction 77/101/EEC) requires that feedstuffs have to be free of any residues which may originate from their treatment and/or processing. This applies particularly to nickel which is used as a catalyst in fat and oil processing⁽²⁾.

The American Food and Drug Administration (FDA) has designated the GRASS-status for animal fats and oil because they are easily bio-degraded by bacteria. They are also not harmful to the environment⁽³³⁾. The maximum tolerance, set by FDA for aflatoxin is 20 ppb and 7.0 ppm for lead. Furthermore, USA regulations call for zero tolerance on salmonella in any kind of feed⁽³³⁾.

3.10 References

1. *Alava, V.* (1986): Combinations of dietary fat sources in dry diets for *Chanos chanos* fingerlings. In: *MacClean, S.; Dizon, L.B.; Hosilloes, L.V.* (eds.): The First Asian Fisheries Forum, Asian Fisheries Society, Manila/Philippines, 1986. 519-521.
2. *Anonymous* (1995): Nickel Im Futter: Die Mühle + Mischfuttermitteltechnik, 132., (30), 499.
3. *Anonymous* (w/o year): Fatty acids. Akzo Chemie, U.K. Ltd. 12/14 St. Ann's Crescent, Wandsworth, London.
4. *Anonymous* (w/o year): Typical fatty acid composition of common fats and oils. Emery Industries, Inc.
5. *Arroyo, P.T.* (1974): The science of Philippine foods, 1st ed. Abaniko Enterprises, Araneta Center, Quezon City/Philippines. 207.
6. *Austreng, E.; Gjefsen, T.* (1981): Fish oils with different content of free fatty acids in diets for rainbow trout fingerlings and salmon parr. *Aquaculture*, 25., 173-183.
7. *Catacutan, M.* (1991): Growth and fatty acid composition of *Penaeus monodon* juveniles fed various lipids. *Bamidgh*, 43., 47-56.
8. *Eusebio, J.H.; Hays, V.W.; Speer, V.C.; McGall, U.T.* (1965): Utilisation of fat by young pigs. *J. Anim. Sci.*, 24., 1001-1007.
9. *Evans, M.* (1985): Nutrient composition of feedstuffs for pigs and poultry. Queensland Dept. of Primary Ind., Brisbane/Australia, Inf. Series Q 185001.
10. *Farries, E.; Schröder, J.* (1977): Zum Einsatz reiner Fettsäuren in der Schweinemast. Proc. VDLUFA-Kongreß, 63-65.
11. *Fowler, L.G.; Wood, E.M.* (1966): Effect of type of supplemental dietary fat on chinook salmon fingerlings. *Progr. Fish-Culturist*, 28., 123-127.
12. *Fracalossi, D.M.; Lovell, R.T.* (1993): Effect of dietary lipid sources and water temperature on mortality of channel catfish fingerlings challenged with *Edwardsiella ictaluri*. In: *Carrillo, M.; Dahle, L.; Morales, J.; Sorgeloos, P.; Suennevig, N.; Wyban, J.* (eds.): From discovery to commercialization. European Aquaculture Soc. No. 19., 224, Oostende/Belgium.
13. *Fracalossi, D.M.; Lovell, R.T.* (1994): Dietary lipid sources influence responses of channel catfish (*Ictalurus punctatus*) to challenge with the pathogen *Edwardsiella ictaluri*. *Aquaculture*, 119., 287-298.
14. *Frinsko, M.O.; Robinette, H.R.; Robinsons, E.H.* (1992): Evaluation of lipid sources for phase II hybrid striped bass (*Morone saxatilis* x *Morone chrysops*). *Aquaculture* 1992: Growing toward the 21st century. 97-98.
15. *Gatlin, D.M. III; Stickney, R.R.* (1982): Fall-winter growth of young channel catfish in response to quantity and source of dietary lipid. *Trans. Am. Fish. Soc.*, 111., 90-93.
16. *Greene, D.H.S.; Selivonchick D.D.* (1990): Effects of dietary vegetable, animal and marine lipids on muscle lipid and hematology of rainbow trout (*Oncorhynchus mykiss*). *Aquaculture*, 89., 165-182.
17. *Hanley, F.* (1991): Effects of feeding supplementary diets containing varying levels of lipid on growth, feed conversion and body composition of Nile tilapia (*Oreochromis nilotica*). *Aquaculture*, 93., 323-334.
18. *Hardy, R.W.; Maysumoto, T.; Farigrieve, W.T.; Stickney, R.R.* (1989): The effects of dietary lipid source on muscle and egg fatty acid composition and reproductive performance of coho salmon (*Oncorhynchus kisutch*). Proc. Third International Symposium on Feeding and Nutrition in Fish., 28 Aug. to 1 Sept. 1989, Toba/Japan, 1990, 347-355.
19. *Hartfiel, W.* (1978): Fette mit höheren Anteilen freier Fettsäuren in der Schweinemast. *Fette, Seifen, Anstrichmittel*, 80., 540-543.
20. *Hartfiel, W.* (1978): Beeinflussen Futterfette mit unterschiedlich hoher Peroxid- und Säurezahl die

- Futteraufnahme und Futterverwertung bei legenden Hennen. Kraftfutter, 61., 58-62.
21. *Hartfiel, W.* (w/o year): Qualitätskriterien für Futterfette. IG Fett, Bonn/Germany.
 22. *Hertrampf, J.* (1980): Lecithin-enriched vegetable oils in mink nutrition. Proc. 2nd Internat. Sci. Congress, Vaedbek/Denmark, April.
 23. *Hertrampf, J.W.* (1987): Vitamin E and fats in feeds. Animal Nutrition News. BASF, Nov. 1987. 2
 24. *Hertrampf, J.W.* (1995): Feeding poultry with lecithin (phospholipids). Lucas Meyer-Publication No. 15, Hamburg/Germany.
 25. *Jones, F.V.; Strawn, K.* (1983): Growth and food utilization of caged Atlantic croaker and striped mullet reared on various lipid diets in a heated water system. J. World Maricult. Soc., 14., 590-594.
 26. *Jørgensen, G.; Glem-Hansen, N.* (1973): Quoted from: *Hertrampf, J.* (1980).
 27. *Lowe, B.* (1943): Experimental cookery from the chemical and physical standpoint, 3rd ed., John Wiley & Sons, Inc.
 28. *Meyer, H.; Heckötter, E.* (1986): Futterwerttabelle für Hunde und Katzen. Schlütersche Verlagsanstalt, Hannover/Germany.
 29. *Murai, T.; Akiyama, T.; Takeuchi, T.; Watanabe, T.; Nose, T.* (1985): Effects of dietary protein and lipid levels on performance and carcass composition of fingerling carp. Bull. Jap. Soc. Sci. Fish. 51., 605-608.
 30. *New, M.B.* (1987): Feed and feeding of fish and shrimp. A manual on the preparation and presentation of compound feeds for shrimps and fish in aquaculture. UNDP/FAO/ADCP/REP/87/26. Rome/Italy.
 31. *Niesar, K.H.* (1964): Qualitätsmerkmale und Qualitätsbewertung der Fettkomponenten im Mischfutter. Bayer. Landw. Jahrbuch, 41., 230-242.
 32. *NRA* (1992): Rendered animal fats and oils. National Renderers Ass., Inc., Alexandria, Virg./USA (Leaflet, July).
 33. *NRA* (1993): Pocket information manual - a buyers guide to rendered products. National Renderers Ass., Inc., Alexandria, Virg./USA.
 34. *NRA* (w/o year): Animal fats and oils - the environmental perspective. National Renderers Ass., Inc., Alexandria, Virg./USA (Leaflet).
 35. *NRC* (1993): Nutrient requirements of fish. National Academy Press, Washington D.C.
 36. *Pathamasothy, S.* (1993): Private communication.
 37. *Pfirter, H.P.; Wenk, C.* (1984): Die Verwendung von Fett in Schweinerationen. 35th Ann. Meeting EVT, The Hague/The Netherlands.
 38. *Reinitz, G.L.; Yu, T.C.* (1981): Effects of dietary lipids on growth and fatty acid composition of rainbow trout (*Salmo gairdneri*). Aquaculture, 22., 359-366.
 39. *Renner, R.; Hill, F.W.* (1960): The utilisation of corn oil, lard and tallow by chicken of various ages. Poultry Sci., 39., 849-854.
 40. *Shepherd, A.J.; Iverson, J.L.; Weihrach, J.L.* (1978): Composition of selected dietary fats, oils, margarines and butter. In: *Kuksis, A.* (ed.): Fatty acids and glycerides. Oxford, Plenum Press. 341-379.
 41. *Steffens, W.; Albrecht, M.-L.* (1979): Einsatz von hartem Fett in Trockenmischfutter für Regenbogenforellen (*Salmo gairdneri*). 1. Mitt. Zuwachs und Futterverwertung bei der Setzlingsaufzucht. Arch. Tierernährung, 27., 161-169.
 42. *Stickney, R.R.; Andrews, J.W.* (1972): Effects of dietary lipids on growth, food conversion and lipid and fatty acid composition of catfish. J. Nutrition, 102., 249-258.
 43. *Stickney, R.R.; McGeachin, R.B.* (1984): Growth, food conversion and survival of fingerling *Tilapia aurea* fed differing levels of dietary beef tallow. Prog. Fish. Cult., 46., 102-105.
 44. *Tacon, A.G.J.* (1987): The nutrition and feeding of farmed fish and shrimp - A Training Manual, 2. Nutrient Sources and Composition. Field Document 5/E GCP/RLA/075/ITA. (FAO) Brasilia/Brazil.

45. Takeda, M.; Shimeno, S.; Hosokawa, H.; Kajiyama, H.; Kaisho, T. (1975): The effect of dietary calorie to protein ratio in the growth, feed efficiency and body composition of young yellowtail. *Nippon Suisan Gakkashi*, 41., 443-447.
46. Takeuchi, T.; Shiina, Y.; Watanabe, T. (1992): Suitable protein and lipid levels in diet for fingerlings of yellowtail. *Nippon Suisan Gakkashi*, 58., 1333-1339.
47. Takeuchi, T.; Shiina, Y.; Watanabe, T. (1991): Suitable protein and lipid levels in diet for fingerlings of red sea bream (*Pagrus major*). *Nippon Suisan Gakkashi*, 57., 293-299.
48. Takeuchi, T.; Watanabe, T.; Ogino C. (1978): Use of hydrogenated fish oil and beef tallow as a dietary energy source for carp and rainbow trout. *Bull. Jap. Soc. Sci. Fish.*, 44., 875-881.
49. Täufel, A.; Ternes, W.; Tunger, L.; Zobel, M. (1993): *Lebensmittel-Lexikon*. Behr's Verlag, Hamburg/Germany.
50. Watanabe, T. (1983): Effect of nutritional quality of broodstock diets on reproduction of rainbow trout and their egg quality. *Salmonid Reproduction: International Symp.*, Washington Univ., Seattle/U.S.A., Sea Grant Program. 21.
51. Watanabe, T. (1988): *Fish nutrition and mariculture*. Kanagawa Int'l. Fisheries Training Centre. Japan International Cooperation Agency.
52. Weinreich, O.; Koch, V.; Knippel, J. (1994): *Futtermittelrechtliche Vorschriften*. Buchedition Agrimedia, Hamburg/Germany.
53. Winfree, R.A.; Stickney, R.R. (1984): Formulation and processing of hatchery diets for channel catfish. *Aquaculture*, 41., 311-323.
54. Xu, X.L.; Ji, W.J.; Castell, J.D.; O'Dor, R.K. (1993): Effect of dietary lipids on fecundity, hatchability and egg fatty acid composition of Chinese prawn (*Penaeus chinensis*). In: Carillo, M.; Dahle, L.; Morales, J.; Sorgeloos, P.; Svennevig, N.; Wyban, J. (eds.): *From Discovery to Commercialization*. European Aquaculture Soc., 19., 98, Oostende/Belgium.
55. Yu, T.C.; Sinnhuber, R.O. (1981): Use of beef tallow as an energy source in coho salmon (*Oncorhynchus kisutch*) rations. *Can. J. Fish. Aquat. Sci.*, 38., 367-370.
56. Yu, T.S.; Sinnhuber, R.O.; Putnam, G.B. (1977): Use of swine fat as an energy source in trout rations. *Progr. Fish-Culturist*, 39., 95-97.

4. BILE ACID PRODUCTS

4.1 Rationale

Bile is formed in the liver cells (*hepatocytes*) and secreted into the small intestine via the bile duct. Due to its detergent properties bile emulsifies the fats in the small intestine. Bile, therefore, is essential for lipid digestion and absorption. The constituents of bile are bile acids, which are lipoides; bile pigments, which belong to the chromoproteides; phospholipids (see chapter 41); cholesterol and inorganic matter (e.g. sodium and phosphorus compounds).

Commercial bile acids have a wide range of applications in the pharmaceutical and chemical industries, such as laboratory chemicals like TCBS (thiosulphate-citrate-bile-salts-sucrose-agar). A substance derived from shark bile has been reported to cure acne⁽¹⁾ and according to a Chinese belief, bile of the grass carp (*Ctenopharyngodon idellus*) may improve visual acuity⁽³⁾.

4.2 Manufacture and Processing

Fluid bile is derived from fresh bile of cattle and pigs collected from abattoirs. The feed grade quality of bile acid is manufactured from crude bile acid on a carrier.

For pharmaceutical and chemical application the fluid bile is filtered, concentrated and spray-dried into a fine powder.

4.3 Chemical and Physiological Properties

Bile acids are also called bile salts, and other Latin names used are: *Fel tauri*, *Bilis bovis*, *Sales biliaris*.

Chemical Properties

Bile acid is a natural product. The composition varies not only from species to species but also within the same species (Table 4-01). The very high content of phospholipids in the bile of ruminants is the basis for the surfactant property of bile acids (Table 4-02). In man about 15% of the bile lipids are phospholipids of which 96% is phosphatidylcholine⁽²⁾.

Table 4-01: Composition (%) of gall-bladder bile of cattle, pig and dog⁽¹⁶⁾

	Cattle	Pig	Dog
Moisture	89.40	81.10 - 88.50	77.60 - 88.60
Biliary bile acid	7.20	8.50 - 12.00	7.90 - 15.00
Lecithin	0.52	1.20 - 2.90	2.30 - 7.00
Cholesterol	0.04	0.13 - 0.18	0.08 - 0.10
Protein (mainly mucine)	0.42	0.28 - 0.41	0.19 - 0.52
Bilirubin	-	0.03 - 0.03	0.09 - 0.17

Table 4-02: Lipids of the bile of sheep⁽¹⁷⁾

Lipids	g/l
Phospholipids	11.48
Lysophospholipids	1.17
Phosphatidylethanolamine	0.44
Cholesterol	0.86
Cholesterol ester	0.31
Triglyceride	0.37
Unesterified fatty acids	0.40

Physiological Properties

Very little is known of the role of bile acids in aquatic animals⁽¹³⁾. The two major bile acids in salmonids are “taurocholic acid” (cholic acid conjugated with taurine) and “taurochenodesoxycholic acid” (Table 4-03)^(4, 11, 19, 23, 25).

Table 4-03: Composition of the bile of fishes (%)

	TCA ¹	TCDOCA ²	OBA ³	Ref.
Rainbow trout (<i>Salmo gairdneri</i>)	85.0	14.0	1.0	(4)
Channel catfish (<i>Ictalurus punctatus</i>)	83.0	15.0	2.0 ⁴	(15)
Blue catfish (<i>Ictalurus furcatus</i>)	84.0	16.0	0	(15)

¹ Taurocholic acid; ² Taurochenodesoxycholic acid; ³ other bile acids; ⁴ Taurodesoxycholic acid

There are considerable variations in the yield of bile between marine and freshwater fish as well as between the species of both groups. It ranges from 0.04 to 0.06% of the total body weight of fish⁽¹⁸⁾. The bile of rainbow trout (*Salmo gairdneri*) does not have any enzyme⁽⁷⁾. The ingestion of the bile of grass carp (*Ctenopharyngodon idellus*) may kill human (in severe cases) and experimental animals. The gastric intubation of grass carp bile extract killed all the experimental rats in two to eight hours. Rats that ingested pig bile showed no significant changes in the recorded parameters⁽³⁾.

4.4 Feeding Value

The principal function of bile salts in the body is to aid in the digestion of dietary lipids and to enhance the absorption of fat-soluble vitamins. It plays also an integral role in the homing of salmonid fishes^(6, 9, 10, 27). Other olfactory functions of bile salts such as orienting and snapping have been demonstrated^(12, 26).

The feeding value of exogenous bile acids has been tested more extensively in terrestrial animals than in aquatic organisms. Supplementing chicken diets with bile salts at the inclusion rate of 0.1 to 0.5% cholic acid, 0.5% chenodesoxycholic acid and 0.4 to 4.0% ox bile, respectively, improved lipid digestibility and performances⁽¹⁴⁾. Piglets responded less positively to the addition of 0.15 to 0.60% bile salts to the diet⁽²²⁾.

The addition of 0.02% ursodesoxycholic acid, a bile acid, to a diet containing pollack liver oil (20%) for yellowtail (*Seriola quinqueradiata*) improved the nutritional value of the diet⁽⁵⁾.

Cod lipase from defatted pyloric caeca of the cod (*Gadus morhua*) showed an absolute requirement for bile salts on olive oil hydrolysis. When tributyrine was used as substrate, the bile salt dependence was less pronounced⁽⁸⁾. Results of another experiment on the influence of dietary lipid classes on the fatty acid composition of juvenile cod suggested that cod larvae and small juveniles may not fully digest neutral lipid classes due to lack of suitable lipases, bile acids or both⁽²⁰⁾.

Studies on the effect of bile salts on the growth of bacteria in the gut of fish showed that bile salts do not inhibit growth of enteric luminous bacteria found in the gut of the fish⁽²¹⁾. Intestinal vibrio species isolated from yellowtail (*Seriola quinqueradiata*) which were commercially cultured, were able to grow well at 37°C, but were resistant to low pH (4.5) and bile acid⁽²⁴⁾.

Commercial bile products are commonly added to fortify aquaculture diets, particularly those for crustaceans although there are no experimental results that clearly define the rationale for adding bile salts.

4.5 Recommended Inclusion Rates

The role of exogenous bile acids has hardly been studied in aquaculture organisms. The usefulness of bile acids as a feed additive, therefore, cannot clearly be established. In commercial diets bile products are used at levels of 0.2 to 0.5%.

4.6 Legal Aspects

Commercial bile products are non-toxic. Nevertheless, national legal regulations for the application of bile acids to aquaculture feeds have to be observed.

4.7 References

1. *Anonymous* (1993h): Shark bile - a cure for acne. Infofish International, (6), 59.
2. *Avogaro, P.; Mancini, M.; Ricci, G.; Paoletti, R.* (1983): Phospholipids and atherosclerosis. Raven Press, New York.
3. *Chen, C.F.; Lin, M.C.; Liu, H.M.* (1990): Plasma electrolyte changes after ingestion of bile extract of the grass carp (*Ctenopharyngodon idellus*) in rats. Toxic. Letters, 50., (2/3), 221-228.
4. *Denton, J.E.; Yousef, M.K.; Yousef, I.M.; Kuksis, A.* (1974): Bile acid composition of rainbow trout, *Salmo gairdneri*. Lipids, 9., (12), 945-951.
5. *Deshimaru, O.; Kuroki, K.; Yone, Y.* (1982): Suitable levels of lipids and ursodesoxycholic acid in diet for yellowtail. Bull. Jap. Soc. Sci. Fish., 48. (9), 1265-1270.
6. *Døving, K.B.; Sæset, R.; Thommesen, G.* (1980): Olfactory sensitivity to bile acids in salmonid fishes. Acta Physiol. Scand., 108, 123-131.
7. *Falge, R.* (1973): Untersuchungen von Enzymaktivitäten im Darminhalt der Regenbogenforelle (*Salmo gairdneri*) nach Fütterung mit natürlicher und halbsynthetischer Nahrung. Diss. University Rostock/Germany.
8. *Gjellesvik, D.R.; Raae, A.J.; Walther, B.T.* (1989): Partial purification and characterization of a triglyceride lipase from cod (*Gadus morhua*). Aquaculture, 79., (1-4), 177-184.
9. *Groves, A.B.; Collins, C.B.; Trefethen, P.S.* (1968): Roles of olfaction and vision in choice of spawning site by homing adult chinook salmon (*Oncorhynchus tshawytscha*). J. Fish. Res. Board Canada, 25., 867-876.
10. *Hara, T.J.; McDonald, S.; Evans, R.E.; Marui, T; Arai, S.; McCleve, J.D.; Arnold, S.; Dodson, J.J.; Neill, W.H.* (1984): Morpholine, bile acids and skin mucus as possible chemical cues in salmon homing: Electrophysiological re-evaluation . Mechanism of migration of fishes. NATO Conf, Ser. 4, Mar. Sci., 14., 363-378.
11. *Hasslewood, G.A.D.* (1967): Bile salt evaluation. J. Lipid Res., 8., 535-550.
12. *Hellström, T.; Døving, K.B.* (1986): Chemoreception of taurocholate in anosmic and slam-operated cod (*Gadus morhua*). Behav. Brain Res., 21., (2), 155-162.
13. *Hepher, B.* (1988): Nutrition of pond fishes. Cambridge University Press, Cambridge.
14. *Hertrampf, J.H.* (1995): Feeding poultry with lecithin (phospholipids). Lucas Meyer, Hamburg/Germany, Publication No.15.
15. *Kellogg, T.F.* (1975): The biliary bile acids of the channel catfish , *Ictalurus punctatus*, and the blue catfish, *Ictalurus furcatus*. Comp. Biochem Physiol., 50B., 109-111.
16. *Kolb, E.* (1984): Lehrbuch der Physiologie der Haustiere. VEB Gustav Fischer Verlag, Jena, 5th Ed.
17. *Lennox et al.* (1989): Quoted from: *Kolb, E.* (1989).
18. *Mathew, P.T.; Naie, K.C.R.; Madhavan, P.; Prabhu, P.V.* (1986): Isolation of bile from fish and identification by thin-layer chromatography. Fish. Techn. Soc. Fish. Techn., Cochín., 23., (1), 13-17.
19. *Nagayoshi, S.; Hoshita, T.; Yukawa, M.; Kazuno, T.* (1964): Studies on the bile of *Plecoglossus altivelis*. Stero-bile acids and bile sterols. LXIX. Hiroshima J. Med. Sci., 13., 333-340.
20. *Olsen, R.E.; Hendersen, R.J.; Pedersen, T.* (1991): The influence of dietary lipid classes on the fatty acid

- composition of small cod (*Gadus morhua* L.) juveniles reared in an enclosure in northern Norway. J. Exp. Mar. Biol. Ecol., 148., (1), 59-76.
21. Ramesh, A.; Venugopalan, V.K. (1989): Response on enteric luminous bacteria to environmental conditions in the gut of the fish. J. Appl. Bacteriology, 66., (6), 529-533.
 22. Reinhart, G.A.; Mahan, D.C.; Cera, K.R. (1989): Bile salt supplementation in weaning pigs. Ohio Swine Res. and Industry Rep., Anim. Sci. Dept., Ser. 89-1 (Ohio State Univ.).
 23. Ripatti, P.O.; Sidorov, V.S. (1971): Quantitative composition of the bile acid of certain vertebrates in connection with the nature of their nutrition. Doklady Akademii Nauk SSSR, 212, 770-773.
 24. Sakata, T.; Nakaji, M.; Kakimoto, D. (1978): Microflora in the digestive tract of marine fish. 1. General characterization of the isolates from yellowtail. Mem. Fac. Fish., Kagoshima Univ., 27., (1), 65-71.
 25. Sasaki, T. (1966): Comparative studies on the bile salts of fishes by thin layer chromatography. Stero bile acids and bile alcohols. LXXXII. J.Biochem., 60., 56-62.
 26. Sorensen, P.W.; Hara, T.J.; Stacey, N.E. (1986): The olfactory sensitivity of mature male, female, immature and hypophysectomized goldfish to l-amino acid, bile acid and steroid compounds by underwater electro-olfactogram (EOG). Chem. Senses, 11., (4), 666.
 27. Wisby, W.J.; Hasler, A.D. (1954): Effect of olfactory occlusion on migrating silver salmon (*Oncorhynchus kisutch*). J. Fish. Res. Board Canada, 11., 472-478.

5. BLEACHING EARTH (USED)

5.1 Rationale

Bleaching earth is used in the refining of vegetable oils and animal fats for human consumption. The absorbent capacity of the bleaching earth removes the impurities and unwanted matter, such as colouring substances (carotenoids), soaps, proteins and others, found in oils and fats. To recover the residual oil is technically possible but uneconomical.

Used Bleaching Earth (UBE) which is also called “Fat-containing Bleaching Earth” is mostly deposited as waste world-wide. It is estimated that annually at least 100,000 MT of fats/oils are ditched in the form of UBE. This not only is an environmental pollutant but also risky to dispose of, because the oil-containing material has a tendency to easily explode.

5.2 Processing

Bleaching earth is geologically a “montmorillonite” which is a group of clays with the general formula $Al_2Si_4O_{10}(OH)_2$. Montmorillonite is so called “swelling clay” because it swells greatly in water. The absorption capacity is two to seven times its volume. The disadvantage of the absorption capacity of swelling clay is the fact that dissolved or dispersed additives (e.g. vitamins) are absorbed and unreleasable⁽³⁾.

The chemical and physical properties of montmorillonite are not constant and vary, depending on the nature of the saturating cation, the origin of the clay and the physical and chemical treatments. Treatments include acid activation to produce H+montmorillonite, soda ash treatment, and substitution of the exchangeable cation by long-chain organic bases which allows the material to swell in oil rather than in water⁽⁴⁾. Bleaching earth used in the vegetable oil and animal fat refining industry is an acid-activated montmorillonite.

For easy handling UBE has to be dried. To form a free flowing feedstuff of high fat content, a process has been developed, where used bleaching earth is combined with cellulosic fibres⁽⁵⁾.

5.3 Chemical and Physiological Properties

The chemical and physical properties of the “unused” acid activated bleaching earth varies (Table 5-01). The quantities of heavy metals found were below the tolerance levels permitted by the EU (European Union) for compound feed (10 ppm for lead and 0.1 ppm for mercury) (Table 5-02).

Table 5-01: Chemical and physical properties of acid-activated bleaching earth

		Malaysia ⁽¹⁾	Europe ⁽⁶⁾
Moisture	%	16.0	N/A ¹
pH (25% suspension)		25 to 3.0	N/A
Oil retention capacity	%	20.0	N/A
SiO ₂	%	68.3	70.0
Al ₂ O ₃	%	16.4	12.0
Fe ₂ O ₃	%	3.9	4.0
TiO ₂	%	N/A	0.8
MgO	%	1.3	2.0
CaO	%	1.2	3.0
Na ₂ O	%	0.4	0.4
K ₂ O	%	0.5	0.8
Loss on ignition	%	8.0	N/A
Organic matter	%	N/A	7.0

¹ not analysed

Table 5-02: Bleaching earth's content of some heavy metals (ppm)

Reference		(6)	(2)
Mercury	(Hg)	0.05	0.01
Cadmium	(Cd)	0.28	<0.1
Lead	(Pb)	5.75	1.5

The residual oil content of UBE depends on the type of oil which has been refined (Table 5-03). The residual oil is prone to oxidation. The fatty acid composition of fat from UBE and corresponding refined oil is not significantly different.

Table 5-03: Residual oil extracted from used bleaching earth

Type of oil refined	Residual oil %	Reference
Soybean oil	27.0	(6)
Marine oil	23.0	(2)
Palm oil	20.0 to 30.0	(7)

The gross energy content of UBE is related to the fat content of the material as found by “adiabatic bomb calorimetry”:

- 3,140 kcal/kg (13.1 MJ/kg) (soybean oil)⁽⁶⁾
- 3,400 kcal/kg (14.2 MJ/kg) (marine oil)⁽²⁾.

There is a discrepancy between the relatively high gross energy content and the analysed crude fat which indicates that a certain portion of the fat is absorbed and unrelased by the bleaching earth^(2, 6).

When UBE used as a feedstuff special attention has to be given because of the ash content of around 85 to 88%.

5.4 Feeding Value

Used bleaching earth is an energy feedstuff. UBE tested at increasing levels in diets for rainbow trout (*Salmo gairdneri*) gave an apparent improvement in growth which is most probably due to the increase in the total fat content of the feed and a reduction in the carbohydrate level (Table 5-04). The digestibility of the nutrients were not affected by UBE although the ash content increased with increasing levels of UBE⁽²⁾.

The feeding value of used bleaching earth has not yet been tested in crustaceans.

Table 5-04: Used bleaching earth (UBE) in diets for rainbow trout (*Salmo gairdneri*)⁽²⁾

UBE	%	0	10.01	20.0	30.0
Wheat flour	%	31.9	22.4	12.9	3.4
Capelin oil	%	11.0	9.5	8.0	6.5

Crude protein	%	36.8	38.1	37.9	37.1
Crude fat	%	16.2	17.5	20.0	20.8
Ash	%	6.3	11.1	16.8	23.0
N-free extract	%	29.7	23.1	15.6	10.2
Metabolisable energy ¹	kcal/kg	3,206	3,256	3,328	3,274
	MJ/kg	13.4	13.6	13.9	13.7

Digestibility:					
Crude protein	%	87.8	87.9	86.9	86.2
Crude fat	%	88.6	85.8	88.0	85.5

Weight gain	g	132.5	147.6	146.7	158.6
	%	100.0	111.0	110.7	119.7
Length	cm	28.7	29.0	28.7	29.4
	%	100.0	101.0	100.0	102.4
Dressing-out	%	87.0	87.1	86.9	86.8

¹ Calculated as follows: 1.0 g fat = 8.0 kcal ME; 1.0 g protein = 3.9 kcal ME; 1.0 carbohydrate (raw starch) = 1.6 kcal

5.5 Recommended Inclusion Rates

The use of UBE is limited by the high ash content. Recommendable inclusion rates for fishes are as follows:

- Starter feed: none
- Grower feed: 3.0 to 7.0%
- Finisher feed: 5.0 to 10.0%.

Used bleaching earth should not be used in feed for crustaceans.

5.6 Legal Aspects

Bleaching earth is a clay. Used Bleaching Earth is a clay plus residual vegetable oil or/and animal fat. It has been given the GRAS status (Generally Recognised As Safe) by the authorities in the U.S.A. Clay is also listed in Section L, Annex I, No. E 588 of the Directive on Feed Additives of the competent EU authorities.

5.7 References

1. *Anonymous* (1989): Wembley activated clay - Technical data sheet.
2. *Austreng, E.* (1978): Fat-containing bleaching earth as a feed constituent for rainbow trout. *Aquaculture*, 15., 333-343.
3. *Dressler, D.* (1971): *Mineralische Elemente in der Tierernährung*. Verlag Eugen Ulmer, Stuttgart/Germany.
4. *Grim, R.E.; Guven, N.* (1978): *Bentonite - Geology, Mineralogy, Properties and Uses*. Elsevier Scientific, Amsterdam/The Netherlands.
5. *Gutcho, M.H.* (1973): *Feeds for livestock, poultry and pets*. Noyes Data Corp., London/England.
6. *Herstad, O.* (1976): Waste fat in fat-containing bleaching earth as feed for chickens. *Acta Agric. Scandinavica*, 26., 87-93.
7. *Oon, S.K.* (1990): Private communication.

6. BLOOD PRODUCTS

6.1 Rationale

Blood products are protein feedstuffs. Blood from slaughtering productive farm animals is used for human consumption but large quantities are still discarded. It is estimated that blood amounts to about 7.5% of the animals' liveweight, ranging from 4.5% for pigs and 8.0% for cows⁽²³⁾. The longer the bleeding time, the more blood can be collected (Figure 6-01)⁽²⁹⁾.

In Norway an estimated 65 to 70% of the collected blood is used as animal feed, 5.0 to 10.0% is consumed as food and 15 to 25% is discarded. However worldwide, the percentage of discarded blood is much higher due to lack of processing facilities. In several countries work has been done to find new ways of utilising blood^(2, 3, 4, 7, 8, 15, 27, 29).

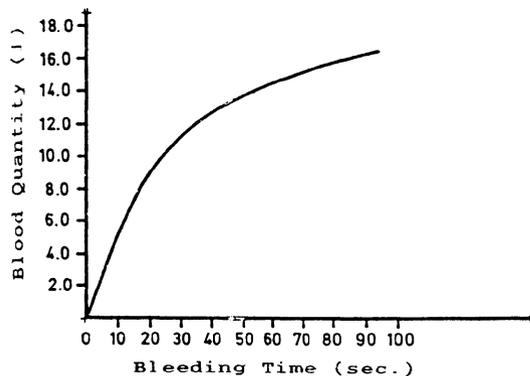


Figure 6-01. The quantity of collected cattle blood in relation to the bleeding time⁽²⁹⁾.

6.2 Collection and Processing

Three methods are used for the collection of blood at slaughter facilities:

- Use of drain tubes,
- Use of a gully or vat,
- A blood-drain on the floor.

The first method is very labour-intensive and only practiced in the collection of blood for processing of high quality products, e.g for human consumption and pharmaceutical preparations. The second and third methods are more commonly used in blood collection but the latter is less hygienic^(23, 29).

Fresh blood coagulates quickly and deteriorates easily. Thus immediately after collection, treatment by preservation or drying is necessary. Stirring fresh blood and/or adding chemical anticoagulants, such as oxalic acid or trisodium citrate solution, prevents coagulation^(29, 43).

Preserving fresh Blood

Fresh blood can be preserved by adding formic acid, salt (NaCl) and unslaked lime, sulphuric acid (H₂SO₄), and potassium-metabisulphite (K₂S₂O₅). Not all of these preservatives have the same degree of efficacy. Acids kill and control growth of germs aside from being a preservative⁽⁴³⁾. Deep-freezing is another practice of preserving fresh blood⁽³⁾.

Drying of Blood

Drying is the most effective mode of preserving fresh blood. However, processes where high temperature is applied for a long period are disadvantageous. The high temperature damages the protein and reduces the digestibility of the blood meal^(14, 20, 41). Spray-drying gives a better blood meal quality than drum-drying. When spray-drying, the blood is evaporated to 40 to 50% solids in a vacuum at low temperature (49°C) after which the material is sprayed into a hot air stream of 316°C^(4, 43).

Coagulated blood is used in the ring drying process (also called flesh-drying). The fluid is pressed-out from the coagulant and the solid matter enters an elliptical hot air stream at 400°C where it stays for less than one minute. Drum-drying follows a similar process⁽²⁶⁾.

Blood meal made from de-fibrinated blood is water soluble, while the meal from coagulated blood is insoluble. The quality of blood meal depends very much on the drying temperature. High quality blood meal is of reddish to dark-greyish colour.

6.3 Chemical, Physiological and other Properties

Chemical Properties

The nutrient content of blood meal varies widely (Table 6-01). The fat and carbohydrate content is rather low.

Table 6-01: Chemical composition of fresh blood and blood meal (% in dry matter)^(10, 14, 28, 30, 43)

	Fresh blood	Blood meal	
		Mean	Variation
Dry matter	-	90.3	87.8 - 93.0
Crude protein	90.8	92.5	72.3 - 96.6
Crude fat	0.5	1.2	0 - 5.9
Crude fibre	-	0.9	0.4 - 1.0
Crude ash	5.8	5.3	2.0 - 15.6
N-free extract	2.9	3.3	0 - 10.7
Organic matter	93.2	92.9	73.8 - 97.8

Protein is the most important component of blood meal and is affected by means of drying (Table 6-02). The variation of the essential amino acids of blood meal is generally not wider than in other feedstuffs, however there is some disproportion^(32, 43). Blood meal is a rich source of leucine but a poor source of methionine and isoleucine⁽²¹⁾. Compared to whole chicken egg protein blood meal is low in isoleucine, cystine and methionine. The aromatic amino acids tyrosine and phenylalanine are sufficiently present and the lysine content is high (Table 6-03)⁽²⁹⁾.

Table 6-02: Effect of drying procedure of blood meal on the crude protein (%) and amino acid (g/16 g N) content⁽⁴⁾

Drying procedure	Crude protein	Amino acids			
		Lysine	Methionine	Cystine	Arginine
Freeze drying	93.5	9.6	1.3	1.5	-
Dried at 100°C/24 hours	94.3	9.2	1.2	1.5	-
Ring-drying	90.0	9.7	1.4	1.4	4.1
Open-air drying	87.3	7.8	1.0	0.7	-
Norwegian Standard ¹	81.5	8.5	1.3	4.3	

¹ Minimum requirement

Table 6-03: Essential amino acid content of the protein (g/16g N) of blood meal^{3, 10, 14, 29, 30, 43}

	Mean	Variation
Arginine	4.01	3.28 - 4.60
Histidine	5.49	4.43 - 5.70
Isoleucine	1.08	0.71 - 1.40
Leucine	11.82	10.18 - 13.40
Lysine	8.53	6.90 - 9.60
Methionine	1.19	0.87 - 1.50
Phenylalanine	6.44	5.66 - 7.30
Threonine	4.50	3.62 - 5.40
Tryptophan	1.21	1.04 - 1.30
Valine	8.10	6.76 - 9.60

The vitamin content of blood meal is quite insignificant. Except for the iron content, provided by haemoglobin which is an organic compound of iron, the macro and trace mineral content of blood meal is low for practical feeding (Table 6-04). The calcium: phosphorus ratio is 1:1.36.

Table 6-04: Macro and trace minerals and vitamin content of blood meal^(14, 30, 37, 43)

Minerals			Vitamins (per 1,000 g)		
Calcium	%	0.30	Vitamin D	I.U.	600
Phosphorus	%	0.22	Vitamin E	mg	20.0
Sodium	%	0.69	Vitamin B ₁	mg	0.4
Potassium	%	0.35	Vitamin B ₂	mg	2.5
Magnesium	%	0.07	Vitamin B ₆	mg	2.0
Sulphur	%	0.33	Vitamin B ₁₂	mcg	14.8
Manganese	mg/kg	11.2	Biotin	mg	0.2
Iron	mg/kg	2,273.0	Folic acid	mg	0.2
Zinc	mg/kg	82.8	Nicotinic acid	mg	27.2
Copper	mg/kg	9.2	Pantothenic acid	mg	2.8
Fluorine	mg/kg	36.7	Choline	mg	818

Physiological Properties

Energy content and digestibility of blood meal are highly affected by the method of drying and the drying temperature (Table 6-05, 6-06). In rats the true digestibility of blood meal protein is as high as 99.0%⁽¹³⁾. The apparent digestibility of blood meal for salmonids (97.0%) and chinook salmon (*Oncorhynchus tshawytscha*) (95.4%) is high^(2, 18) but it is low for rainbow trout (*Salmo gairdneri*) (89.4%)⁽³⁰⁾.

Table 6-05: Digestibility, and metabolisable and digestible energy of differently processed blood meals (basis: dry matter) for rainbow trout (*Salmo gairdneri*) (RT) and chinook salmon (*Oncorhynchus tshawytscha*) (CS)^(18, 30)

Blood meal drying process		Digestibility		Energy	
		Protein %	Energy %	Metabolisable kcal/kg	Digestible kcal/kg
De-hydrated ^{1,4}	RT	32.4	44.8	2,441	2,514
Spray-dried ⁴	RT	65.2	65.8	3,440	3,406
Ring-de-hydrated ^{3,4}	RT	87.0	76.7	3,935	4,383
Ring de-hydrated ^{1,4}	RT	89.4	89.0	4,483	5,086
Disc-dried (30%) ²	CS	29.4	31.9	-	1,864

¹ 50% of diet; ²30% of diet; ³ 25% of diet; ⁴ determined in the metabolism chamber

The average availability of lysine ranges between 70 and 75%. Poorly processed blood meals still have a lysine availability of 65 to 69%^(14, 43). After three months of storage of blood meal, the lysine activity declined by 25%. The content of available amino acids is also affected by the analytical procedure used. The microbiological assay provides the highest results (12.6 mg/16 g N), followed by biological tests (9.5 mg/16 g N) and chemical analysis (7.7 mg/16 g N)⁽⁴³⁾.

Table 6-06: Effect of the drying temperature in the cylindrical dryer on the protein digestibility of blood meal in pigs⁽⁴³⁾

Drying temperature °C	Protein digestibility %
180	64 to 67
80 to 90	87 to 90

Hygienic Aspects

The bacterial count is a significant criteria for the quality of blood meal. It is greatly influenced by the hygienic methods used in the collection of fresh blood and the storage conditions of the processed product. Up to 100 to 100,000 germs per ml were found in fresh blood and blood meal⁽²²⁾. Acid treated blood is less contaminated with germs than untreated blood because the total bacterial count is related to the pH of the material⁽²⁴⁾. Germ count increases rapidly and as much as 25-fold (Table 6-07), even if blood has been collected under very hygienic conditions and is refrigerated⁽²⁹⁾.

Table 6-07: Refrigerated storage of blood and the effect on the bacterial count⁽²⁹⁾

	At time of collection	Days of storage			
		1	2	3	6
Blood, collected by drain-tube	400	400	500	2,000	10,000
Blood, prior to centrifuging	500	1,000	400	70,000	7,900,000
Blood plasma	90	140	900	21,000	8,600,000
Blood corpuscle fraction	400	600	1,000	200,000	9,000,000

6.4 Feeding Value

Carefully processed blood products are useful protein feedstuffs for aquatic animals. In land animals blood meal has been tested widely, but it is not recommended for use as the only protein source of the feed formulation^(3, 4, 26, 43). Blood and blood meal in mink diets contribute to the prevention of fish-induced anaemia after feeding raw fish of certain fish species^(35, 36).

6.4.1 Blood meal

Fishes

In chinook salmon (*Oncorhynchus tshawytscha*) positive effects were observed when up to 5.0% fish meal in starter diets were replaced by spray-dried blood meal. At a level of 17.5% blood meal in exchange for fish meal, pathological effects in fish were noted⁽¹⁶⁾. Chinook salmon responded poorly to a diet containing 30% of a disc-dried blood meal of inferior quality⁽¹⁸⁾.

Two different sources of blood meal replaced herring meal at levels of 13.6% and 27.2% in diets for rainbow trout (*Salmo gairdneri*) and Atlantic salmon (*Salmo salar*). At the lower blood meal level fish yield was significantly better than the control. At the higher inclusion rate there was no difference when compared to the control⁽⁴⁾.

There was little difference in weight gain of rainbow trout when 1/3 of the standard protein (casein-gelatin protein [75:25]) was replaced by blood-feather meal (50:50), but when 2/3 of the standard protein was replaced, weight was reduced. Pathological changes of any organs were not noted. Blood-feather-poultry meal (1/2:1/3:1/3) as the only protein source for rainbow trout is a better combination^(33, 34).

Inconclusive test results were seen when 10% blood meal replaced feather meal of a diet for rainbow trout composed of feather meal and poultry offal meal as the only animal protein sources⁽³⁸⁾. Replacing 75% of the fish meal in a diet for rainbow trouts by a combination of blood meal and rendered carcass meal depressed weight gain and feed conversion by 19% and 20%, respectively. But reducing the replacement level to 25% gave almost similar results as with pure fish meal (Table 6-08)⁽¹⁷⁾.

Table 6-08: Replacement of fish meal by a combination of blood meal and rendered carcass meal in diets for rainbow trout (*Salmo gairdneri*)⁽¹⁷⁾

		Control	Test	Test
Protein provided by:				
Fish meal	%	100.0	25.0	25.0
Poultry offal meal	%	-	-	50.0
Blood meal/rendered carcass meal	%	-	75.0	25.0

Weight gain	g	133	108	130
	rel.	100.0	81.2	97.7
Feed conversion	1:	1.33	1.59	1.34
	rel.	100.0	119.5	100.8

Blood meal trials with tilapia (*Oreochromis* spp.) gave inconsistent results. Best performances of tilapia fingerlings were noted when 10% of the diet's protein was blood meal, but replacement levels of more than 50% of the dietary protein reduced growth rate and feed conversion⁽³¹⁾. However, in the supplemental diet for cage-cultured Nile tilapia around 40 to 60% of the fish meal could be replaced by blood meal without negative response⁽⁴⁰⁾. Exchanging all fish meal with blood meal in the diet for juvenile tilapia resulted in a progressive reduction in growth rate and feed utilisation (Table 6-09)⁽⁹⁾.

Table 6-09: Blood meal replaces fish meal in diets for juvenile tilapia (*Oreochromis mossambicus*) (Feeding period: 7 weeks)⁽⁹⁾

Fish meal	%	21.8	-	-
Meat and bone meal	%	10.0	32.0	18.7
Blood meal	%	-	5.0	10.0
Crude protein	%	35.9	36.6	35.7
Fat	%	12.6	12.5	12.5
Ash	%	13.2	13.4	11.3

Initial weight	g	1.13	1.05	1.07
Weight gain	%	302	266	227
Specific growth rate	%	2.84	2.65	2.42
Feed conversion	1:	2.24	2.47	2.70
PER		1.14	1.01	0.94

Carcass composition (in the dry matter)				
- Crude protein	%	58.5	60.0	62.2
- Lipid	%	21.9	20.3	19.1
- Ash	%	15.5	15.6	16.7

The combination of blood meal (52%) and algae meal (32%) as the major protein sources in the diet for the carnivorous African catfish (*Clarias lazera*) performed better than feeding blood meal or algae meal alone⁽³⁹⁾. Blood meal in the diet for juvenile *Colossama macropomum* was found to be inadequate as the only protein source⁽¹²⁾.

Crustaceans

The partial protein replacement of fish meal by blood meal at inclusion rates ranging from 5.0 to 10.0%⁽⁶⁾ in diets for the yellow leg shrimp (*Penaeus californiensis*) showed growth depression. Blood meal was also found to be inferior in diets for the Sao Paulo shrimp (*Penaeus paulensis*) when it replaced fish meal, shrimp meal, clam, soybean meal and even rice bran⁽²⁵⁾.

Marine, white leg shrimps (*Penaeus vannamei*) did not show significant differences in weight gain, feed conversion and survival when fed diets containing 10% levels of differently processed blood meals (Table 6-10). Blood meal, therefore, may replace marine proteins in grow-out diets for medium sized shrimps⁽¹¹⁾.

Table 6-10: Differently processed blood meal as a protein source in diets for *Penaeus vannamei* (42 days test)⁽¹⁾

Blood meal:						
- Ring-dried	%	-	10.0	-	-	-
- Acidulated ¹	%	-	-	10.0	-	-
- Acidulated ²	%	-	-	-	10.0	-
- Acidulated ³	%	-	-	-	-	10.0
Methionine	%	-	-	-	0.90	-
Protein-mix ⁴	%	45.00	30.65	31.80	30.20	30.60
Crude protein	%	55.40	55.38	55.40	55.39	56.37
Fat	%	5.38	5.38	5.38	5.36	5.36

Mean weight gain	g	4.52	4.50	4.15	4.00	3.69
Feed conversion	1:	1.63	1.91	1.76	2.00	1.99
Survival rate	%	100.0	96.8	96.8	93.6	96.8

¹ Acidulated, sun-dried blood meal; ² Acidulated, sun-dried blood meal with crystalline methionine added; ³ Acidulated, sundried blood meal with covalently linked methionine; ⁴ Marine protein-mix = 1/3 squid meal, 1/3 shrimp meal, 1/3 fish meal

6.4.2 Preserved Blood

Growth was poor, but the fish appeared to be healthy when fed blood preserved by acid as the sole protein source for several weeks⁽⁵⁾.

Acid preserved blood and blood preserved by freezing replaced half the amount of raw fish or fish offal in moist diets for rainbow trout (*Salmo gairdneri*) and Atlantic salmon (*Salmo salar*) without resulting in significant differences from the control in weight gain and health (Table 6-11). This also does not significantly affect the fish quality such as dressing percentage, chemical composition of fish fillets, pigmentation, taste and texture and colour of the liver. Without any performance depressing effect, 17% of the protein in a moist diet for salmonids can be replaced by preserved blood⁽³⁾.

6.5 Recommended Inclusion Rates

Blood meal is a useful protein source for aquatic animals. Its nutritional value highly depends on the drying process of the blood. Blood meal of good quality may replace 25% of the diet's protein content without significant depressing effects. For practical conditions blood meal in aquaculture diets should not exceed 5.0% for young animals and 10.0% for older animals.

Preserved blood is more suitable for older than for young fish. In most diets the application rate is in the range of 15 to 20% of the total protein content.

Table 6-11: Effect of blood silage in the moist diet for rainbow trout (*Salmo gairdneri*) and Atlantic salmon (*Salmo salar*)⁽³⁾

		Control	Test	Change ¹
Fish, frozen	%	60.0	30.0	
Blood silage	%	-	32.6	
Crude protein ²	%	49.4	49.8	
Metabolisable energy ²	kcal/kg	3,560	3,560	
	MJ/kg	14.9	14.9	
Protein from blood	%	0	18.8	

1. Rainbow trout:				
Weight gain	g	944	874	-7.4
Daily growth rate	%	0.50	0.54	+8.0
Condition factor		1.59	1.58	-0.6
Dressing percentage	%	79.1	79.0	-0.1
2. Atlantic salmon:				
Weight gain	g	681	742	+8.8
Daily growth rate	%	0.67	0.71	+6.0
Condition factor		1.18	1.18	±0
Dressing percentage	%	88.4	89.0	+0.7

¹ Control = 100%; ² In the dry matter

6.6 Legal Aspects

AAFCO⁽¹⁾ has listed two blood meal products:

- Blood meal (No. 9.61) (Requirement: The drying process has to be labelled [conventional cooker dried, steamed, hydrolysed]);
- Blood meal, flash dried (No. 9.62) (Requirement: Min. 80% biological activity of lysine).

According to the German feedstuff legislation blood meal is a permitted single feedstuff and defined as “a product derived from blood of slaughtered animals, inclusively poultry blood. It has to be free of impurities”⁽⁴²⁾ and has to meet the following requirements:

- Moisture: max. 10.0%
- Crude protein: min. 80.0%
- Protein digestibility (Pepsin digestibility): min. 90.0%
- Ash: max. 4.5%.

There are no legal restrictions with regard to the use of blood meal provided it is not contaminated with pathogenic organisms such as *Escherichia coli* and Salmonella.

6.7 References

1. AAFCO (1995): Official publication 1995. Ass. of American Feed Control Officials (publisher), Sacramento, CA/USA.
2. *Abou-El-Hassan, A.; El-Abbady, M.R.; Shahein, A.I.H.* (1970): A study on the net protein utilization of blood meal prepared by different methods for feeding poultry. U.A.R.J. Anim. Prod., 10., 317-328.
3. *Åsgård, T.; Austreng, E.* (1986): Blood, ensiled or frozen, as feed for salmonids. Aquaculture, 55., 263-284.
4. *Auklend, G.I.* (1983): Blod som fôr til laksefisk. Hovedoppgave ved Inst. for fjôrfe og pelsdyr. Norges Landbrukshøgskole, Ås-NLH/Norway.
5. *Austreng E.; Refstie* (1973): Quoted from: *Åsgård and Austreng* (1986).
6. *Brand, C.W.; Colvin, L.B.* (1977): Compounded diets for early postlarval *Penaeus californiensis*. Proc. 8th Annu. Meeting World Maricult. Soc., 8., 811-820.
7. *Brunner, M.* (1978): Verarbeitung und Verwertung von Schlachtblut und Knochen. Übersichten zur Tierernährung, 6., 180-181.
8. *Coser, A.M.L.; Jokl, L.; Vieira* (1971): Effects of temperature of processing and of isoleucine fortification on the nutritive value of blood meal. Arch. Latinoam. Nutrition, 27., 297-309.
9. *Davies, S.J.; Williamson, J.; Robinson, M.; Bateson, R.I.* (1989): Practical inclusion levels of common animal by-products in complete diets for tilapia *Oreochromis mossambicus*, Peters). Proc. 3rd Int. Symp. on Feeding and Nutrition in Fish, Toba/Japan, 28.8-1.9, 325-332.
10. *De Boer, F.; Bickel, H.* (1988): Livestock feed resources and feed evaluation in Europe. E.A.A.P. Publication No. 37, Elsevier Science Publishers B.V., Amsterdam/The Netherlands.
11. *Dominy, W.C.; Ako, H.* (1988): The utilization of blood meal as a protein ingredient in the diet of the marine shrimp *Penaeus vannamei*. Aquaculture, 70., 289-299.
12. *Eckmann, R.* (1987): Growth and body composition of juvenile *Colossoma macropomum*, Cuvier 1818 (*Characoides*) feeding artificial diets. Aquaculture, 64., 293-303.
13. *Eggum, B.O.* (1968): Aminosyrekoncentration of proteinkvaliteit. Stougaards Forlag, Copenhagen/Denmark.
14. *Evans, M.* (1985): Nutrient composition of feedstuffs for pigs and poultry. Queensland Dept. of Primary Ind., Info Series Q185001, Brisbane/Australia.
15. *Fong, H.V.; Devendra, C.* (1977): Protein source for feeding pigs in Malaysia, 3. Blood meal. MARDI Res. Bull., 5., 104-110.
16. *Fowler, L.G.; Banks, J.L.* (1976): Animal and vegetable substitutes for fish meal in the Abernathy diet. Prog. Fish. Cult., 38., 123-126.
17. *Gropp, J.; Koops, H.; Tiewes, K.; Beck, H.* (1976): Ersatz von Fischmehl im Forellenfutter. Arb. Deutscher Fischerei-Verb., No.19, 85-102.
18. *Hajen, W.E.; Higgs, D.A.; Beames, R.M.; Dosanjh, B.S.* (1993): Digestibility of various feedstuffs by post-juveniles chinook salmon (*Oncorhynchus tshawytscha*) in sea water. 2. Measurement of digestibility. Aquaculture, 112., 333-348.
19. *Halver, J.E.* (1989): Fish Nutrition. Academic Press, Inc., London (2nd ed.).
20. *Hamm, D.; Searcy, G.K.* (1976): Some factors which affect the availability of lysine in blood meal. Poultry Sci., 55., 582-587.
21. *Hardy, R.P.* (1989): Quoted from: *Halver, J.E.* (1989).
22. *Hrusovska, A.K.; Stefunka, M.; Muransky, M.* (1974): Microbiological picture of fresh blood. Folia Vet., 18. (3/4), 513-528.
23. *Jordfald, G.* (1975): Blod som forurensningskomponent. PRA-Rapport No.3, Landbrukets Bygge- og Rasjonaliseringskontor A/L, Sandvik/Norway.

24. *LBR* (1975): Quoted from: *Auklend* (1983).
25. *Marchiori, M.; Magalhaes, C.V.; Yunes, J.S.; Levy, J.A.* (1982): Studies on artificial feeding of *Penaeus paulensis*. *Atlantica*, 5., (1), 43-48.
26. *Miller, E.R.* (1990): Blood meal: Flesh-dried. In: *Thacker, P.A.; Kirkwood, R.N.* (1990): Nontraditional feed sources for use in swine production. Butterworth Publishers, Stoneham, MA/USA.
27. *Neelakantan, S.* (1975): Preparation and nutritive value of serum and whole blood protein meals from slaughter animal blood. *J. Food Sci. Technology*, 12., 289-291.
28. *New, M.B.* (1987): Feed and feeding of fish and shrimp. *Aquaculture Dev. and Coord, Progr.* (ADCP/REP) 87/26, UNDP/FAO, Rome/Italy.
29. *Nordal, J.; Fretheim, K.* (1978): Utnyttelse av slakteriblod i næringsmidler. Rapport no. 27, Norsk Institutt for Næringsmiddelforskning, Ås-NLH/Norway.
30. *NRC* (1981): Nutrient requirement of coldwater fish. *Natl. Res. Council, No. 16, Natl. Acad. Press, Washington, D.C.*
31. *Otobusin, S.O.* (1987): Effects of different levels of blood meal on pelleted feeds on tilapia, *O. niloticus*, production in floating bamboo net-cages. *Aquaculture*, 65., 263-266.
32. *Pavlasova, M.; Vesley, Z.* (1983): Amino acid composition of animal meals in relation to possibility of replacing fish meal. *Zivoc. Vyr.*, 28., 481-486.
33. *Schulz, D.; Hartfiel, W.; Greuel, E.* (1982): Verwendung von Nebenprodukten tierischer Herkunft in der Ernährung von Regenbogenforellen (*Salmo gairdneri*). I. Einsatz von Blut- und Federmehl in einer gereinigten Diät. *Z. Tierphysiol., Tierernährung, Futtermittelkd.*, 47., 79-85.
34. *Schulz, D.; Hartfiel, W.; Greuel, E.* (1982): Verwendung von Nebenprodukten tierischer Herkunft in der Ernährung von Regenbogenforellen (*Salmo gairdneri*). II. Einsatz von Blut-, Feder- und Geflügelschlachtabfallmehl sowie Gelatine in einer gereinigten Diät. *Z. Tierphysiol., Tierernährung, Futtermittelkd.*, 48., 267-275.
35. *Skrede, A.* (1970): Dietary blood in the prevention of fish-induced anaemia in mink. I. Iron absorption studies. *Acta Agric. Scandinavica*, 20., 265-274.
36. *Skrede, A.* (1970): Dietary blood in the prevention of fish-induced anaemia in mink. II. Feeding experiments. *Acta Agric. Scandinavica*, 20., 276-285.
37. *Steffens, W.* (1985): Grundlagen der Fischernährung. VEB Gustav Fischer Verlag, Jena/Germany.
38. *Tiews, K.; Koops, H.; Beck, H.; Schwalb-Bühling, A.; Gropp, J.* (1981): Entwicklung von Ersatzfutter für die Regenbogenforelle. Bundesforschungsanstalt für Fischerei, Veröffentl. des Inst. für Küsten- und Binnenfischerei, Hamburg/Germany, Publ. No. 75.
39. *Ufodike, E.B.C.; Ekokotu, P.A.* (1986): Protein digestibility and growth of African catfish (*Clarias lazera*) fed blood meal and algal diets. *Acto Hydrobiol.*, 28., 237-243.
40. *Ufodike, E.B.C.; Ugwuzor, G.N.* (1985): Effects of fish meal, cow blood meal, and sorghum diets in food utilization and growth of cage-cultured *Oreochromis niloticus*. *Biol. Afric.*, 2., 69-74.
41. *Waibel, P.E.; Cuperlovic, M.; Hurrell, R.F.; Carpenter, K.J.* (1977): Processing damage to lysine and other amino acids in the manufacture of blood meal. *Food Chem.*, 25., 171-174.
42. *Weinreich, O.; Koch, V.; Knippel, J.* (1994): Futtermittelrechtliche Vorschriften. Buchedition Agrimedia, Hamburg/Germany.
43. *Wöhlbier, W.; Tran Thu, D.* (1977): Blutmehl. In: *Kling, M.; Wöhlbier, W.*: Handelsfuttermittel. Verlag Eugen Ulmer, Stuttgart/Germany.

7. BREWERS' GRAINS (DE-HYDRATED)

7.1 Rationale

Brewers' grains is a by-product of beer brewing which has been practised by the ancient Egyptians 5,000 years ago. Beer is an alcoholic, carbon dioxide-containing beverage. It is produced by fermentation, predominantly from barley, yeast, hops and water. Wheat, rice, maize, sugar cane and tapioca can also be used for beer making. Even in Great Britain alone, about 900,000 MT fresh brewers' grains, equivalent to 200,000 MT dried brewers' grains, are available annually⁽¹⁷⁾.

7.2 Manufacture and Processing

After the initial stage of malting grains (barley), enzymes (amylases) are formed and convert the starch into sugar. Enzymatic activity is stopped by drying the sprouted barley. Malt hulls are removed and the pure malt is mashed together with other components. The mash is pressed to separate the liquid (wort) from the solids (brewers' grains)^(5, 9). Only the liquid wort is of interest for beer brewing (Figure 7-01). Fresh brewers' grains contain only 20 to 24% dry matter and cannot be stored because at high environmental temperature fresh brewers' grains decay rapidly.

De-hydration of brewers' grains is costly⁽⁹⁾. Between 110 to 130 kg fresh brewers' grains (20% dry matter) are obtained from 100 kg barley. Dried brewers' grains may contain 3.0% dried spent hops and 0.25 to 0.80% of the malt dry matter as dreg⁽⁵⁾.

7.3 Chemical, Physiological and other Properties

Chemical Properties

The raw materials used affect the chemical composition of dried brewers' grains. When dried spent hops and dreg are added to dried brewers' grains, the chemical composition is adulterated and no longer typical of the product⁽⁵⁾. The chemical composition of dried brewers' grains is compiled in Table 7-01. Seriously limiting amino acids are lysine and methionine + cystine⁽¹²⁾. Lysine availability amounts to only 0.78 g/16 g N (total lysine: 0.88 g/16 g N) (Table 7-02)⁽⁷⁾. The crude fat contains 3.0% linoleic acid (18:2n-6). Of the total phosphorus content only 0.15% are available phosphorus (Table 7-03)⁽⁷⁾.

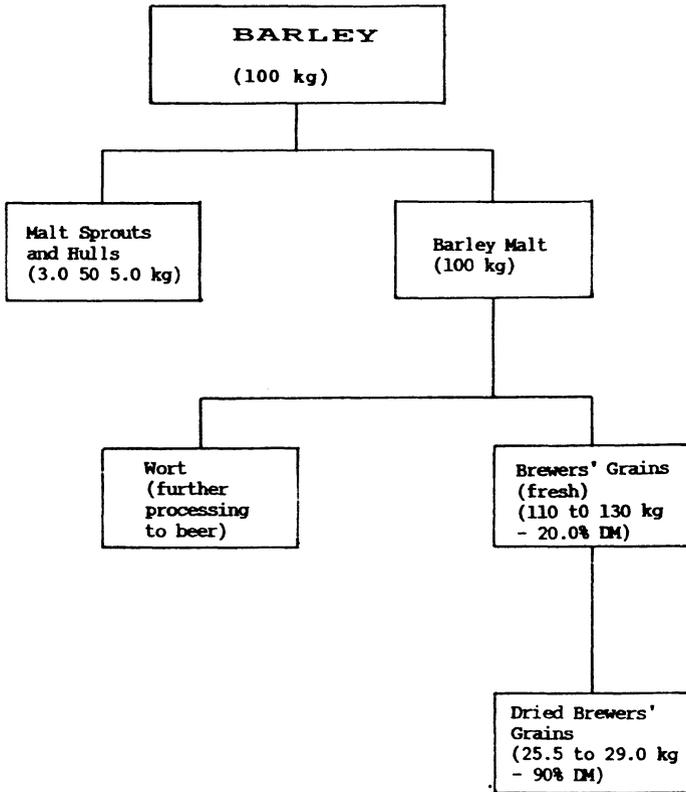


Figure 7-01. Diagram of the processing of dried brewers' grains (data from: (4)).

Table 7-01: Chemical composition of dried brewers' grains (as fed)^(3, 6, 7, 9, 14)

		Mean	Variation
Dry matter	%	92.3	92.0 - 93.0
Crude protein	%	25.9	23.4 - 27.2
Crude fat	%	7.0	5.9 - 9.2
Ash	%	4.3	3.6 - 5.2
Crude fibre	%	14.4	12.0 - 18.5
N-free extract	%	44.5	

Table 7-02: Essential amino acid profile of dried brewers' grains (g/16 g N)

	(7)	(15)	Mean
Arginine	1.30	1.27	1.29
Histidine	0.60	0.52	0.56
Isoleucine	2.00	1.54	1.77
Leucine	3.20	2.49	2.81
Lysine	0.88	0.88	0.88
Methionine	0.45	0.46	0.46
Phenylalanine	1.80	1.44	1.62
Threonine	1.00	0.93	0.97
Tryptophan	0.37	0.37	0.37
Valine	1.20	1.61	1.41

Table 7-03: Mineral and vitamin contents of dried brewers' grains

Minerals ^(3, 7, 13, 15)			Vitamins (per 1,000 g) ^(7, 14, 15)		
Calcium	%	0.30	Vitamin E	mg	26.60
Phosphorus	%	0.54	Vitamin B ₁	mg	0.63
Sodium	%	0.23	Vitamin B ₂	mg	1.40
Potassium	%	0.08	Vitamin B ₆	mg	1.03
Magnesium	%	0.15	Vitamin B ₁₂	mcg	40.00
Chlorine	%	0.15	Biotin	mg	0.44
Sulphur	%	0.30	Folic acid	mg	0.38
Manganese	mg/kg	37.3	Nicotinic acid	mg	43.70
Iron	mg/kg	245.0	Pantothenic acid	mg	8.33
Zinc	mg/kg	27.5	Choline	g	1.79
Copper	mg/kg	21.2			
Selenium	mg/kg	0.7			
Iodine	mg/kg	0.06			
Cobalt	mg/kg	0.07			

Physiological Properties

Dried brewers' grains is merely a feedstuff for ruminants and the use for monogastric land animals is limited⁽⁸⁾ due to its high crude fibre content. Its protein fraction is relatively insoluble in the rumen⁽²⁾.

The metabolisable energy of dried brewers' grains for cold water fish and for poultry is not much different (Table 7-04). The digestibility of dried brewers' grains in aquatic animals has not yet been established but the digestibility of the organic matter for pigs and ruminants is only 46% and 64%, respectively⁽⁹⁾.

Table 7-04: Metabolisable energy values of dried brewers' grains (as fed)

Species	kcal/kg	MJ/kg	Reference
Cold water fish	2,392	10.01	(13)
Poultry	2,510	10.50	(7)

Other Properties

Dried brewers' grains has a bulk density of 0.22 to 0.25 MT/m³. It is an ingredient antagonistic to water durability of aquaculture feed pellets, particularly if used at high levels⁽¹²⁾. The pelletising ability is low and the molasses-absorption capacity amounts to only 9.0%⁽¹⁰⁾.

7.4 Feeding Value

Comparable experiments with dried brewers' grains in aquatic animals have not been carried-out. Under extensive systems of fish production dried brewers' grains have been used for fishes which are not too finicky with regard to their diet (Table 7-05). The feeding value of dried brewers' grains for aquaculture diets is low just like experiences with terrestrial farm animals, except of ruminants^(4, 8, 9). Nevertheless, it can be a source of protein and energy for aquaculture diets⁽¹²⁾

Table 7-05: Dried brewers' grains in practical fish diets

Fish species	Inclusion rate	Type of feed/ weight of animal	Country	Reference
African catfish <i>Clarias gariepinus</i>	10.0	grower	CAR ¹	(18)
Tilapia <i>Tilapia discolor</i>	12.0-19.0	3.0-10.0 g	Ghana	(16)

¹ Central African Republic

7.5 Recommended Inclusion Rates

Dried brewers' grains is a feedstuff for undemanding aquatic animals that are produced under extensive conditions. The inclusion rate of the completed feed ranges between 10 and 15%.

7.6 Legal Aspects and Precautions

Legal Aspects

Brewers' dried grains is a permitted single feedstuff in the U.S.A. and EU. In U.S.A. brewer's dried grains (No. 15.01) may contain not more than 3.0% pulverised dried spent hops⁽¹⁾. The EU regulation does not have any specific requirements for brewers' grains, de-hydrated (No. 1.41). The German feedstuff legislation rules that brewers' grains, de-hydrated, has to meet the following specification⁽¹⁹⁾:

- Moisture: max. 13.0%
- Crude fibre: max. 17.0%
- Crude ash: max. 4.5%.

Precautions

Dried brewers' grains should not be used if infected with the pathogenic *Bacillus cereus* which is the cause of food and feed poisoning and also of bovine mastitis⁽²⁰⁾. According to U.S.A.-estimates in 1989 about 84,000 cases of *Bacillus cereus* infections were recorded⁽¹¹⁾

7.7 References

1. *AAFCO* (1995): Official publication 1995. Ass. of American Feed Control Officials (publisher), Sacramento, CA/USA.
2. *Barber, W.P.; Lonsdale, C.R.* (1980): By-products from cereal, sugar beet and potato processing. In: *Oerskov, E.R.*: By-products and wastes in animal feeding. Occasional Publ. No. 3, British Soc. Anim. Prod.
3. *Castaldo, D.J.* (1994): Squeezing more out of by-products. *Feed International*, 15., (10), 34-38.
4. *Cheeke, P.R.* (1987): Rabbit feeding and nutrition. Academic Press, Inc., Orlando, Florida/U.S.A.
5. *De Boer, F.; Bickel, H.* (1988): Livestock feed resources and feed evaluation in Europe. Elsevier Sciences Publishers, Amsterdam/The Netherlands.
6. *Dupree, H.K.; Huner, J.V.* (1984): Third report to the fish farmers. Publ. U.S. Fish and Wildlife Service, Washington, D.C.
7. *Evans, M.* (1985): Nutrient composition of feedstuffs for pig and poultry. Queensland Dept. Primary Ind., Brisbane/Australia (Series Q 185001).
8. *Feltwell, R.; Fox, S.* (1978): Practical poultry feeding. Faber and Faber, London and Boston.
9. *Friesecke, H.* (1984): Handbuch der praktischen Fütterung von Rind, Schaf, Pferd, Schwein, Geflügel und Süßwasserfischen. BLV Verlagsges., München/Germany.
10. *Hertrampf, J.W.* (1992): On the water durability of aquaculture feed pellets - A review. *Advances in Feed Techn.*, (7), 18-38.
11. *Miller Jones, J.* (1992): Food safety. Eagan Press, St. Paul, Minnesota/U.S.A.
12. *New, M.B.* (1987): Feed and feeding of fish and shrimps - A manual on the preparation and presentation of compound feeds for shrimps and fish in aquaculture. UNDP/FAO/ADCP/REP/87/26, Rome/Italy.
13. *NRC* (1981): Nutrient requirements of coldwater fishes. National Academy Press, Washington, D.C.
14. *NRC* (1983): Nutrient requirements of warmwater fishes and shellfishes. National Academy Press. Washington, D.C.
15. *NRC* (1989): Nutrient requirements of horses. National Academy Press, Washington, D.C.

16. *Oduro-Boateng, F.* (1986): Quoted from: *New, M.B.* (1987).
17. *Oerskov, E.R.* (1988): *Feed Science*, B 4, Disciplinary approach. Elsevier Science Publishers, Amsterdam.
18. *Viveen, W.J.A.R. et al.* (1985): Quoted from: *New, M.B.* (1987).
19. *Weinreich, O.; Koch, V.; Knippel, J.* (1994): *Futtermittelrechtliche Vorschriften*. Buchedition Agrimedia, Hamburg/Germany.
20. *West, G.P.* (1992): *Black's veterinary dictionary*. A & C Black, London, 17th Edition.

8. CASEIN (DE-HYDRATED)

8.1 Rationale

Casein is the protein of milk and the basic component of cheese. The term “casein” is derived from the Latin word “*caseus*” for cheese. World production of casein is growing steadily with New Zealand as the main producer. In Norway about 80% of casein production is extracted from cow’s milk and the remaining 20% from goat’s milk⁽⁷⁾.

Casein is used in diets for human and animal (land and aquatic) consumption. Dehydrated casein has a wide field of application and is primarily used for industrial purposes, as in the paper, paint, cosmetics, pharmaceutical and food industries, leather processing, plastics and industrial glues. A new product is garment buttons from casein⁽¹⁵⁾.

8.2 Manufacture and Processing

Skimmed milk, derived from the separation of the butterfat from whole milk, is the basis for casein production. It is pasteurised prior to adding coagulants. By addition of acid or rennet the precipitation of casein as casein curd in the watery media is achieved. The curd is extensively washed, dried and ground. A dehydrated casein with a brownish colour may be obtained due to lactose that has not been removed before drying. Sodium caseinate and calcium caseinate are salts of casein.

8.3 Chemical, Physiological and other Properties

Chemical Properties

Casein is a protein feedstuff with a mean crude protein content of 87.9% (Table 8-01). Not less than 78% of the milk’s total nitrogen content is casein-nitrogen (Figure 8-01). The protein is available in the form of phosphoprotein.

Table 8-01: Chemical composition (%) of casein (dehydrated) (as fed)^(4, 11, 12, 14, 31, 49)

	Mean	Variation
Dry matter	91.2	88.4 - 94.0
Crude protein	87.9	84.0 - 92.5
Crude fat	0.7	0.2 - 1.1
Ash	3.3	1.8 - 5.5
Crude fibre	1.1	0.2 - 2.0
N-free extract	5.9	
Lactose	<0.1	

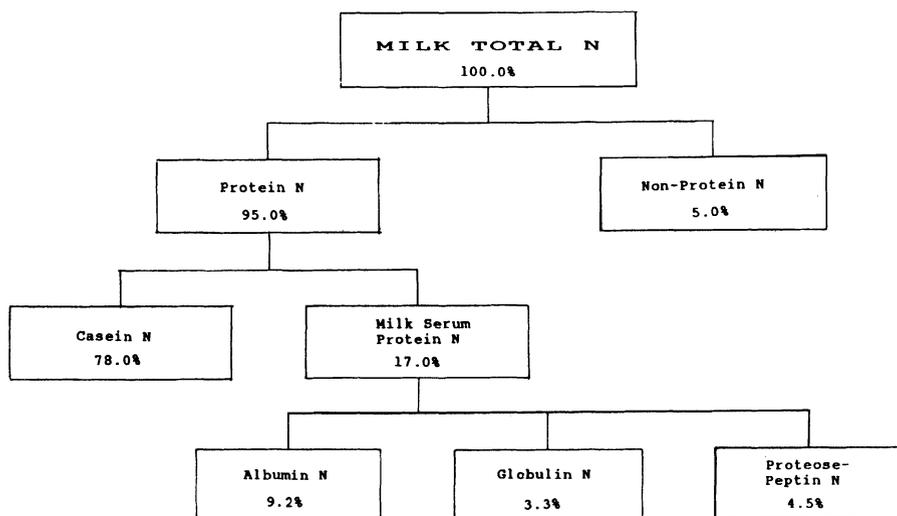


Figure 8-01. Composition of the nitrogen fraction of milk^{(data from: (14))}.

Casein contains adequate amounts of all the essential amino acids but with a wide variation within the individual amino acid (Table 8-02). This variation is influenced by seasonal changes (Figure 8-02)⁽¹⁹⁾, location of the dairy farms, species and breeds^(3, 25, 39, 40, 41, 48, 54).

Table 8-02: Essential amino acid profile of dehydrated casein (g/16 g N)^(4, 7, 11, 12, 31, 43, 49)

	Mean	Variation
Arginine	3.69	3.32 - 4.00
Histidine	2.54	2.59 - 3.40
Isoleucine	5.26	4.10 - 7.70
Leucine	9.41	8.70 - 11.00
Lysine	7.89	7.14 - 8.40
Methionine	2.91	2.19 - 3.40
Phenylalanine	5.22	4.67 - 5.60
Threonine	4.16	3.71 - 4.60
Tryptophan	1.20	0.92 - 1.50
Valine	6.37	5.40 - 7.50

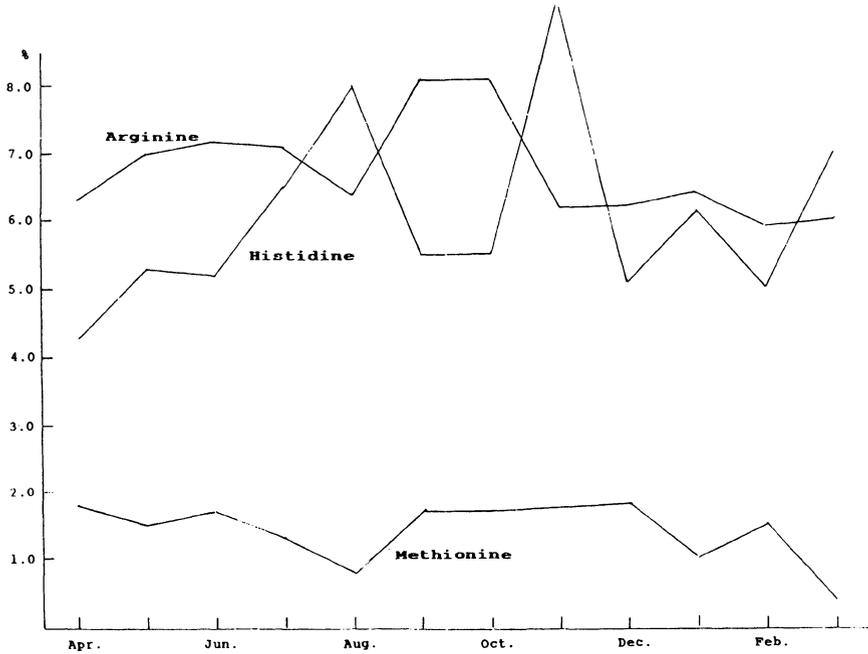


Figure 8-02. Seasonal variation of casein's amino acids^{(data from: (19))}.

Fat-soluble vitamins are associated with butterfat, hence casein contains only traces of them. The water-soluble vitamins are available in nutritionally significant amounts (Table 8-03). The content of macro and trace minerals of casein are in Table 8-03.

Table 8-03: Mineral and vitamin contents of de-hydrated casein

Minerals ^(5, 12, 31)			Vitamins (per 1,000 g) ^(5, 12, 31)		
Calcium	%	0.32	Vitamin A	I.U.	69
Phosphorus	%	0.58	Vitamin E	mg	0.5
Phosphorus, available	%	0.41	Vitamin B ₁	mg	0.40
Sodium	%	0.01	Vitamin B ₂	mg	1.50
Potassium	%	0.01	Vitamin B ₆	mg	0.63
Magnesium	%	0.01	Vitamin B ₁₂	mcg	14.00
Manganese	mg/kg	4.2	Biotin	mg	0.03
Iron	mg/kg	14.0	Folic acid	mg	0.37
Zinc	%	27.0	Nicotinic acid	mg	1.43
Copper	mg/kg	4.0	Pantothenic acid	mg	2.60
			Choline	g	208.50

Physiological Properties

The protein digestibility of casein depends on the species (Table 8-04), the period of feeding, size of the animal and the starch content of the diet. The higher the dietary starch content, the lower the protein digestibility of the casein⁽²¹⁾. The apparent digestibility in juvenile rainbow trouts (*Salmo gairdneri*) is lower than that of larger fish⁽²⁰⁾.

Table 8-04: Protein digestibility (%) of casein

Species	Digestibility	Reference
1. Apparent digestibility		
Salmonids (<i>Salmo</i> spp.)	92.0 ¹	(17,20,22,37,44)
Common carp (<i>Cyprinus carpio</i>)	92.4 ²	(17)
Channel catfish (<i>Ictalurus punctatus</i>)	92.6 ³	(17)
European eel (<i>Anguilla anguilla</i>)	99.0	(42)
Tiger prawn (<i>Penaeus monodon</i>)	97.9	(9)
2. True digestibility		
Rainbow trout (<i>Salmo gairdneri</i>)	99.0	(32)
Common carp (<i>Cyprinus carpio</i>)	99.0	(20)

¹ average of 24 analysis; ² average of 18 analysis; ³ average of 8 analysis

The Protein Efficiency Ratio (PER), Net Protein Utilisation (NPU) and the Biological Value (BV) of casein protein, range between 2.0 and 3.9, 38 and 63, and 38 and 80, respectively^(8, 28, 30, 33, 34).

The gross energy of casein-silage (33.3% dry matter) for rainbow trout is 7.27 MJ/kg (1,737 kcal/kg) and the metabolisable energy is 5.04 MJ/kg (1,205 kcal/kg)⁽⁷⁾. The digestible energy of de-hydrated casein for rainbow trout is 21.80 MJ/kg (5,210 kcal/kg)⁽²⁷⁾.

The energy digestibility of casein for the European eel (*Anguilla anguilla*) is 98.0%⁽⁴²⁾. Salinity does not affect the apparent digestibility of dry matter and protein by the tiger prawn (*Penaeus monodon*) (Table 8-05). The amino acid digestibility was lowest for phenylalanine (71.0%) and best for lysine (94.5%)⁽⁴⁵⁾.

The phosphorus availability of casein is 90% for rainbow trout, 97% for common carp (*Cyprinus carpio*) and 90% for channel catfish (*Ictalurus punctatus*)^(35, 53).

Table 8-05: Apparent digestibility of casein by penaeid shrimps

Species	Salinity ppt	Digestibility (%)		Reference
		Dry matter	Protein	
<i>Penaeus vannamei</i>	-	91.4	91.1	(2)
<i>Penaeus monodon</i>	16	84.3	93.3	(45)
	32	83.5	93.0	(45)

Other Properties

Since casein is used in technical glues it has a good pellet binding capacity and improves the water durability of aquaculture feed pellets⁽²⁷⁾. Dietary amino acids coated with casein are better utilised by the common carp than blends of amino acids and casein⁽²⁶⁾. Finally, casein is non-toxic⁽³⁶⁾.

8.4 Feeding Value

Semi-purified and Purified Diets

Semi-purified and purified research diets are made from refined ingredients with defined analysis. Casein has been found to be a good protein source for test diets and can be made vitamin-free for requirement studies. For test diets casein can be combined with gelatine in the ratio of 5:1.

Diets with casein as the major protein source could nourish test animals without showing symptoms of deficiencies or abnormal mortality rates^(16, 18, 43). On the contrary some research workers have reported lower feed intake, poorer growth rates and fatty livers when casein was the only or the major protein source of a purified test diet^(37, 38).

Fishes

About 1,000 g trout protein was produced from 2,000 g feed protein from casein as the only protein source in a rainbow trout diet^(46, 47). Lower performances were obtained when moist diets containing casein silage were fed to rainbow trout and Atlantic salmon (*Salmo salar*) (Table 8-06)⁽⁷⁾. The common carp (*Cyprinus carpio*) responded better on untreated casein than on casein hydrolysate⁽⁶⁾.

Table 8-06: Effect of preserved crude casein in moist pellets on performances of rainbow trout (*Salmo gairdneri*) and Atlantic salmon (*Salmo salar*)⁽⁷⁾

Casein	%	-	18.6	18.6
Raw fish	%	60.0	33.6	33.6
Crude protein	%	49.4	49.6	49.6

1. <u>Rainbow trout</u>				
Weight gain	g	944	900	811
Dressing percentage	%	79.1	78.5	79.0
Colour of liver	score	0.6	0.5	0.5
2. <u>Atlantic salmon</u>				
Weight gain	g	681	704	671
Dressing percentage	%	88.4	88.6	88.3
Colour of liver	score	1.5	1.6	1.4

The total replacement of protein from fish meal or krill meal by casein in diets fed to rainbow trouts resulted in poor feed conversion and insufficient growth rates. The poor effect could have been due to the low availability of some amino acids of casein and inadequate supply of non-lipid nutrients^(36, 38). Insufficient growth rates were also obtained when part of the animal protein (fish meal, feather meal, poultry offal-meal) were replaced by casein^(24, 49).

Feeding casein to rainbow trouts at varying levels also caused changes in the liver and fatty livers (Table 8-07)^(23, 36, 38).

Table 8-07: Casein as the protein source in diets fed for 100 days to rainbow trout (*Salmo gairdneri*)⁽³⁶⁾

Casein	%	20.0	40.0	40.0
Krill meal	%	30.0	-	30.0
Crude protein	%	36.3	36.4	55.4

Slaughter weight	g	114	81	159
Feed conversion	1:	1.14	1.63	0.92
Hepato-somatic index ¹		2.74	2.26	1.70

$$^1 \frac{\text{liver weight (g)} \times 100}{\text{Body weight (g)}}$$

Crustaceans

Partial replacement of short-necked clam (*Venerupis philippinarum*) by casein in purified basal diets for the kuruma prawn (*Penaeus japonicus*) did not give results comparable to the nutritional value of the protein from short-necked clam. Furthermore, supplementation of the diet with apparently deficient amino acids as well as the treatment of casein hydrolysate with various types of protease did not improve performances⁽¹⁰⁾. However, by reducing the casein level in the diet to only 17.9%, prawns performed equally well as compared to those fed the clam-protein diet. But by increasing the casein inclusion rate to 36.4%, the performances of the prawns were inferior in growth and feed efficiency (Table 8-08)⁽¹¹⁾.

Molluscs

Casein is considered as the most suitable protein source for maximising growth and survival of cultured abalone (*Haliotis* spp.) and is even better than diets containing fish meal^(13, 50, 51). Feeding the terrestrial snail *Arion ater* until maturity with casein containing diets gave adequate growth and survival while reproduction performance was poor⁽⁵⁵⁾.

Table 8-08: Replacement of clam protein by casein and other animal protein sources in diets for *Penaeus japonicus*⁽¹⁾

Casein	%	-	17.9	36.4
Clam protein	%	75.3	-	-
Other animal protein	%	-	41.6	24.4
Crude protein	%	59.3	56.5	56.7

Body weight	g	1.92	2.05	1.72
Daily feed intake	%	5.3	9.6	15.3
Weight gain	%	200.0	210.6	164.6
Feed efficiency ¹	%	67.4	38.0	21.1

$$^1 \frac{\text{Body weight (g)} \times 100}{\text{Feed intake (g)}}$$

8.5 Recommended Inclusion Rates

Casein may not be used as the only protein source, but can partly replace other protein sources. The following inclusion rates are recommended:

- Fish feed: 10 to 15% casein (de-hydrated)
- Prawn feed: 10 to 15% casein (de-hydrated)
- Mollusc feed: 20 to 30% casein (de-hydrated).

8.6 Legal Aspects

Casein is approved as a single feedstuff (No. 8.06) by the EU (EU-Directive 92/87 EEC of 26 October, 1992). The feedstuff legislation of the Federal Republic of Germany rules, that de-hydrated casein should contain not more than 12% moisture and at least 75% crude protein⁽⁵²⁾. Two different casein products are approved in the U.S.A.⁽¹⁾:

- Casein, acid precipitated and de-hydrated (min. 80% crude protein) (No. 54.16);
- Casein, hydrolysed and de-hydrated (min. 74% crude protein) (No. 54.21).

8.7 References

1. AAFCO (1995): Official publication 1995. Ass. of American Feed Control Officials (publisher), Sacramento, CA/USA.
2. Akiyama, D.M. (1988): Soybean meal utilization by marine shrimp. Proc. AOCS World Congress on Veg. Protein Utilization in Human Food and Animal Feedstuffs, Singapore, 2-7 October.

3. *Alais, C.; Jolles, P.* (1967): Isolation, purification and analysis of two k-casein-like fractions from sheep casein. *J. Dairy Sci.*, *50.*, 1555-1561.
4. *Anonymous* (w/o years): Typical amino acid profiles for casein products. New Zealand Dairy Board, Wellington, EC01.
5. *Anonymous* (w/o year): A vitamin guide for the ALA range of milk protein products. New Zealand Dairy Board, Wellington, EZ10.
6. *Aoe, H.; Abe, I.; Fukawa, H.; Koyama, H.* (1974): Nutrition of protein in young carp. II. Nutritive value of protein hydrolysates. *Bull. Jap. Soc. Sci. Fisheries*, *40.*, 375-379.
7. *Åsgård, T.; Austreng, E.* (1985): Casein silage as feed for salmonids. *Aquaculture*, *48.*, 233-252.
8. *Atack, T.; Matty, A.J.* (1979): The evaluation of some single-cell proteins in the diet of rainbow trout. In: *Halver, J.E.; Tiews, K.* (eds.): *Finfish Nutrition and Fish Feed Technology*, Hamburg, *2.*, 261-273.
9. *Catacutan, R.M.* (1994): Apparent protein digestibility of feedstuffs in *Penaeus monodon* Fabricius. (unpublished mimeograph).
10. *Deshimaru, O.* (1981): Studies on nutrition and diets of prawns, *Penaeus japonicus*. Mem. Kagoshima Pref. Fish. Exp. Station, (12), December.
11. *Deshimaru, O.* (1982): Protein and amino acid nutrition of the prawn *Penaeus japonicus*. Proc. 2nd Intern. Conf. Aquaculture Nutrition, 27 to 29 October, 106-123. (Louisiana State Univ., Baton Rouge/USA).
12. *Evans, M.* (1985): Nutrient composition of feedstuffs for pigs and poultry. Queensland Dept. of Primary Ind., Brisbane/Australia, Info. Series Q 185001.
13. *Fallu, R.* (1991): Abalone farming. Fishing News Books, Oxford/England.
14. *Friesecke, H.* (1984): Handbuch der praktischen Fütterung von Rind, Schaf, Pferd, Schwein, Geflügel und Süßwasserfischen. BLV Verlagsgesellschaft, München/Germany.
15. *Gilbert, R.* (1993): Casein country. Extrusion Communiqué, *6.*, (4), 5-6.
16. *Halver, J.E.* (1957): Nutrition of salmonoid fishes. IV. An amino acid test diet for chinook salmon. *J. Nutrition*, *63.*, 245-254.
17. *Hepher, B.* (1988): Nutrition of pond fishes. Cambridge University Press, Cambridge/England.
18. *Kanazawa, A.* (1982): Penaid nutrition. Proc. 2nd Intern. Conf. Aquaculture Nutrition, 27 to 29 October, 87-105. (Louisiana State Univ., Baton Rouge/USA).
19. *Kiermeier, F.; Kirchmeier, O.* (1963): Über fütterungsbedingte, jahreszeitliche Veränderungen der Aminosäurezusammensetzung des Caseins. *Biochemische Zeitschrift*, *337.*, 519-524.
20. *Kitamikado, M.; Morishita, T.; Tachino, S.* (1964): Digestibility of dietary protein in rainbow trout. I. Digestibility of several dietary proteins. *Bull. Jap. Soc. Sci. Fisheries*, *30.*, 46-49.
21. *Kitamikado, M.; Morishita, T.; Tachino, S.* (1964): Digestibility of dietary protein in rainbow trout. II. Effects of starch and oil contents in diets, and size of fish. *Bull. Jap. Soc. Sci. Fisheries*, *30.*, 50-54.
22. *Lall, S.P.; Bishop, F.J.* (1977): Studies on mineral and protein utilisation by Atlantic salmon (*Salmo salar*) grown in seawater. Fish. Mar. Serv. Techn. Report, (688), 1-17.
23. *Lee, D.; Wales, J.H.* (1973): Observed liver changes in rainbow trout (*Salmo gairdneri*) fed varying levels of casein-gelatine mixture and herring oil in experimental diets. *J. Fish. Res. Board Canada*, *30.*, 1017-1020.
24. *Lee, D.J.; Sinnhuber, R.O.; Wales, J.H.; Putnam, G.B.* (1978): Effect of dietary protein on the response of rainbow trout (*Salmo gairdneri*) to aflatoxin B₁. *J. National Cancer Inst.*, *60.*, 317-320.
25. *Lyster, R.L.J.* (1972): Reviews of the progress of dairy science. Sec. C. Chemistry of milk protein. *J. Dairy Sci.*, *39.*, 279-318.
26. *Murai, T.; Ogata, H.; Nose, T.* (1982): Methionine coated with various material supplemented to soybean meal diet for fingerling carp, *Cyprinus carpio*, and channel catfish, *Ictalurus punctatus*. *Bull. Jap. Soc. Sci. Fisheries*, *48.*, 85-88.

27. *New, M.B.* (1987): Feed and feeding of fish and shrimps. A manual on the preparation and presentation of compound feeds for shrimp and fish in aquaculture. UNDP/FAO/ADCP/REP/87/26, Rome, Italy.
28. *Nose, T.* (1963): Determination of nutritive value of food protein in fish. 2. Effect of amino acid composition of high protein diets on growth and protein utilization of the rainbow trout. *Bull. Freshwater Fish. Res. Lab. Tokyo*, *13.*, 41-50.
29. *Nose, T.* (1967): On the metabolic fecal nitrogen in young rainbow trout. *Bull. Freshwater Fish. Res. Lab. Tokyo*, *17.*, 97-105.
30. *Nose, T.* (1971): Determination of nutritive value of food protein in fish. III. Nutritive value of casein, white fish meal and soybean meal in rainbow trout fingerlings. *Bull. Freshwater Fish. Res. Lab. Tokyo*, *21.*, 85-98.
31. *NRC* (1983): Nutrient requirement of warmwater fishes and shellfishes. National Academy Press, Washington, D.C.
32. *Ogino, C.; Chen, M.* (1973): Protein nutrition in fish. III. Apparent and true digestibility of dietary protein in carp. *Bull. Jap. Soc. Sci. Fisheries*, *39.*, 649-651.
33. *Ogino, C.; Chen, M.* (1973): Protein nutrition in fish. IV. Biological value of dietary proteins in carp. *Bull. Jap. Soc. Sci. Fisheries*, *39.*, 797-800.
34. *Ogino C.; Nanri, H.* (1980): Relationship between the nutritive value of dietary protein for rainbow trout and the essential amino acid composition. *Bull. Jap. Soc. Sci. Fisheries*, *46.*, 109-112.
35. *Ogino, C.; Takeuchi, L.; Takeda, H.; Watanabe, T.* (1979): Availability of dietary phosphorus in carp and rainbow trout. *Bull. Jap. Soc. Sci. Fisheries*, *45.*, 1527-1532.
36. *Petrash, R.; Pfeffer, E.* (1982): Studies with rainbow trout (*Salmo gairdneri*) on the optimum level of dietary protein and on the utilisation of casein. *Arch. Tierernährung*, *32.*, (7/8), 563-568.
37. *Pfeffer, E.* (1993): Ernährungsphysiologische und Ökologische Anforderungen an Alleinfutter für Regenbogenforellen. *Übers. Tierernährung*, *21.*, 31-54.
38. *Pfeffer, E.; Petrasch, R.; Eckhardt, O.* (1980): Untersuchungen über mögliche Protein- und Fettträger in gereinigten Diäten für Regenbogenforellen (*Salmo gairdneri* R.). *Z. Tierphysiol, Tierernährg., Futtermittelkd.*, *43.*, 254-263.
39. *Resmini, P.; Semenza, F.; Zanini, A.* (1967): Studi sui lattii di diversae specie. *Ric. Sci., Parte 1, Rivista*, *37.*, 74-78.
40. *Richardson, B.C.; Creamer, L.K.* (1975): Comparative micelle structure. III. The isolation and chemical characterization of caprine B₁-casein and B₂-casein. *Biochem. Biophys. Acta*, *365.*, 133-137.
41. *Richardson, B.C.; Creamer, L.K.; Munford, R.E.* (1973): Comparative micelle structure. I. The isolation and chemical characterization of caprine k-casein. *Biochem. Biophys. Acta*, *310.*, 111-117.
42. *Schmitz, O.; Greuel, E.; Pfeffer, E.* (1984): Digestibility of crude protein and organic matter of potential sources of dietary protein for eels (*Anguilla anguilla*). *Aquaculture*, *41.*, 21-30.
43. *Schulz, D.; Hartfiel, W.; Greuel, E.* (1981): Eignung einer gereinigten Diät für vergleichende Untersuchungen an Regenbogenforellen (*Salmo gairdneri*) und Coho-Lachsen *Oncorhynchus kisutch*. *Z. Tierphys., Tierernährg., Futtermittelkd.*, *45.*, 252-261.
44. *Shanks et al.* (1964): Quoted from: *NRC* (1981).
45. *Shiau, S.-Y.; Lin, K.-P.; Chiou, C.L.* (1992): Digestibility of different protein sources by *Penaeus monodon* raised in brackish water and sea water. *J. Appl. Aquaculture*, *1.*, (3), 47-53.
46. *Takeuchi, T.; Arai, S.; Watanabe, T.; Shimma, Y.* (1978): Optimum ratio of protein to lipid for trout. *Bull. Jap. Soc. Sci. Fisheries*, *44.*, 683-688.
47. *Takeuchi, T.; Yokoyama, M.; Watanabe, T.; Ogino, C.* (1978): Optimum ratio of dietary energy to protein for rainbow trout. *Bull. Jap. Soc. Sci. Fisheries*, *44.*, 729-732.
48. *Thompson, M.P.; Kiddy, C.A.; Pepper, L.; Zittle, C.A.* (1962): Variation in the α_s -casein fraction of

individual cow's milk. *Nature*, 195., 1001-1002.

49. *Tiews, K.; Koops, H.; Beck, H.; Schwalb-Bühling, A.; Gropp, J.* (1981): Entwicklung von Ersatzfuttern für die Regenbogenforelle. Veröffentl. Inst. Küsten- und Binnenfischerei, Hamburg/Germany, No.75/1981.
50. *Ushi, N.* (1994): Quoted from: *Walker, N.* (1994).
51. *Walker, N.* (1994): A revolutionary feedingstuff. *Extrusion Communiqué*, 7., (1), 12-13.
52. *Weinreich, O.; Koch, V.; Knippel, J.* (1994): Futtermittelrechtliche Vorschriften. Buchedition Agrimedia, Hamburg/Germany.
53. *Wilson, R.P.; Robinson, E.H.; Gatlin, D.M.; Poe, W.E.* (1982): Dietary phosphorus requirement for channel catfish. *J. Nutrition*, 82., 475-482.
54. *Woodward, D.R.* (1976): The chemistry of mammalian caseins: A review. *Dairy Sci.*, 38., 137-150 (Abstr.).
55. *Wright, A.A.* (1973): Evaluation of a synthetic diet for the rearing of the slug *Arion ater*. *Comp. Biochem. Physiol.*, 45A., 593-603.

9. CHEESE SCRAP

9.1 Rationale

Cheese is a food made from the curds of soured milk or fresh milk coagulated by rennet. The major portion of cow's milk is processed in dairy factories into butter and cheese. Denmark produces not less than 40 different types of cheese amounting to 280,000 MT a year⁽⁸⁾, and the Netherlands export around 500,000 MT of a total production of 580,000 MT⁽³⁾. The entire Europe produces more than 1.7 million MT of all kinds of cheese⁽⁴⁾.

A by-product of processing, trimming and packing of cheese is cheese scrap. The available quantity of cheese scrap is unknown because it is used for making cheese spread and cheese powder for human consumption. Dairy factories also extract the protein and fat from the scrap or throw into the dairy's waste-water treatment^(6, 9, 13, 14).

9.2 Processing

There are various methods used to dry cheese scrap. But it is also fed as is or mixed with a carrier.

9.3 Chemical and Physiological Properties

Chemical Properties

Cheese scrap is both a protein and energy source. The percentage of the latter depends merely on the fat content of the cheese used as food. Analytical data are shown in Tables 9-01, 9-02 and 9-03.

Physiological Properties

Cheese protein is highly digestible. In dogs digestibility was found to be 88.7%. The digestible energy varies with the fat content. The digestible energy of cheese in dogs is 4,183 kcal/kg (17.5 MJ/kg)⁽¹⁰⁾. Cheese is also considered as a good source of biotin⁽¹²⁾.

Cheese scrap contains nitrosamines which are known to be a powerful chemical carcinogen⁽¹⁵⁾. The estimated exposure to nitroso compounds of cheese in the U.S.A amounts to 0.03 mcg per person per day⁽¹¹⁾

Table 9-01: Chemical composition of cheese and cheese scrap (in dry matter)

		Cheese ¹		Cheese scrap	
		(10)	(7)	(2)	
Dry matter	%	35.0	62.0	91.0	
Crude protein	%	41.5	23.8	37.3	
Crude fat	%	46.2	30.7	22.0	
Ash	%	6.2	3.8	6.6	
Crude fibre	%	-	-	1.1	
N-free extract	%	6.1	41.7	33.0	
Carbohydrates	%	-	3.8	-	
Protein digestibility	%	88.7	-	-	
Digestible energy	kcal/kg	4,183 ³	-	4,355 ⁴	
	MJ/kg	17.5	-	18.2	

¹ Swiss Emmental; ² Manufacturer's data; ³ in dogs; ⁴ calculated

Table 9-02: Profile of essential amino acids of cheese and cheese scrap (g/16 g N)

	Cheese ⁽¹⁰⁾	Cheese scrap ¹
Arginine	0.91	1.31
Histidine	0.73	0.94
Isoleucine	1.43	1.54
Leucine	2.26	4.17
Lysine	1.73	3.00
Methionine	0.60	0.96
Phenylalanine	1.70	1.75
Threonine	0.91	1.51
Tryptophan	0.28	0.39
Valine	1.48	1.74

¹ Manufacturer's data

Table 9-03: Macro and trace mineral and vitamin contents of cheese (in dry matter)⁽¹⁰⁾

Minerals			Vitamins (per 1,000 g)		
Calcium	%	1.01	Vitamin A	IU	9,191
Phosphorus	%	1.08	Vitamin B ₁	mg	0.7
Sodium	%	0.53	Vitamin B ₂	mg	4.8
Potassium	%	0.45	Vitamin B ₆	mg	2.65
Magnesium	%	0.01	Vitamin B ₁₂	mcg	23.1
Iron	mg/kg	16.5	Biotin	mcg	23.1
Copper	mg/kg	1.8	Nicotinic acid	mg	1.45
Iodine	mcg/kg	50.0	Pantothenic acid	mg	3.85

9.4 Feeding Value

Cheese and cheese scrap are a high quality protein source in feed formulations for poultry and dogs^(5, 10).

Cheese scrap was tested in diets for the rainbow trout (*Oncorhynchus mykiss*). Fishes of two sizes (23.0 to 25.4 cm and 5.0 to 7.5 cm) were used for the experiment. The test diets contained unprocessed cheese scrap (38% moisture) and were supplemented with some amino acids. Weight gain of the small fish responded best on the cheese scrap diet but feed efficiency was low. This indicates that the small fish may have difficulty utilising the high fat content of the test diet (22.0%) compared to the control group (5.0% fat). For the larger trout the cheese scrap diets were significantly ($P < 0.05$) superior to the control diet in both weight gain and feed efficiency. However, cheese scrap group had a larger amount of abdominal fat than the control⁽⁷⁾.

9.5 Recommended Inclusion Rates

Cheese scrap appears to be a satisfactory ingredient in the diets of fish⁽⁷⁾. Manufacturers of cheese scrap recommend inclusion rates of 3.0 to 6.0%.

9.6 Legal Aspects and Precautions

Legal Aspects

AAFCO⁽¹⁾ has listed cheese scrap under No. 54.17 as “cheese rind” which is obtained by cooking cheese trimmings devoid of fat other than milk fat. No other requirements have to be met.

Precautions

When not carefully handled and stored cheese scrap might be contaminated with mycotoxins which are toxic to aquatic organisms. Aflatoxin can penetrate as deep as 4.0 cm from the surface of a whole cheese loaf⁽¹¹⁾. Adulteration with other by-products from cheese making might cause a high salt content of the cheese scrap⁽⁵⁾.

9.7 References

1. AAFCO (1995): Official publication 1995. Ass. of American Feed Control Officials (Publisher), Sacramento, CA/USA.
2. Anonymous (1989): Alternate feeds for trout. *Feed Management*, 40., (5), 32-33. - 17 -
3. Anonymous (1993): *Lebensmittelindustrie. Agrar-Holland*, (3+4), 5.
4. De Boer, E.; Bickel, H. (1988): *Livestock feed resources and feed evaluation in Europe*. Elsevier Sciences Publishers B.V., Amsterdam/The Netherlands.
5. Feltwell, R.; Fox, S. (1978): *Practical poultry feeding*. Faber and Faber, London and Boston.
6. Hansen, R. (1989): Mejerispildevand er ikke længere noget problem. *North European Food and Dairy J.*

- 55., (2), 30-39.
7. *Haskins; Katayama* (1988): Quoted from: *Anonymous* (1989).
 8. *Imhof, W.* (1995): Private communication.
 9. *Lund, H.H.* (1995): Private communication.
 10. *Meyer, H.* (1990): Ernährung des Hundes. Verlag Eugen Ulmer, Stuttgart/Germany (2nd ed.).
 11. *Miller Jones, J.* (1992): Food safety. Eagan Press, St. Paul, Minnesota/USA.
 12. *New, M.B.* (1987): Feed and feeding of fish and shrimps - A manual on the preparation and presentation of compound feeds for shrimps and fish in aquaculture. UNDP/FAO/ADCP/REP/87/26, Rome/Italy.
 13. *Rusten, B.; Lundar, A.; Eide, O.; Ødegaard, H.* (1993): Chemical pretreatment of dairy wastewater. *Water Sci. Technology*, 28., (2), 67-76.
 14. *Schmidt, J.* (1995): Private communication.
 15. *West, G.P.* (1992): Black's veterinary dictionary. A&C Black, London, (17th ed.).

10. COCOA-POD HUSK MEAL

10.1 Rationale

Cocoa (*Theobroma cacao*) of the family *Sterculiaceae*, is the ever-green tree of 6.0 to 8.0 m height of the tropical rainforest. The cocoa bean is an old Mexican stimulant and foodstuff. From Mexico, it spread to all over the world. Africa is the major producer of cocoa beans (53% of the total world production) followed by Latin America (31.3%) and Asia (8.8%). The five most important cocoa producing countries supply almost 75% of the total production (Ivory Coast, 26.0%; Brazil, 22.9%; Ghana, 12%; Malaysia, 6.5%; Nigeria, 6.2%).

In Nigeria, more than 1.5 million MT of cocoa-pod husk are wasted annually⁽¹⁷⁾ and in Malaysia, an estimated 217,600 pods and 9,500 MT of bean shells are available⁽²²⁾. In Nigeria, cocoa-pod husk is used as organic fertilizer⁽¹⁵⁾ in soap manufacture⁽¹⁷⁾ and animal feeds^(2, 14), Cocoa-pod husk has been utilised in poultry feed⁽¹⁾, pigs⁽⁶⁾ and in ruminants^(3, 4, 5).

The use of cocoa-pod husk meal (CPHM) has been found to be a potential feedstuff in semi-intensive fish culture^(8, 9, 10, 12).

10.2 Manufacture and Processing

Cocoa berries which contain about 20 to 50 cocoa beans are fermented for the removal of the pulp. After drying, either under the sun or in a drier, the beans are screened and crushed and separated into broken cocoa beans, husks and slacks (Figure 10-01)⁽²⁰⁾.

Husks can be also sliced from fresh ripe cocoa-pods into flakes, oven-dried at 80°C to moisture content of 10 to 12%. The dry husks are then milled⁽⁹⁾.

Theobromine as well as fat, are also extracted for pharmaceutical use from the pod husks⁽²⁰⁾.

10.3 Chemical, Physiological and Other Properties

Chemical Properties

CPHM is low in protein and high in crude fibre and N-free extract and the lipid content is quite low (Table 10-01) and majority of the glycerides are available in the form of triglycerides.

The most important fatty acids of cocoa fat are:⁽²³⁾

- | | | |
|-----------------|---------|---------------|
| • Palmitic acid | 16:0 | 22.0 to 30.0% |
| • Stearic acid | 18:0 | 32.0 to 37.0% |
| • Oleic acid | 18:1n-9 | 30.0 to 37.0% |
| • Linoleic acid | 18:2n-6 | 2.0 to 4.0% |

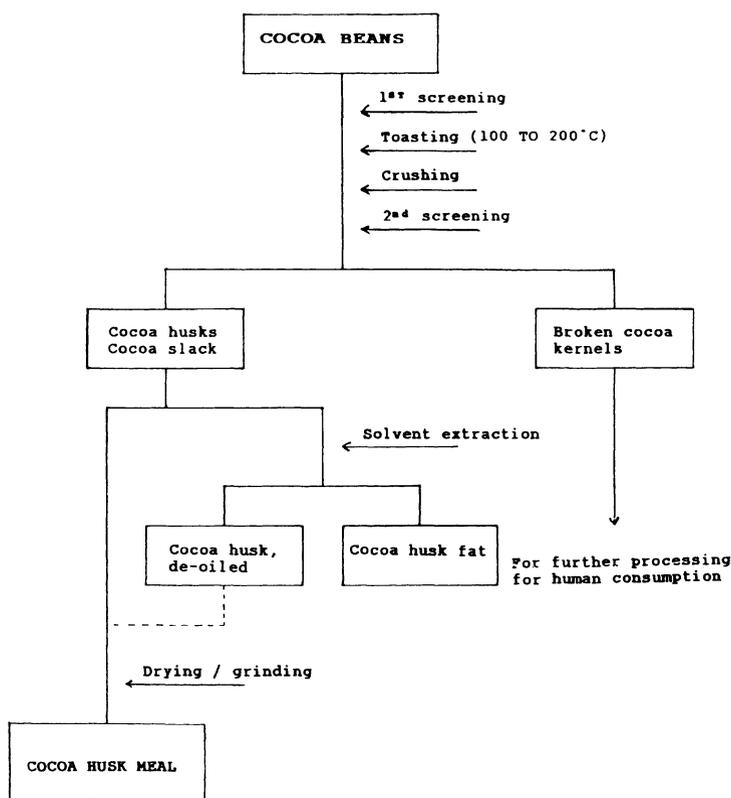


Figure 10-01. Flow diagram in the processing of cocoa beans (Data from: 20).

Table 10-01: Chemical composition (%) of heat-processed cocoa-pod husk meal (CPHM), cocoa pods, cocoa shells and cocoa beans, (10, 20)

	CPHM	Cocoa pods	Cocoa shells	Cocoa beans
Dry matter	87.7	90.4	91.8	94.0-95.0
Crude protein	9.0	6.3	8.0	17.0
Crude fat	2.5	0.5	1.7	50.0-60.0
Crude fibre	23.4	24.0	30.6	-
Carbohydrates	-	-	-	9.0
Ash	7.4	7.8	8.3	-
N-free extract	57.7	61.4	51.4	14.0
Calcium	-	0.41	0.41	-
Phosphorus	-	0.39	0.41	-
Theobromine	-	-	-	0.15
Caffeine	-	-	-	0.2

Physiological Properties

Cocoa-pod husk meal has a high gross energy content but the digestible and metabolisable energy is low. The following energy values were found in the African catfish (*Clarias isheriensis*)⁽¹¹⁾

- Gross energy: 4,293 kcal/kg (18.0 MJ/kg)
- Digestible energy: 2,146 kcal/kg (9.0 MJ/kg)
- Metabolisable energy 1,690 kcal/kg (7.1 MJ/kg)

One drawback on the use of CPHM is its theobromine content but there is no adverse effect at certain levels in the fish diet. Apparent digestibility decreases with increase in levels of CPHM (Table 10-02)⁽⁹⁾. *In vitro* dry matter digestibility and organic matter digestibility of dried, chemically treated or ensiled cocoa-pods is lower than that of fresh or frozen cocoa-pods⁽²³⁾.

Table 10-02: Apparent digestibility (%) of CPHM in diets for African catfish (*Clarias isheriensis*)⁽¹¹⁾

CPHM	0	15	30	45
Dry matter	83.0	75.9	73.5	69.7
Protein	85.0	76.9	72.6	69.0
Fat	86.2	78.3	76.0	75.7
Crude fibre	71.3	65.3	63.1	61.4
N-free extract	82.1	77.8	77.6	77.7

Other Properties

Theobromine (C₇H₈O₂N₄) a 3, 7-dimethylxanthine is a bitter, crystalline and toxic alkaloid. It has diuretic and corona-widening properties⁽²⁰⁾. A high theobromine content is due to fermentation of the shells before drying. Combined heat and chemical treatment can reduce theobromine markedly^(16,18). Cocoa-pod husk meal contains much lower theobromine than other cocoa by-products. Depressed digestibility may be caused also by tannins and related phenols⁽⁷⁾. Theobromine has deleterious effects on animals which may restrict the use of cocoa by-products⁽¹⁹⁾. However, an intake of 24 mg theobromine per kg liveweight did not harm sheep or cattle⁽²²⁾.

10.4 Feeding Value

CPHM has been studied as an alternative energy source in low cost diets for the African catfish where up to 45% maize was replaced⁽¹²⁾. With increasing levels of CPHM in the diet, the performances declined due to the increasing content of crude fibre and theobromine (Table 10-03)⁽⁹⁾. A protein:energy ratio of 120 mg protein:1.0 kcal digestible energy is required for optimum growth and maximum body protein deposition in African catfish⁽¹¹⁾.

Cocoa-pod husk has been also found to be useful in supplemental diets in semi-intensive culture of Nile tilapia (*Oreochromis niloticus*) and common carp (*Cyprinus carpio*)^(8, 13).

Table 10-03: Performances by African catfish (*Clarias isheriensis*) fed increasing levels of CPHM for 180 days⁽⁹⁾

CPHM	%	0	15	30	45
Mean initial weight	g	60.42	60.42	60.42	60.42
Mean final weight	g	225.24	220.52	213.97	210.86
Mean weight gain	g	164.82	160.10	158.55	150.44
SGR/day	%	0.73	0.72	0.72	0.69
PER		1.46	1.39	1.30	1.28
Feed conversion	1:	1.85	1.94	2.07	2.11

10.5 Recommended Inclusion Rates

Cocoa-pod husk meal may serve as an energy feedstuff for less demanding fish species in extensive fish culture. The crude fibre content is the limiting factor. Levels between 15 and 25% in diets for these species of fish are recommended.

10.6 Legal Aspects

Trading of cocoa-pod husk meal is not allowed in certain countries⁽²⁰⁾. In Germany, only the meal of solvent extracted cocoa beans is a permitted feedstuff⁽²¹⁾, which must meet the following requirements:

- Moisture: max. 13.0%
- Crude protein: min. 23.0%
- Crude fat: max. 4.0%

According to German feedstuff legislation theobromine is an undesirable substance, and not more than 300 ppm are permitted in a single feedstuff⁽²¹⁾.

10.7 References

1. Adeyanju, S.A.; Ogotuga, D.B.A.; Illori, J.O.; Adegbola, A.A. (1975): Cocoa husk in poultry diets. Mal. Agric. Res., 4., 131-136.
2. Aletor, V.A. (1986): Agro-industrial by-products and wastes in livestock feeding. World Review of Animal Production, 22., 35-41.

3. *April, R.D.; Ellenberger, H.B.* (1927): Effect of feeding cocoa meal to milking cows. *Vt. Agr. Exp. Sta. Bull.*, No. (272), 3-19.
4. *Bateman, J.F.; Larrangan, A.* (1966): El uso de cassava de cocoa en raciones pars al engorde de bovinos. *Turrialba*, 16., 25-28.
5. *Bateman, J.V.; Frensillo, O.* (1967): Digestibility of theobroma cocoa-pods when fed to cattle. *J. Agric. Sci.*, 68., 23-28.
6. *Braude, R.; Foot, A.S.* (1942): Cocoa by-product in pig feeding: cocoa cake meal and detheobrominated cocoa-cake meal as feedingstuffs for pigs. *Emp. J. Expt. Agric.*, 10., 182-189.
7. *Devendra, C.* (1985): Non-conventional feed resources in Asia and the Pacific. 2nd ed. FAO Regional Animal Production and Health Commission for Asia, the Far East and the South-West Pacific, Bangkok/Thailand.
8. *Fagbenro, O.A.* (1988): Results of preliminary studies on the utilization of cocoa-pod husks in fish production in South-West Nigeria. *Biological Wastes*, 25., 233-237.
9. *Fagbenro, O.A.* (1992): Utilization of cocoa-pod husk in low-cost diets by the clarid catfish (*Clarias isheriensis* Sydenham). *Aquaculture and Fisheries Management*, 23., 175-182.
10. *Fagbenro, O.A.* (1995): Evaluation of heat processed cocoa-pod husk meal as energy feedstuff in production diets for the clariid catfish (*Clarias isheriensis*, Sydenham). *Aquaculture Nutrition*, 1., 221-225
11. *Fagbenro, O.A.* (1996): Apparent digestibility of crude protein and gross energy in some plant and animal-based feedstuffs by *Clarias isheriensis* (Siluriformes: Claridae) (Sydenham, 1980). *J. Appl. Ichthyol.* 12., 67-68.
12. *Fagbenro, O.A.; Sydenham, D.H.J.* (1988): Evaluation of *Clarias isheriensis* (Sydenham) under semi-intensive management in ponds. *Aquaculture*, 74., 287-291.
13. *Falaye, A.E.* (1987): Utilization of cocoa husk in the nutrition of tilapia (*Oreochromis niloticus* Twevavas, 1985) under tropical conditions. University of Ibadan/Nigeria (Mimeograph).
14. *Fetuga, B.L.; Tewe, O.O.* (1984): Potentials of agro-industrial by-products and crop residues as animal feeds. *Nigeria Food Jour.*, 2., 136-142.
15. *Oladokun, M.A.O.* (1986): Use of cocoa-pod husk as fertilizer for maize production. *Nigerian J. Agronomy*, 1., 103-109.
16. *Omole, T.A.* (1970): An investigation into the use of discarded cocoa beans on the metabolism of growing pigs. M.P.H. Thesis, Univ. of Ife/Nigeria.
17. *Opeke, L.K.* (1984): Optimising economic returns from cacao cultivation through efficient use of cocoa by-products. Proc. 9th Inter. Cocoa Res. Conf. 489-493, (Lome/Togo, Cocoa Producers Alliance, London).
18. *Orok, E.F.; Bowland, J.P.* (1974): Nigeria cocoa husk and cassava meal as sources of energy for rats fed soybean meal or peanut meal supplemented diets. *Can. J. Anim. Sci.*, 54, 229-238.
19. *Owusu-Domfeh, K.* (1972): The future of cocoa and its by-products in the feeding of livestock. *Ghana, J. Agri Science*, 5., 57-64.
20. *Täufel, A.; Ternes, W.; Tunger, L.; Zobel M.* (1993): *Lebensmittel-Lexicon*. Behr's Verlag, Hamburg/Germany.
21. *Weinreich, O.; Koch, V.; Knippel, J.* (1994): *Futtermittelrechtliche Vorschriften*. Buchedition Agrimedia, Hamburg/Germany.
22. *Wong, H.K.; Abu Hassan, O.; Mohd. Sukri, H.I.* (1987): Utilization of cocoa-by products as ruminant feed. In: *Dixon, R.M.* (ed.): *Ruminant feeding systems utilizing fibrous agricultural residues*, 1987. Intern. Dev. of Australian Universities and Colleges Ltd. Canberra/Australia.
23. *Wong, H.K.; Osman, A.H.; Kumaran, N.* (1987): The effects of drying, ensilage and alkali treatment on *in vitro* digestibility of cocoa-pods. In: *Dixon, R.M.* (ed.): *Ruminant feeding systems utilizing fibrous agricultural residues*, 1986. Intern. Dev. of Australian Universities and Colleges Ltd. Canberra/Australia.

11. COFFEE PULP (DE-HYDRATED)

11.1 Rationale

Coffee is a drink brewed from coffee beans that comes from the tropical shrub of the genus *Coffea*, botanical family *Rubiaceae*. Coffee beans are the shrub's seeds embedded in red berries. The botanical variety and the area where the coffee is grown are factors that determine the quality of the coffee.

World-wide, about 5.5 to 6.0 million MT green coffee beans are produced a year, of which more than 50% are grown in Central and South America. The coffee seed amounts to about 20 to 25% of the weight of the red coffee berry. This means that a total of about 18 to 20 million MT of fresh coffee pulp is annually available. Only a small amount is used as fertiliser for coffee plantations and as feed for cattle. The major portion of the available coffee pulp is a pollutant to the environment.

Coffee hulls and spent coffee, the residues of instant coffee production, are not suitable as a feedstuff for aquaculture^(3, 6).

11.2 Processing

The coffee bean is obtained by either removing the fruit-flesh (wet process) by fermentation or by removing the flesh mechanically from the seed. After that the beans are dried under the sun⁽¹²⁾. Fresh coffee pulp which deteriorates quickly, if not preserved by drying, consists of the exocarp (outer fruit skin), the fruit-flesh and the seed skin (endocarp)^(1, 10).

11.3 Chemical, Physiological and other Properties

The chemical composition of the individual components of coffee pulp (exocarp, fruit-flesh, endocarp) is considerably different (Table 11-01). Dried coffee pulp has a crude protein content similar to that of maize. The amino acid composition is given in Table 11-02. Crude fibre, ash content and also N-free extract are high. Coffee pulp, therefore, is merely an energy feedstuff (Table 11-02).

The fat of coffee pulp contains:

- Palmitic acid (C16:0) 28%
- Stearic acid (C18:0) 13%
- Oleic acid (C18:1) 17%
- Linoleic acid (C18:2) 36%.

The unsaponifiable matter is around 28% and contains among others γ -sitosterine and di-terpenoids⁽¹²⁾.

Coffee pulp also contains alkaloids and hydrocarbons such as caffeine (2.0%), tannic acid (5.0%), polyphenols (3.0%) and chlorogenic acid⁽¹⁾. In seed skin 0.25% caffeine were found but in hulls only 0.07 to 0.12%⁽¹⁰⁾. High mortalities and weight losses were observed in chicks and rats when diets contained 30 to 50% coffee pulp. Fermentation of the pulp not only reduces and eliminates the toxic effects⁽⁴⁾ but also lowers the palatability of the dry pulp when fed to steers⁽⁵⁾.

Table 11-01: Chemical composition of the components of coffee pulp and spent coffee⁽¹⁰⁾

		Exocarp	Fruitflesh (dried)	Endocarp	Spent coffee (dried)
Dry matter	%	85.5	96.4	89.6	91.3
Crude protein	%	8.6	6.6	2.9	13.2
Crude fat	%	1.6	2.4	0.5	6.9
Ash	%	6.8	7.8	1.4	5.1
Crude fibre	%	31.0	-	63.7	33.9
N-free extract	%	-	-	24.5	31.2

Table 11-02: Essential amino acid content of dried coffee pulp⁽¹¹⁾

Arginine	%	0.55
Isoleucine	%	0.47
Leucine	%	0.86
Lysine	%	0.76
Methionine	%	0.15
Phenylalanine	%	0.55
Threonine	%	0.52
Valine	%	0.83

11.4 Feeding Value

Coffee pulp has been used as cattle feed at various inclusion rates. With increasing levels of coffee pulp in the ration, the weight gain and feed conversion decreased. However, coffee pulp inclusion of 10% gave a favourable economic conversion^(7, 9).

In tilapia (*Tilapia aurea*) a supplementary feed containing 30% coffee pulp was evaluated against a feed without coffee pulp as a positive control. Compared with the

control group there were no significant differences in mean weight gain and feed conversion (Table 11-03). Coffee pulp was efficiently and economically converted into fish flesh⁽¹⁾.

Table 11-03: Effect of dried coffee pulp in the diet for male tilapia (*Tilapia aurea*) fingerlings (trial period: 70 days)⁽¹⁾

		Trial	Control	
			Positive	Negative ¹
Coffee pulp	%	30	-	-
Wheat bran	%	10	25	-
Groundnut seeds	%	24	24	-
Cottonseed meal	%	15	9	-

Fishes	Nos.	100	100	100
Initial liveweight	g	50	51	56
Final liveweight	g	92	94	79
Daily weight gain	g	1.21	1.24	1.06
Feed conversion	1:	1.95	1.96	N/R ²

¹ Chicken manure as the only feed; ² Not recorded

Coffee pulp at a level of 30% in the diet of common carp (*Cyprinus carpio*) and catfish (*Clarias mossambicus*) did result in decreased growth rates compared to the control group. Daily weight gain of common carp was reduced by 79.3%. Catfish which were tested in earthen pond, floating cages and concrete tanks showed, for all treatments, daily growth rates which were 45% lower than in the control group. Hence it was concluded that the low cost coffee pulp is not an economical feed ingredient for common carp and cat fish⁽²⁾.

11.5 Recommended Inclusion Rates

Coffee pulp may be a feed component for fish species that are not very demanding as to the feed quality. The inclusion rate of dried coffee pulp in fish diets should not exceed 10 to 12%.

11.6 Legal Aspects and Precautions

German legislation prohibits trading of coffee pulp because it does not meet the requirement of a feedstuff⁽¹⁰⁾. Otherwise no legal restrictions are known. However, due to the

relatively high content of substances with toxic properties, the use of coffee pulp in feed for aquatic animals should be carefully considered. Caffeine received a category III GRAS-rating. This indicates that the use of caffeine is not a hazard but uncertainties exists. Polyphenols, tannic acid and chlorogenic acids are naturally occurring toxicants⁽⁸⁾.

11.7 References

1. Bayne, D.R.; Dunseth, D.; Ramirios, C.G. (1976): Supplemental feeds containing coffee pulp for rearing tilapia in Central America. *Aquaculture*, 7., 133-146.
2. Christensen, M.S. (1981): Preliminary tests on the suitability of coffee pulp in the diets of common carp (*Cyprinus carpio*) and catfish (*Clarias mossambicus*). *Aquaculture*, 25., 235-242.
3. Devendra, C. (1985): Non-conventional feed resources in Asia and the Pacific. FAO-UN, Reg. Anim. Prod. and Health Commission, Bangkok (2nd ed.).
4. Flores Soriano, J.A. (1970): Contribucion al estudio de la pulpa de café en la alimentacion del ganado. Thesis Univ. Veracruzana, Veracruz.
5. Fonseca, H.A. (1973): Need for new improved technology in the processing of feeds in Latin America. College Agric. Univ. Costa Rica (Mimeograph).
6. Hertrampf, J.W. (1980): Mischfutter 2000. Die Mühle + Mischfuttertechnik, 117., (19), 235-238.
7. Jaraqu'n, R.; Bressani, R.; Gonzales, J.M.; Braham, E. (1971): Pulpa de café en alimentacion de ruminantes. Mem. Assoc. Latino-Americano Prod. Animale, Mexico, (1).
8. Miller Jones, J. (1992): Food safety. Eagan Press, St. Paul, Minnesota/USA.
9. Osegueda, F.L.; Quiteno, R.A.; Martinez, R.A.; Rodriguez, C.M. (1969): Uso de la pulpa café seca en el engorde de nonllos en confinamento. *Agric. El Salvador*, 10., (1), 3-9.
10. Stählin, A. (1957): Methodenbuch, Vol. XII. Die Beurteilung der Futtermittel. Neumann Verlag, Radebeul and Berlin/Germany.
11. Tacon, A.G.J. (1993): Feed ingredients for warmwater fish, fish meal and other processed feedstuffs. FAO Fisheries Circular No.C 856 (FIR/C 856), FAO-UN, Rome/Italy.
12. Täufel, A.; Ternes, W.; Tunger, Liselotte; Zobel, M. (1993): Lebensmittel-Lexikon. Behr's Verlag, Hamburg/Germany.

12. CRAB MEAL

12.1 Rationale

Crabs are crustaceans and belong to the zoological order of *Decapoda* and the huge class of gill-breathing *Articulata* and are important for human nutrition. They are found in cold and warm waters, and live in freshwater and seawater⁽²⁰⁾.

World-wide about 1,720,800 MT of crabs were landed in 1993⁽⁶⁾. Crab meal is a by-product from the processing of crabs for canning and deep-freezing. Depending on the mode of processing and the species, about 60 to 80% of a crab is offal⁽²⁰⁾, composed of shells, viscera and unextracted meat. Waste as well as whole animals from various species are used for producing crab meal^(3, 8, 21, 23).

12.2 Manufacture and Processing

Crab meal is produced by drying the waste from crab processing and/or whole crabs. Screening the crab waste prior to drying to remove the larger portion of shells, improves the nutrient content of the crab meal. Sun-drying, produces poor quality crab meal, due to the fast deterioration of the material. The use of drying equipment gives better quality meal. After drying, the product is ground and screened⁽²¹⁾.

Crab protein concentrate is obtained from deboned crabs and purifying the meat with isopropanol (Figure 12-01).

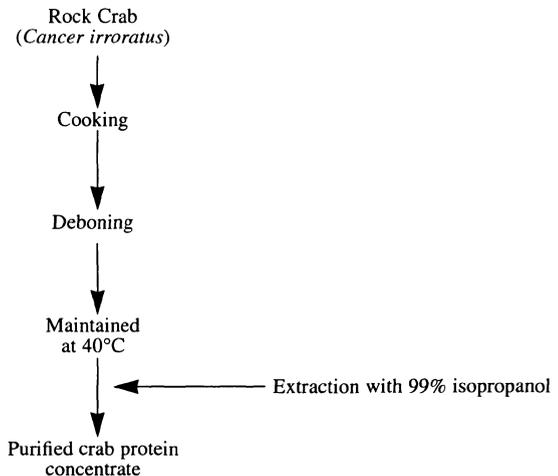


Figure 12-01. Flow diagram for processing of crab protein concentrate⁽⁴⁾.

12.3 Chemical, Physiological and other Properties

Chemical Properties

The chemical composition of crab meal is rather heterogeneous due to the variability of the raw material. The average crude protein is about 32.2% with a wide variation (Table 12-01)⁽⁸⁾. Pure crab meal contains 89% protein⁽²⁰⁾. Crab protein concentrate on the other hand has a crude protein content almost double that of crab meal (Table 12-01). The highest protein content is in the shoulder of the snow crab (*Chionoecetes opilio*) (24.0%) and the lowest is in the legs (15.7%). While the lysine content is relatively high, the methionine content is low (Table 12-02), the lysine:methionine ratio for crab meal and crab protein concentrate is 2.6 and 2.9, respectively⁽¹⁵⁾.

Table 12-01: Chemical composition of crab meal, crab protein concentrate and pure crab meal

	Crab meal (as fed) (7, 11, 12, 19, 21)		Crab protein concentrate (as fed) ⁽¹²⁾
	Mean	Variation	
Dry matter	92.7	92.0 - 93.5	90.0
Crude protein	32.2	31.0 - 37.6	60.5
Crude fat	2.8	2.0 - 5.0	0.4
Ash	39.4	36.1 - 41.2	6.1
Crude fibre (chitin)	10.6	10.5 - 10.7	-
Carbohydrate (glucose)	21.6	-	-
N-free extract	7.7	-	-

Table 12-02: Essential amino acid profile of crab meal and crab protein concentrate (g/16 g N)

	Crab meal (12, 15, 17, 21)		Crab protein concentrate (12, 15, 17, 22)	
	Mean	Variation	Mean	Variation
Arginine	1.94	1.6 - 2.5	6.48	5.5 - 7.6
Histidine	0.93	0.5 - 1.8	2.76	2.3 - 3.6
Isoleucine	1.62	1.2 - 2.5	3.36	2.7 - 3.7
Leucine	2.24	1.5 - 3.6	5.56	5.1 - 6.0
Lysine	2.26	1.4 - 4.0	4.19	2.5 - 6.7
Methionine	0.86	0.5 - 1.2	1.43	0.8 - 2.1
Phenylalanine	1.38	1.2 - 1.8	5.44	5.1 - 6.0
Threonine	1.03	1.0 - 1.1	4.00	3.5 - 4.7
Tryptophan	0.67	0.3 - 1.3	1.18	0.8 - 1.6
Valine	1.82	1.5 - 2.5	6.39	5.0 - 7.9

The mean fat content of crab meal is low (Table 12-01). However, crab meal is rich in poly-unsaturated fatty acids (38.6%) which are essential for penaeid shrimps⁽²⁾. Furanoid fatty acids also referred to as "F-acids" have been found in tissues of crayfish (*Procambarus clarkii*), particularly in the hepato-pancreas. They are components of cholesteryl esters and triglycerides⁽¹⁸⁾.

The crude fibre content of about 10% is moderately high due to the presence of chitin which has a molecular structure similar to that of cellulose (Table 12-01)⁽¹⁴⁾. The chitin content of snow crab averages to 16%⁽¹³⁾. The highest chitin content was found in softshell crab backs (32.3%) and legs (32.3%) and lowest in hardshell crab backs (18.7%)⁽¹⁵⁾.

The high ash content of crab meal (Table 12-01) is due to the exoskeleton of crabs which is particularly high in calcium (Table 12-03) with levels between 9.0 and 21%⁽⁷⁾. There is little information on the vitamin content of crab meal but the contents of Vitamin B₁₂ and choline are relatively high (Table 12-03). Crabs are rich in carotenoids whose distribution in the different parts of the crab vary widely. The back parts of the exoskeleton have the highest pigment content (14.0%)⁽¹⁵⁾.

Table 12-03: Mineral and vitamin contents of crab meal and crab protein concentrate

Minerals		Vitamins (per 1,000g)				
		Crab Meal (12, 31)	Crab protein concentrate ⁽¹²⁾	Crab Meal ⁽¹²⁾		
Calcium	%	16.03	0.10	Vitamin B ₁	mg	0.5
Phosphorus	%	1.72	0.66	Vitamin B ₂	mg	6.7
Sodium	%	0.99		Vitamin B ₆	mg	7.2
Potassium	%	0.51		Vitamin B ₁₂	mcg	475.0
Magnesium	%	0.99		Biotin	mg	0.07
Chlorine	%	1.64		Folic acid	mg	0.1
Sulphur	%	0.31		Nicotinic acid	mg	49.0
Manganese	mg/kg	145		Pantothenic acid	mg	7.0
Iron	mg/kg	4,724		Choline	g	2.18
Copper	mg/kg	35.3				
Iodine	mg/kg	2.6				

Physiological Properties

Limited information on energy values of crab meal are available. They are in Table 12-04. The digestibility of whole crab (dehydrated) in rainbow trout (*Salmo gairdneri*) is 71.9% for protein and 85.1% for energy⁽¹⁷⁾. The relatively low protein digestibility may be due to the high ash content of crab meal and the practically indigestible, tough and horny polysaccharide chitin^(10, 21).

Table 12-04: Energy values of crab meal per kg

	Gross energy		Metabolisable energy		Digestible energy		Reference
	kcal	MJ	kcal	MJ	kcal	MJ	
	3,983	16.7	-	-	-	-	(20)
Rainbow trout	-	-	3,214	13.4	3,878	16.2	(16)
Fish ¹	-	-	2,957	12.4	-	-	(11)
Pigs	-	-	-	-	1,380	5.8	(21)

¹ species not stated

Other Properties

Crab meal is a good source of cholesterol and an excellent chemo-attractant⁽¹³⁾. In addition, it supplies phospholipids.

12.4 Feeding Value

Crab meal and crab protein concentrate are preferably used in crustacean diets rather than in fish diets as a protein source and chemo-attractant.

Crab Meal

In diets for post-larvae and juvenile brown shrimp (*Penaeus californiensis*) red crab meal replaced shrimp meal. The post-larvae shrimps responded better on crab meal than the juveniles (Table 12-05)^(22, 23).

Table 12-05: Response of the brown shrimp (*Penaeus californiensis*) post-larvae and juveniles fed diets containing crab meal instead of shrimp meal⁽²³⁾ (Basal crude protein:38%)

Crab meal	%	0	10
Fish meal	%	25	25
Shrimp meal	%	10	0
Soy bean meal	%	27	27

Post-larvae:			
Daily weight gain	g	0.350	0.044
Survival	%	85.0	85.0
Feed conversion	1:	5.0	4.1
Juveniles:			
Daily weight gain	g	0.040	0.037
Survival	%	66.7	70.0
Feed conversion	1:	4.1	4.4

Feeding crab meal as supplemental food for hard clam juveniles (*Mercenaria mercenaria*) for 30 days showed that growth from final and dry weight were 2.5 times significantly greater in the crab meal-fed clams than those of the non-fed control which were kept only in flowing seawater⁽⁵⁾.

Crab Protein Concentrate

Crab protein concentrate is a suitable protein source for purified diets for crustacean nutrition research⁽⁴⁾. Crab protein concentrate, and other animal and vegetable proteins were used in determining the effect of protein on energy utilisation of kuruma prawn (*Penaeus japonicus*). The better growth of prawns fed crab protein concentrate was due to the efficient energy utilisation and the better digestibility of the crab protein compared to fish meal with its lower digestibility⁽⁸⁾.

12.5 Recommended Inclusion Rates

Recommended inclusion rates for crustacean feed:

- Crab meal 5.0 to 10.0%
- Crab protein concentrate 5.0 to 15.0%

These inclusion rates provide sufficient chemo-attractant power. Pelletising will be more difficult if higher levels are used and crab meal will provide too much calcium to the diet.

12.6 Legal Aspects and Precautions

Legal Aspect

By-products of the processing of crustaceans are permitted as feedstuff by German feedstuff legislation. It should contain not more than 4.0% ash and 12.0% moisture. Crude protein, crude ash, and CaCO₃ content have to be declared on the label⁽²⁴⁾.

Crab meal (AAFCO No. 51.4) in the United States has to contain not less than 25% crude protein. A salt (NaCl) content of more than 3.0% has to be declared. In no case must the salt content of crab meal exceed 7.0%⁽¹⁾.

Precaution

The use of a good quality crab meal is important because a nearly all shell crab meal has very little feeding value⁽¹⁰⁾. Crab meal is prone to contamination with salmonella. Requirements of the USA Feed and Drug Administration, therefore, have to be observed. Not properly heated and processed crab meal also may be contaminated with other microbe-producing toxins⁽⁹⁾.

12.7 References

1. AAFCO (1995): Official Publication 1995. Ass. of American Food Control Officials (publisher). Sacramento, CA/USA.

2. *Akiyama, D.M.; Dominy, W.G.* (1989): Penaeid shrimp nutrition for the commercial feed industry. In: Texas Shrimp Farming Manual, vol. 1. Grow-Out Technology. Texas Agricultural Extension Services and Texas A&M University Sea Grant College Program. 50.
3. *Castell, J.D.* (1989): Reference diet for crustaceans: Principles of experimentation. *Advances in Tropical Aquaculture, Tahiti*, Aquacop Ifremer Actes de Colloque, 9., 339-354.
4. *Castell, J.D.; Kean, J.C.; McCann, D.G.C.; Boghen, A.D.; Conklin, O.E., D'Abranno L.R.D.* (1989): A standard reference diet for crustacean research. II. Selection of a purification procedures for production of the rock crab (*Cancer irroratus*) protein ingredient. *J. World Aqua.Soc.* 20., 100.
5. *Duncan, P.L.; Castagna, M.; DuPaul, W.D.* (1984): Preliminary data on the use of crab meal as a supplemental food for juveniles of *Mercenaria mercenaria* (Linné). *J. Shellfish Res.*, 4., 87.
6. Globefish, 1995. The world market for crabs. FAO/Globefish research program Vol. 37, Rome/FAO.
7. *Johnson, D.* (1988): Crab meal as feed for hogs. Prince Edward Isl. Agric. and Food Dev. Sub-Agreement Rep., Technology Dev. 1-53.
8. *Koshio, S.; Tasuno, K.; Teshima, S.; Kanazawa, A.* (1995): The effect of protein sources on the energy budget of juvenile kuruma prawn, *Penaeus japonicus*. 5th International Working Group on Crustacean Nutrition Symp., 22 to 24 April, Kagoshima University, Kagoshima, Japan. (Abstr.).
9. *Miller Jones, J.* (1992): Food safety. Eagan Press, St. Paul, Minnesota/USA.
10. *New, M.B.* (1987): Feeds and feeding of fish and shrimp - A manual on the preparation and presentation of compound feeds for shrimp and fish in aquaculture. UNDP/FAO/ADCP/REP/87/26 Rome.
11. *NRC* (1981): Nutrient requirements of coldwater fishes. National Academy Press, Washington D.C.
12. *NRC* (1983): Nutrient requirements of warmwater fishes. National Academy Press. Washington D.C.
13. *Paulraj* (1995): Aquaculture: Marine Prod. Export Dev. Authority. Kochi/India 2nd ed. (Publisher).
14. *Pond, W.G.; Maner, J.H.* (1994): Swine production and nutrition. AVU Publishing Co., Westport, Connecticut/USA.
15. *Shahidi, F.; Synowiecki, J.* (1991): Isolation and characterization of nutrients and value-added products from snow crab (*Chionoecetes opilio*) and shrimp (*Pandalus borealis*) processing discards. *J. Agric. Food Chem.*, 39., 1527-1532.
16. *Smith, R.R.; Peterson, M.C.; Allred, A.C.* (1980): The effect of leaching on apparent digestion coefficients in determining digestibility and metabolizable energy of feedstuffs for salmonids. *Prog. Fish. Cult.*, 42., 195-199.
17. *Spinelli, J.; Lehman, L.; Wieg, D.* (1975): Composition processing and utilization of red crab (*Pleuroncodes planipes*) as an aquacultural feed ingredient. *J. Fish. Res. Board Can.*, 31., 1025-1029.
18. *Stansby, M.E.; Schlenk, H.; Gruger, E.G.* (1990): Fatty acid composition of fish. In: *Stansby, M.E.* (ed.): Fish oils in nutrition. Van Norstrand Reinhold, New York/USA.
19. *Tacon, A.G.J.* (1987): The nutrition and feeding of farmed fish and shrimp. 2. A training manual on nutrient sources and composition. Field Document 5/E GCP/RLA/075/ITA, FAO. 129 pp. Brasilia/Brazil.
20. *Täufel, A.; Ternes, W.; Tunger, L.; Zobel, M.* (1993): Lebensmittel-Lexikon Behr's Verlag, Hamburg/Germany.
21. *Van Lunen, T.A.; Anderson, D.M.* (1990): Crab meal. In: *Thacker, P.A.; Kirkwood, R.N.* (eds.): Nontraditional feed sources for use in swine production. Butterworths Publishers, Stoneham, MA/USA.
22. *Villareal, H.; Castro, M.P.* (1992): Preliminary studies on the effect of protein content on the growth of *Penaeus vannamei* at marine salinities. *Aquaculture'92: Growing Toward the 21st Century.* 225-226. (Summary only).
23. *Villareal, H.; Rivera, M.C.; Millan, A.* (1991): *Penaeus californiensis*. The Crustacean Nutrition Newsletter, 7., (1), 12-23.
24. *Weinreich, O.; Koch, V.; Knippel, J.* (1994): Futtermittrechtliche Vorschriften. Buchedition Agrimedia. Hamburg/Germany.

13. DISTILLERY BY-PRODUCTS

13.1 Rationale

Fermentation and distillation of alcohol from grains has been known for at least 10,000 years⁽⁴⁾. The earliest recorded reference to distilling whisky in Scotland dates back to 1494⁽³⁾. The recovery of materials from grains which has undergone fermentation (distillers' feed) was developed by the beverage distilling industry⁽⁸⁾.

Originally distillers' feeds were by-products from malted barley only. Nowadays, all kind of grains are used for transforming starch into spirit⁽²⁾. There are four different products of distillers' feed⁽⁸⁾:

- Distillers' dried grains (DDG)
- Distillers' dried solubles (DDS)
- Distillers' dried grains with solubles (DDGS)
- Condensed distillers' solubles (CDS).

Current annual production of distillers' dried grains in USA exceeds one million tonnes. Twenty kg distillers' dried grains (90% dry matter) and 12.6 kg distillers' dried solubles (90% dry matter) are recovered after de-alcoholisation from 100 kg maize⁽⁷⁾.

13.2 Manufacture and Processing

Distillers' grains are simply spoken "grains minus the starch". They are obtained from the de-alcoholised fermentation residues which remain after grains have been fermented by the yeast species *Saccharomyces cerevisiae*. All the important starchless nutrients are recovered as distillers' grains by condensing the remaining nutrients after starch removal⁽⁶⁾. Because of the high moisture content fresh distillers' grains cannot be stored, particularly under hot weather conditions. To make them an easy to handle feedstuff, they have to be drum-dried and preferably pelletised.

"Light" distillers' dried grains (DDG) are obtained when the whole stillage is screened for the removal of the coarser particles, pressing out the excess water and drying. "Dark" distillers' dried grains (DDG) are derived from processing the whole stillage. The latter is more common^(3, 8).

The "thin stillage" is very watery, but contains large quantities of water soluble material (e.g. protein, vitamins). The dry matter content amounts to 4.0% only. Thin stillage is also named "pot ale", if it comes from a malt distillery and "spent wash", if the source is from a grain distillery⁽³⁾.

Condensed distillers' solubles (distillers' syrup) (CDS) are derived from condensing the material to a dry matter content of 40 to 50%. Distillers' dried solubles (DDS) is then the spray or drum dried "pot ale syrup" and "evaporated spent wash", respectively

(Figure 13-01)⁽³⁾. Condensed distillers' solubles are not used in the feed milling industry as a feedstuff.

Distillers' dried solubles (DDS) is a superior feedstuff. Since its processing is costly, the distilling industry adds back the condensed distillers' solubles to the press cake prior to drying⁽¹⁷⁾. "Distillers' dried grains with solubles" (DDGS) is now the prevailing distillery by-product. It represents over 95% of the distillers' feeds used in animal feed such as in pig formulations⁽²⁴⁾.

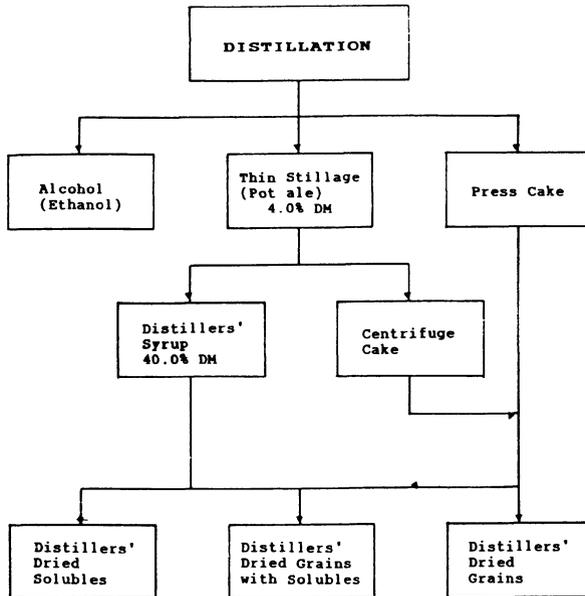


Figure 13-01. Diagram of the processing of distillers' dried feeds.

13.3 Chemical, Physiological and other Properties

Chemical Properties

The chemical composition of distillers' feeds is influenced by the raw materials used as well as by the processing procedure and the type of equipment used in distillation⁽⁵⁾.

In general, distillers' dried products are medium high protein feedstuffs (Table 13-01). Wheat DDG have the highest crude protein content while rye DDG have the lowest (Figure 13-02). However, the quality of the protein is not satisfactory due to an imbalance of several amino acids (Table 13-02)⁽²⁴⁾.

The fat content of maize DDG is considerably higher than those of other grains used for distilling. The fat of maize DDG is rich in linoleic acid (18:2n-6) (3.0%) and linolenic acid (18:3n-3) (0.4%). DDG and DDS also contain lactic acid at levels of about 4.0 and 8.0%, respectively⁽⁸⁾.

Table 13-01: Chemical composition of distillers' dried products (% dry matter)

	DDG from:			DDGS from:		DDS	
	Maize (2,3,6,23,24,26)	Wheat (2,3,13)	Rye (13)	Malt (3)	Milo (8)	Maize (6, 8,17,24)	Maize (3,17,24)
Dry matter	92.3	89.5	-	90.0	-	90.8	90.6
Crude Protein	28.5	31.8	21.2	27.5	27.0	27.8	29.5
Crude fat	10.2	6.6	6.9	3.5	7.0	10.0	11.3
Ash	4.6	4.9	4.4	6.0	5.0	4.7	9.0
Crude fibre	11.3	8.0	11.2	12.1	8.0	10.9	5.4
N-free extract	46.9	54.6	56.3	-	-	-	-

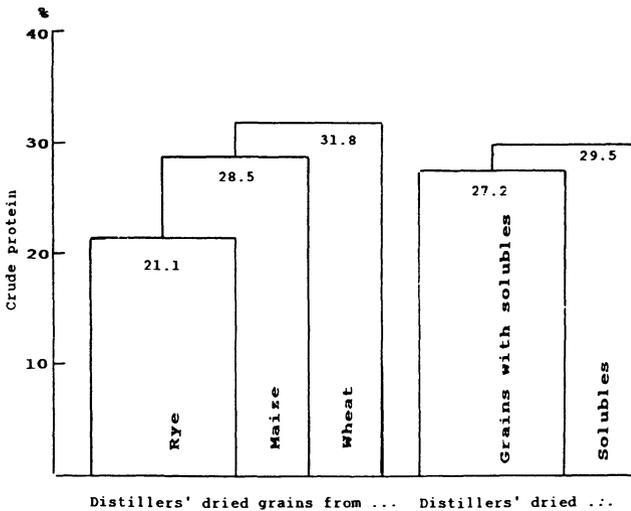


Figure 13-02. Variation of the crude protein content of distillers' dried products.

Table 13-02: Essential amino acid profile of distillers' dried products (g/16 g N)^(8, 24, 26)

	DDG	DDS	DDGS
Arginine	1.10	0.97	1.34
Histidine	0.60	0.67	0.67
Isoleucine	1.00	1.32	1.30
Leucine	3.00	2.34	2.91
Lysine	0.60	0.91	0.76
Methionine	0.50	0.56	0.52
Phenylalanine	1.20	1.48	1.49
Threonine	0.90	1.01	0.93
Tryptophan	0.20	0.55	0.35
Valine	1.30	1.54	1.42

The variation of the mineral content of distillers' dried products is wide. They are a good source of phosphorus, but the calcium content is low. Compared with maize (0.07 mg/kg) the selenium content appears to be high (Table 13-03).

Distillers' dried products are good sources of vitamins. They contain at least three-fold as much Vitamin B₂, nicotinic acid, pantothenic acid, folic acid and choline than the raw grain (Table 13-04)⁽⁸⁾.

Table 13-03: Macro and trace mineral contents of distillers' dried products (as fed)^(3, 8, 24, 25, 26)

		DDG	DDS	DDGS
Calcium	%	0.14	0.35	0.15
Phosphorus	%	0.70	1.24	0.70
Sodium	%	0.15	0.14	0.43
Potassium	%	0.71	1.40	0.55
Magnesium	%	0.20	0.66	0.21
Chlorine	%	0.08	0.26	0.17
Sulphur	%	0.42	0.36	0.31
Manganese	mg/kg	25.00	63.00	23.67
Iron	mg/kg	214.00	555.00	269.00
Zinc	mg/kg	42.75	131.50	77.33
Copper	mg/kg	41.72	124.50	47.45
Selenium	mg/kg	0.27	0.36	0.39
Cobalt	mg/kg	0.14	-	0.12

Table 13-04: The vitamins of distillers' dried products (1,000 g, as fed)^(8, 24, 25, 26)

		DDG	DDS	DDGS
Vitamin A	I.U.	1,104	-	1,363
Vitamin D ₃	I.U.	-	-	600
Vitamin E	mg	-	50.5	40.7
Vitamin B ₁	mg	1.83	6.6	5.9
Vitamin B ₂	mg	4.25	17.0	8.39
Vitamin B ₆	mg	5.59	10.9	4.60
Vitamin B ₁₂	mcg	0.30	7.00	1.50
Biotin	mg	0.34	1.60	1.04
Nicotinic acid	mg	39.40	122.0	88.50
Folic acid	mg	0.98	1.30	0.73
Pantothenic acid	mg	9.05	22.9	13.83
Choline	mg	1,080	4,687	2,548

Physiological Properties

Distillers' feeds are both protein and energy sources. However, only few information is available on the energy value for aquatic animals (Table 13-05). The digestibility of maize distillers' dried solubles in rainbow trouts (*Salmo gairdneri*) is 71.9% for protein and 58.6% for carbohydrates⁽³⁰⁾. In channel catfish (*Ictalurus punctatus*) the apparent protein digestibility is 67.0%⁽²¹⁾.

DDG and DDGS are relatively high in crude fibre which may limit their use as an energy source, especially for salmonids⁽²⁷⁾. The fortification of the compound feed with lysine may be necessary when the source of distillers' feeds is maize,

Table 13-05: Energy values of distillers' dried products

Type of energy	Product	Species	kcal/kg	MJ/kg	Ref.
Metabolisable	DDS	Trout	2,283	9.55	⁽³⁰⁾
Digestible	DDS	Trout	2,436	10.19	
Digestible	DDGS	Pig	3,640	15.23	⁽²⁴⁾
Digestible	DDS	Pig	3,346	14.00	⁽³⁾
Digestible	DDGS	Pig	2,271	9.50	

Other Properties

Although distillers' feeds are reported to have a positive effect on the pellet quality of pelleted feed⁽²⁾, according to CPM-tests the pelletising ability and abrasiveness of these products ranges only between low and medium⁽¹⁵⁾.

Distillers' feeds are also a source of unidentified growth factors (UGF) (see chapter 44)^(8, 9, 22).

The toxicity to salmonid fishes of certain distillers' feeds due to the relatively high copper content is questionable⁽²⁷⁾.

13.4 Feeding Value

Fishes

In feeds for salmonids maize distillers' dried solubles at levels of up to 10.0% have not shown any negative response^(16, 29). DDS when replaced by DDG in diets for the chinook salmon (*Oncorhynchus tshawytscha*) significantly reduced growth due to poor acceptance of the diet^(10, 11, 12).

In the lake trout (*Salvelinus namaycush*) no substantial differences were found when maize DDS and maize DDGS levels of 8.0% were compared. Weight and protein efficiency ratio were not significantly different. Feed efficiency was significantly greater in fish fed DDS but carcass protein of fish fed DDGS was significantly higher than fish fed DDS^(17, 18).

Distillers' feeds are more useful in feeding of channel catfish (*Ictalurus punctatus*). With DDS at levels of 5.0 to 14.0% good results were obtained⁽¹⁴⁾. A suitable ingredient for channel catfish diets is DDGS which has been used at inclusion rates of up to 40%. Juvenile channel catfish fed diets wherein fish meal was partially or totally replaced with DDGS and soybean meal showed no significant differences in weight gain, feed conversion and survival rate to that of the control (Table 13-06)^(22, 28, 31, 34, 35). However, at a level of 70% DDGS the diet was lysine-deficient since the addition of chrySTALLINE lysine significantly improved growth⁽³⁵⁾.

Table 13-06: Replacement of fish meal by a fixed level of distillers' dried grains with solubles (DDGS) and soy-bean meal in diets for juvenile channel catfish (*Ictalurus punctatus*) (trial period: 12 weeks)⁽³⁶⁾

DDGS	%	0	35.0	35.0	35.0	35.0
Menhaden meal (67%)	%	12.0	8.0	4.0	0	0
Soybean meal (44%)	%	48.0	35.0	42.0	39.0	48.5
Lysine (added)	%	0	0	0	0	0.4
Methionine (added)	%	0	0	0	0	0.1
Crude protein	%	35.8	36.1	35.3	36.0	35.5
Fat	%	6.2	10.0	8.4	8.7	8.4
Digestible energy	kcal/kg	2,880	2,930	2,920	2,900	2,900
Lysine (total)	%	1.80	1.70	1.79	1.72	1.81
Methionine (total)	%	0.64	0.63	0.63	0.60	0.63

Weight gain	g	41.6	42.5	36.7	38.0	42.0
	%	362	354	299	337	406
Feed conversion	1:	2.16	2.09	2.29	2.36	2.05
Survival rate	%	100.0	100.0	100.0	97.5	100.0

Feeding of DDGS does not significantly affect dressing percentage and carcass composition of channel catfish (Table 13-07)⁽³⁴⁾.

Under extensive conditions in Puerto Rico, Tilapia (*Tilapia aurea*) were fed with raw, viscous distillers' soluble from rum distillation which were dumped into the ponds at 2,010 to 4,000 l/ha. The distillers' soluble-treated ponds yielded 100% more than the ponds without any feeding but 50% less than fish meal-fed ponds⁽²⁰⁾.

Crustaceans

Information on the use of distillers' feeds in crustaceans diets is scarce. Inconclusive results were obtained when DDGS were fed to marine shrimps⁽¹⁹⁾. More promising results were observed in the pond culture of the freshwater prawn *Macrobrachium rosenbergii*. Results of increasing levels of DDGS up to 40% demonstrated its suitability as a feedstuff for the freshwater prawn (Table 13-08)^(32, 33).

Table 13-07: Effect of increasing levels of distillers' dried grains with solubles (DDGS) on dressing percentage and body composition of channel catfish (*Ictalurus punctatus*)⁽³⁴⁾

DDGS	%	0	10	20	30
Final body weight	g	217.6	207.8	224.4	226.4
Dressing percentage		53.4	52.2	54.0	54.4
Carcass composition:					
- Protein	%	59.2	59.9	55.3	54.8
- Fat	%	36.1	36.7	40.6	39.4
- Ash	%	5.9	5.6	5.9	6.5

Table 13-08: Effect of distillers' dried grains with solubles (DDGS) as an ingredient in diets for the freshwater prawn *Macrobrachium rosenbergii*⁽³²⁾¹

DDGS	%	0	20.0	40.0	
Fish meal	%	15.0	15.0	15.0	
Crude protein	%	29.4	28.7	29.3	
Fat	%	5.2	5.5	6.9	

Body weight at harvest	g	59.0	60.7	50.9	
Feed conversion	1:	3.1	3.1	3.2	
Survival rate	%	68.6	75.5	81.3	
Tail composition:					
- Protein	%	20.3	20.5	20.0	
- Fat	%	<0.1	<0.1	<0.1	

¹ There were no significant differences ($P > 0.05$) for any variables among treatments

13.5 Recommended Inclusion Rates

Distillers' dried grains with solubles (DDGS) and distillers' dried solubles (DDS) are suitable feedstuffs for aquaculture feed. DDGS may replace animal and vegetable protein feedstuffs. Distillers' dried grains (DDG) are less useful for aquatic animals. Practical application rates are as follows:

- DDS: Fishes: 3.0 to 10.0%
Crustaceans: 4.0 to 6.0%
- DDGS: Fishes: 10.0 to 35.0%
Crustaceans (marine): nil
Crustaceans (freshwater): 10.0 to 40.0%

13.6 Legal Aspects

AAFCO⁽¹⁾ has listed the following five different distillers' feeds:

- Distillers' dried soluble (No. 27.4),
- Distillers' dried grains (No. 27.5),
- Distillers' dried grains with solubles (No. 27.6),
- Condensed distillers' solubles (No. 27.7),
- Distillers' wet grains (No. 27.8).

The products may be obtained from the distilling of barley, maize, rye, sorghum, wheat and mixtures thereof. The predominant grain of distillers' feed must be declared and used as the first word in the labels of commercially available products in the U.S.A. as e.g. "Maize distillers' dried grains with solubles"⁽⁸⁾.

The EU-Directive accordingly lists distillery by-products as:

- Distillers' grains, dried,
- Distillers' grains, dried and dark.

The approved products by the German feedstuff legislation and their specification are in (Table 13-09).

Table 13-09: Specification for distillers' feeds by the German feedstuff legislation⁽³⁷⁾

	Moisture max. %	Crude protein min %	Crude fibre max. %	Ash max. %
Distillers' grains (wet)	-	-	-	-
Distillers' grains, dried	13.0	20.0	17.0	5.5
Insoluble matters of distillers' grains, dried	13.0	22.0	12.0	5.0
Soluble matters of distillers' grains, dried	13.0	25.0	-	10.0

13.7 References

1. AAFCO (1995): Official publication 1995. Ass. of American Feed Control Officials (Publisher), Sacramento, CA/USA.
2. Anonymous (w/o year): A guide to using distillers' feed on the farm. Trident Feeds, Petersborough/U.K. (brochure).
3. Black, H.; Edwards, S.; Kay, M.; Thomas, S. (1991): Distillery by-products as feed for livestock. Report to Malt Distillers' Ass. of Scotland.
4. Brooke, M. (1992): A wee drop of Scotch. Silver Kris, 19., (9), 19-24.
5. Carpenter, L.E. (1970): Nutrient composition of distillers' feed. Proc. 25th Distillers Feed Conf., 25., 54-61.
6. Castaldo, D.J. (1994): Squeezing more out of by-products. Feed International, 15., (10), 34-38.
7. De Boer, F.; Bickel, H. (1988): Livestock feed resources and feed evaluation in Europe. Elsevier Sciences Publishers, Amsterdam/The Netherlands.
8. DFRC (w/o year): Distillers grains. Distillers Feed Research Council, Des Moines, Iowa/USA.

9. Fairbanks, B.W.; Krider, J.L.; Carroll, W.E. (1944): Distillers by-products in swine rations. I. Creep feeding and growing fattening rations. *J. Animal Sci.*, 3., 29-40.
10. Fowler, L.G.; Banks, J.L. (1972): Alteration tests for the Abernathy salmon diets. U.S. Bur. Sport Fish. Wildl. Techn. Paper, 64.
11. Fowler, L.G.; Banks, J.L. (1976): Fish meal and wheat germ substitutes in the Abernathy diet. *Prog. Fish-Culturist*, 38., 127-130.
12. Fowler, L.G.; Banks, J.L.; Elliot, J.W. (1972): Tests of variations of the Abernathy salmon diet. U.S. Bur. Sport Fish. Wildl. Techn. Paper, 61. 14.
13. Friesecke, H. (1984): *Handbuch der praktischen Fütterung von Rind, Schaf, Pferd, Schwein, Geflügel und Süßwasserfischen*. BLV Verlagsges., München/Germany.
14. Hastings, W.H. (1967): Reviews of the nutritional needs of warmwater fish. *Feedstuffs*, 39., (24), 31.
15. Hertrampf, J.W. (1992): On the water durability of aquaculture feed pellets - A review. *Advances in Feed Techn.*, (7), 18-38.
16. Hilton, J.W.; Slinger, S.J. (1981): Nutrition and feeding of rainbow trout. *Can. Spec. Publ. Fish. Aquat. Sci.*, 55., 15.
17. Hughes, S.G. (1986): Replacement of distillers' dried grains with solubles compared for salmon diet formulation. *Feedstuffs*, 58., (53), 10.
18. Hughes, S.G. (1987): Distillers products in salmon diets. *Proc. Distillers Feed Conf.*, 42., 27-31.
19. Kohler, C.C. (1987): The use of ethanol distillery by-products in aquaculture. Report to Illinois Dept. of Energy and Natural Resources, Springfield, Illinois/USA
20. Kohler, C.C.; Pagan-Font, F.A. (1978): Evaluation of rum distillation wastes, pharmaceutical wastes and chicken feed for rearing *Tilapia aurea* in Puerto Rico. *Aquaculture*, 14., 339-347.
21. Lovell, R.T. (1977): Feeding practices. In: *Nutrition and feeding of channel catfish*. Southern Cooperative Series, 218., 50-55.
22. Lovell, R.T. (1980): Nutritional value of solid by-products from ethanol production of corn. Auburn Techn Assistance Center, Auburn, AL/USA.
23. New, M.B. (1987): Feed and feeding of fish and shrimps - A manual on the preparation and presentation of compound feeds for shrimps and fish in aquaculture. UNDP/FAO/ADCP/REP/87/26, Rome/Italy.
24. Newland, H.W.; Mahan, D.C. (1990): Distillers by-products. In: *Thacker, P.A.; Kirkwood, R.N.*: Non-traditional feed sources for use in swine production. Butterworth Publishers, Boston/USA.
25. NRC (1983): Nutrient requirements of warmwater fishes and shellfishes. National Academy Press. Washington, D.C.
26. NRC (1989): Nutrient requirements of horses. National Academy Press, Washington, D.C.
27. Pass, R.T. (1994): Private communication.
28. Robinette, H.R. (1984): Feed formulation and process. In: *Robinson, E.H.; Lovell, R.T. (Eds.)*: Nutrition and feeding of channel catfish (review). *South Coop. Techn. Bull.* 296, Texas A&M Univ. College Station, TX, 29-33.
29. Sinnhuber, R.D. (1964): Pelleted fish feed. *Feedstuffs*, 36., (28), 16.
30. Smith, R.R.; Peterson, M.C.; Allred, A.C. (1980): The effect of leaching on apparent digestion coefficients in determining digestibility and metabolizable energy of feedstuffs for salmonids. *Prog. Fish Culturist*, 42., 699-718.
31. Tidwell, J.H.; Webster, C.D.; Yancey, D.H. (1990): Evaluation of distillers' dried grains with solubles in prepared channel catfish diets. *Trans. Ky. Academy Sci.*, 51., (2/4), 135-158.
32. Tidwell, J.H.; Webster, C.D.; Clark, J. A., D'Abramo, L.R. (1993): Evaluation of distillers' dried grains with solubles as an ingredient in diets for pond culture of the freshwater prawn *Macrobrachium rosenbergii*.

- J. World Aquaculture Soc., 24., (1), 66-70.
33. Tidwell, J.H.; Webster, C.D.; Yancey D.H., D'Abramo, L.R. (1993): Partial and total replacement of fish meal with soybean meal and distillers' by-products in diets for pond culture of the freshwater prawn *Macrobrachium rosenbergii*. Aquaculture, 118., 119-130.
 34. Webster, C.D.; Tidwell, J.H.; Goodgame, L.S. (1993): Growth, body composition and organoleptic evaluation of channel catfish feed diets containing different percentage of distillers' dried grains with solubles. Progr. Fish Culturist, 55., (2), 95-100.
 35. Webster, C.D.; Tidwell, J.H.; Yancey, D.H. (1991): Evaluation of distillers' dried grains with solubles as a protein source in diets for channel catfish. Aquaculture, 96., 179-190.
 36. Webster, C.D.; Tidwell, J.H.; Yancey, D.H.; Goodgame, L.S.; Mackey, L. (1992): Use of soybean meal and distillers' dried grains with solubles as partial or total replacement of fish meal in diets for channel catfish (*Ictalurus punctatus*). Aquaculture, 106., 301-309.
 37. Weinreich, O.; Koch, V.; Knippel, J. (1994): Futtermittelrechtliche Vorschriften. Buchedition Agrimedia, Hamburg/Germany.

14. EGG POWDER

14.1 Rationale

Processed eggs are widely used in the food industry, for pet foods and aquaculture feed. Culture media, vaccine production, cosmetics, and shampoos are the areas for the non-food application of processed eggs.

The chicken (*Gallus domesticus*) egg consists of the embryo, yolk or vitellus, white or albumin, two membranes and the shell (Table 10-01)⁽¹⁰⁾.

Table 14-01: Constituents of eggs of some fowl species⁽⁵⁾

	Egg weight g	Egg white %	Egg yolk %	Shell %
Ostrich	1,400	53.4	32.5	14.1
Goose	250	52.5	35.1	12.4
Duck	80	52.6	35.4	12.0
Turkey	85	55.9	32.3	11.8
Chicken	58	55.8	31.9	12.3
Pigeon	17	74.0	17.9	8.1

14.2 Manufacture and Processing

Egg powder as a feedstuff is generally processed from eggs cracked and/or not fit for human consumption. Increasing quantities of fresh eggs are also processed into egg powder and used for human as well as animal food.

The whole eggs are washed, broken and the liquid is pasteurised, and in a vacuum concentrated to 30 to 40% solids prior to spray-drying the material (Figure 14-01)⁽⁶⁾. The drying process can significantly affect the nutritional value of the product. Drying at high temperature damages the nutrients. Antioxidants and anti-caking agents are commonly added to commercial egg powder for avoiding autoxidation of the high fat content of the egg and lumping of the hygroscopic product.

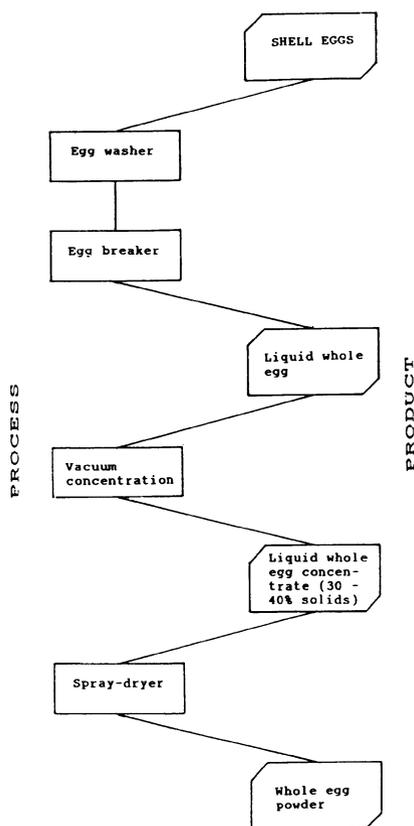


Figure 14-01. Diagram of processing whole egg powder.

14.3 Chemical and Physiological Properties

Chemical Properties

The whole egg has an ideal combination of all nutrients which the embryo needs for its development. The crude protein content of whole egg powder is about 47.0% but that of egg albumin is as high as 77.4% (Table 14-02). Egg white protein is a conglomerate of at least 50 different proteins. The principal egg white proteins are in Table 14-03⁽¹²⁾. The amino acid composition of whole egg powder is balanced (Table 14-04). The fat content of 41.8% consists of⁽⁴⁾:

- Saturated fatty acids: 32.1%
- Mono-unsaturated fatty acids: 55.4%
- Poly-unsaturated fatty acids: 12.5%

Table 14-02: Chemical composition of spray-dried egg products (% as fed)^(2, 3, 5, 9)

	Whole egg	Egg white
Dry matter	95.3	91.0
Crude protein	47.2	77.4
Fat	40.5	-
Ash	4.4	4.3
Crude fibre	0.1	-
N-free extract	3.0	-

Table 14-03: Principal egg white protein (%) in the domestic fowl⁽¹²⁾

Protein type	Egg white	Protein type	Egg white
Ovalbumin	54.0	Ovoglycoprotein	1.5
Ovotransferrin	12.0	Faloprotein	0.8
Ovomucoid	11.0	Ovomacroglobulin	0.5
Lysozyme	3.4	Avidin	0.05
Ovomucin	2.9	G ₂ -Globulin	1.0
Ovoinhibitor	1.5		

Table 14-04: Essential amino acid content of whole egg powder (g/16 g N)
(2, 4, 8, 9, 13)

	Mean	Range
Arginine	4.36	2.83 - 6.40
Histidine	1.79	1.04 - 3.20
Isoleucine	4.47	2.59 - 7.70
Leucine	6.05	3.90 - 9.20
Lysine	4.63	3.10 - 7.00
Methionine	2.38	1.48 - 4.00
Phenylalanine	3.91	2.50 - 6.30
Threonine	3.31	2.26 - 5.20
Tryptophan	1.03	0.71 - 1.50
Valine	4.93	3.16 - 7.30

The vitamin and mineral contents of egg powder are in Table 14-05. The phosphorus content is 2.7 times higher than the calcium content. A high calcium content indicates a high portion of egg shells in the egg powder.

Table 14-05: Mineral and vitamin contents of whole egg powder^(2,3, 4, 5, 9)

Minerals			Vitamins (per 1,000 g)		
Calcium	%	0.29	Vitamin A	IU	40,000
Phosphorus	%	0.78	Vitamin E	mg	57
Potassium	%	0.53	Vitamin K	mcg	76
Chlorine	%	0.68	Vitamin B ₁	mg	3.6
Magnesium	%	0.05	Vitamin B ₂	mg	11.5
Sodium	%	0.55	Vitamin B ₆	mg	6.0
Iron	mg/kg	39.5	Vitamin B ₁₂	mcg	39.4
Zinc	mg/kg	55.0	Biotin	mcg	2.4
Iodine	mg/kg	0.04	Folic acid	mg	0.8
			Nicotinic acid	mg	3.3
			Pantothenic acid	mg	75.8
			Choline	g	20.1

Fresh whole eggs without shells have a cholesterol content of 3.2% in the dry matter⁽⁴⁾. The total sterol content of whole egg powder ranges between 1.2 to 1.5% with the following breakdown⁽²⁾:

- Cholesterol: 92.2%
- Cholesterol ester: 5.0%
- Brassicasterol: 1.2%
- Campesterol: 1.2%
- Stigmasterol: 0.2%
- β -sitosterol: 0.2%

Egg powder is also a source of phospholipids. The dry matter of whole egg powder without shells contains 12.3% phospholipids⁽⁴⁾ (see chapter 41).

Physiological Properties

The crude protein digestibility is 87% in vitro and has been found to be 100% soluble. The digestible energy is estimated to be 5,140 kcal/kg (21.5 MJ/kg) and the metabolisable energy is computed to be 4,950 kcal/kg (20.7 MJ/kg).

Eggs might also be toxic. Rats fed raw egg white showed signs of toxicity similar to those fed raw soybeans. These so called toxic factors were subsequently shown to be enzyme inhibitors⁽⁷⁾. Such proteinase inhibitors are ovomucoid and ovomucoid inhibitor (Table 14-03)⁽¹²⁾.

The whole egg protein is often used to compare the protein value of other feedstuffs by computing the "Egg Protein Ratio" (EPR) and the "Essential Amino Acid Index" (EAA-Index)⁽¹¹⁾ (see Table 2-04).

14.4 Feeding Value

Whole egg powder when carefully processed has a high feeding value for aquaculture feeds. It provides protein, fat, cholesterol and phospholipids. Whole egg powder is a feedstuff particularly for very young aquatic organisms and is widely used in commercial aquaculture feed. There is still a lack of scientific studies showing the feeding value in aquaculture diets.

The feeding value of chicken egg lecithin as a source of phospholipids is discussed in Chapter 41.

14.5 Recommended Inclusion Rates

Whole egg powder is widely used in fish and shrimp feed, particularly in larvae feed. An inclusion rate of 1.0 to 3.0% is commonly practised.

14.6 Legal Aspects

The use of whole egg powder in feed is unrestricted. However, according to the "Egg Products Inspection Act of 1970" egg processing plants in the U.S.A. have to undergo continuous inspections⁽⁷⁾. In the U.S.A. all egg powder used for feeding purposes has to be denaturated with addition of green or brown dye in order to make sure that feed grade quality is not used for human consumption. From the safety standpoint, the product should be free of any pathogenic organisms, particularly salmonella.

AAFCO⁽¹⁾ specifies egg powder as "egg product" (No. T9.74). It should be free of shells or other non-egg materials except in such amounts which might occur unavoidably in good processing practices. The maximum ash content should not exceed 6.0% on a dry matter basis

14.7 References

1. AAFCO (1995): Official publication 1995. Ass. of American Feed Control Officials (Publisher), Sacramento, CA/USA.
2. Anonymous (1993): Animal Feed is our concern, ingredients for aquaculture, livestock and poultry feeds (product specifications). Tesgo Services B.V, Hoogerheide/The Netherlands.
3. Anonymous (1994): Spray dried egg product (specification). California Spray Dry Co., Stockton, CA/USA.
4. Feltwell, R.; Fox, S. (1978): Practical poultry feeding. Faber and Faber, London & Boston.
5. Kolb, E. (1989): Lehrbuch der Physiologie der Haustiere, Vol. II. VEB Gustav Fischer Verlag, Jena/Germany.
6. MacNeil, J.H. (1994): Eggs for the 21st century. Poultry International, 33., (4), 20-24.
7. Miller Jones, J. (1992): Food safety. Eagan Press, St. Paul/USA.
8. Nordal, J.; Fretheim, K. (1978): Utnyttelse av slakteriblod i næringsmidler. Rapport no. 27, Norsk Institutt for Næringsmiddelforskning, Ås-NLH/Norway.
9. NRC (1983): Nutrient requirements of warmwater fishes and shellfishes. Natl. Res. Council (Revised ed.),

Natl. Acad. Press, Washington, D.C.

10. *Say, R.* (1987): Manual of poultry production in the tropics. CAB International, Wallingford, Oxon/UK.
11. *Steffens, W.* (1985): Grundlagen der Fischernährung, VEB Gustav Fischer Verlag, Jena/Germany.
12. *Stevens, L.* (1991): Genetics and evolution of the domestic fowl. Cambridge University Press, Cambridge/UK.
13. *Wöhlbier, W.; Tran Thu, D.* (1977): Blutmehl. In: *Kling, M.; Wöhlbier, W.*: Handelsfuttermittel. Verlag Eugen Ulmer, Stuttgart/Germany.

15. FEATHER MEAL (HYDROLYSED)

15.1 Rationale

Feathers are the very complex derivatives of the integuments to be found in any vertebrate. They can be divided into three categories:

- Contour feathers, inclusively the remiges of the wings and the rectrices of the tail;
- Down feathers;
- Filoplume.

They can be further subdivided into the barbules and barbicels⁽³¹⁾. Feathers consist of several morphological different parts, the horny central shaft (quill), partly hollow, from which soft and narrow barbs extend. The composition depends on the type of feather (Figure 15-1). The remiges of the wings are composed of the⁽³⁶⁾:

- Quill 55.0%
thereof: Rachis 19.0%
 Shaft 36.0%
- Barb 32.0%
- Down traces
- Quill marrow 13.0%

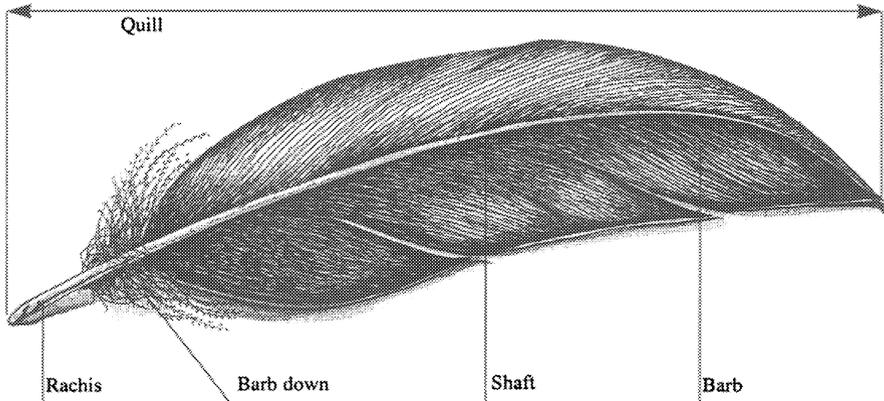


Figure 15-01. The parts of the poultry feather.

The chemical composition and the amino acid profile of the individual parts of the feather are different (Table 15-01).

Feather meal is a by-product of poultry meat processing. Annually large quantities of feathers are available. World-wide more than 25,000 million broilers are slaughtered per year. A 2.0 kg live chicken produces 180 g of feathers⁽²⁶⁾ which gives a potential

of 4,500 million MT of fresh feathers. In the USA only more than one million MT of feather meal are produced a year⁽²⁶⁾.

Fresh feathers contain about 90% crude protein⁽³¹⁾. Due to the high level of keratin, which is a tough, fibrous, insoluble protein, and the strong disulphide bonding, the digestibility of fresh feathers is less than 5.0%. However, with proper processing, raw feathers can be converted into a valuable protein feedstuff^(11, 26). This kind of recycling of feathers is environmental friendly.

Table 15-01: Chemical composition and the profile of essential amino acid of the individual parts of the feather (% or g/16 g N)⁽³⁶⁾

	Rachis	Shaft	Barb	Feather marrow
Nitrogen	16.62	16.40	16.28	16.36
Ash	0.87	0.80	0.86	0.77
Sulphur	2.47	2.32	2.85	2.40

Arginine	6.45	6.46	6.69	6.78
Histidine	0.36	0.31	0.26	0.27
Isoleucine	4.04	3.67	5.02	4.11
Leucine	10.52	8.71	7.94	9.44
Lysine	0.91	0.76	1.04	0.95
Methionine	0.12	0.19	0.22	0.27
Phenylalanine	4.96	5.27	4.89	5.45
Threonine	4.78	4.11	5.21	3.36
Tryptophan	1.48	1.58	0.45	1.53
Valine	8.86	7.88	8.26	9.01

15.2 Manufacture and Processing

Hydrolysing Process

Hydrolysed feather meal is derived by pressure cooking the clean, undecomposed feathers from slaughtered poultry. This process actually is not a hydrolysis but a denaturation process whereby some compounds are split, while the properties of protein remain⁽³⁶⁾. The quality of the final product depends on the hydrolysing process. Processing methods are^(11, 26):

- Low pressure (< 207 kPa) at 130°C for 150 minutes;
- High pressure (> 207 kPa) at 145°C for 30 minutes.

Feather meal is produced in batch cookers and in high-volume continuous hydrolysers, respectively.

Autoclaving of the feathers breaks down the keratin by destroying the linkage of the high level of cystine. As a result, the value of the product improves^(11, 21). After cooking

the material is dried at 60°C and ground. The physical appearance of feather meal varies according to the feathers used. Feathers of a light colour result in a light golden, brown meal while feathers of dark colour give a dark, brown-black meal⁽²¹⁾. Feather meal has a fresh odour. It can be stored without fear of rotting⁽¹¹⁾.

The quality of feather meal is affected by the degree of hydrolysis. Too high autoclaving (pepsin digestibility = 90%) will produce overcooked meal with a lower protein quality. Also, undercooked meal (pepsin digestibility below 65%) results in a lower protein quality⁽²¹⁾. Steaming for a long time decreases the true availability of many amino acids⁽²⁴⁾.

Other Processes

Feathers could be denatured also into a feedstuff by treatment with sodium hydroxide (0.25% NaOH)⁽³⁰⁾. The process significantly increases dry matter and protein digestibility of feather meal *in vitro*. However, the difficulty in handling, disposal or neutralisation of NaOH may limit this type of treatment on a commercial scale.

Another technology for making feather meal is bacterial fermentation, whereby the feathers are autoclaved and inoculated with a bacterial culture of *Bacillus licheniformis*. Processing time is as much as five days and is uneconomical⁽³⁵⁾.

Dry extrusion technology has been tried for converting feather meal into a feedstuff. The product from this process has similar feeding value as feather meal from the hydrolysing process⁽⁹⁾, but the process is uneconomical⁽²⁶⁾.

15.3 Chemical, Physiological and other Properties

Chemical Properties

The crude protein content of feather meal in the dry matter averages 86.9% with a variation of more than 20% (Table 15-02).

Table 15-02: Chemical composition of feather meal
(in dry matter)^(2, 3, 11, 13, 14, 18, 20, 23, 36)

		Mean	Variation
Dry matter	%	93.3	90.0 - 92.5
Crude protein	%	86.9	71.7 - 92.7
Crude fat	%	3.6	1.8 - 5.0
Ash	%	3.1	1.9 - 4.6
Crude fibre	%	0.8	0.4 - 2.0
N-free extract	%	0.6	0.5 - 0.9

The level of the essential amino acids histidine, lysine, methionine and tryptophan is deficient⁽³⁶⁾. In general, the amino acid content of feather meal is lower than of untreated feathers (Table 15-03). Pressure used in the processing may affect the amino acid content to a certain extent⁽¹⁸⁾. Cystine is particularly affected by pressure. It is partly

destroyed and converted into the amino acid lanthionine and loses half the sulphur in the process^(18, 25, 36).

Table 15-03: Essential amino acid profile of hydrolysed feather meal and untreated feathers (g/16 g N)^(11, 19, 23, 36)

	Hydrolysed feather meal		Untreated feathers
	Mean	Variation	
Arginine	6.11	4.99 - 7.58	5.61
Histidine	0.80	0.99 - 1.06	0.42
Isoleucine	4.29	3.92 - 4.63	4.28
Leucine	6.96	6.37 - 7.73	8.65
Lysine	2.28	1.72 - 2.98	1.03
Methionine	0.65	0.59 - 0.72	0.30
Phenylalanine	4.01	3.28 - 4.57	5.22
Threonine	0.58	0.51 - 0.67	4.68
Tryptophan	3.75	3.16 - 4.27	1.25
Valine	5.73	4.27 - 7.62	8.37

The fat content varies significantly from 1.8 to 4.6% with a mean value of 3.6% (Table 15-02). A high level of fat indicates feather contamination with skin tissue. High quality feather meal should have a fat content not exceeding 5.0%⁽²¹⁾.

The crude fibre content of feather meal is most probably an insoluble nitrogen-containing substance which is already included in the protein content⁽³⁶⁾.

The ash content depends on the cleanliness of the feathers. The mineral and vitamin contents of feather meal are compiled in Table 15-04.

Table 15-04: Mineral and vitamin contents of hydrolysed feather meal

Minerals ^(3, 11, 20, 22, 36)			Vitamins (per 1,000 g) ^(11, 22, 23, 36)		
Calcium	%	0.45	Vitamin B ₁	mg	0.1
Phosphorus	%	0.55	Vitamin B ₂	mg	2.2
Sodium	%	0.54	Vitamin B ₆	mg	3.2
Potassium	%	0.25	Vitamin B ₁₂	mcg	84.9
Magnesium	%	0.15	Biotin	mcg	80.0
Chlorine	%	0.22	Folic acid	mcg	170.0
Sulphur	%	1.60	Nicotinic acid	mg	21.4
Manganese	mg/kg	27.9	Pantothenic acid	mg	9.3
Iron	mg/kg	116.0	Choline	mg	493.0
Zinc	mg/kg	101.4			
Copper	mg/kg	15.6			
Selenium	mg/kg	0.9			

Physiological Properties

Few data are available on the energy content of hydrolysed feather meal (Table 15-05).

Feather meal has a high crude protein content but its digestibility, ranging between 52% and 74%, is unsatisfactory (Table 15-06). With increasing processing pressure, the pepsin digestibility increases (Figure 15-02). Recent studies have demonstrated that when the concentration of pepsin is 0.002% rather than the normal 0.2%, the pepsin digestibility value is more closely related to *in vivo* performances⁽²¹⁾.

The amino acid digestibility of feather meal manufactured by using different processing pressures declines as the pressure increases⁽¹⁸⁾.

The lipid digestibility of feather meal is better than that of protein but this is of less importance because it has low fat content (Table 15-06).

Table 15-05: Energy values of hydrolysed feather meal (in dry matter)

Type of energy	Species	kcal/kg	MJ/kg	Reference
Digestible	Rainbow trout	3,753	15.7	(6)
Digestible	Fish ¹	3,689	15.5	(20,23)
Digestible	Poultry	2,730	11.4	(11)

Metabolisable	Carp	2,904	12.2	(33)
Metabolisable	Fish ¹	3,096	13.0	(21)
Metabolisable	Poultry	3,220	13.5	(11)
Metabolisable	Pigs	2,360	9.9	(36)

¹ species not specified

Table 15-06: Digestibility of hydrolysed feather meal (%)

Species	Digestibility				Reference
	Dry matter	Crude protein	Fat	Gross energy	
Salmonids	-	62.3	68.0	73.7	(16)
Rainbow trout	75.0	55.2	68.0	70.0	(5,6,29)
Channel catfish	-	65.8	83.0	66.6	(10,16)

Other Properties

Feather meal most probably contains unidentified growth factors (UGF) as observed in broilers and hatchability rate of chicks⁽³⁶⁾ (see chapter 44). Feather meal may be contaminated with salmonella, if improperly processed.

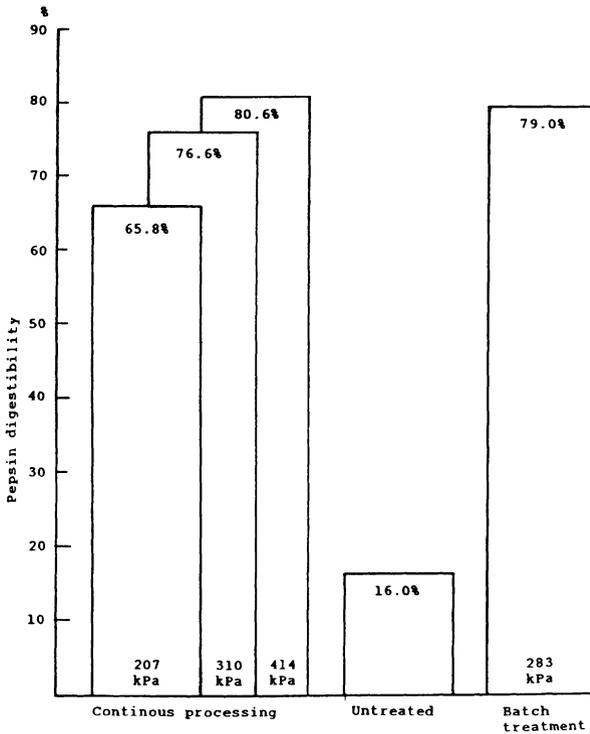


Figure 15-02. The effect of increasing processing pressure on the pepsin digestibility of continuously and batch processed hydrolysed feather meal^(data from: 18).

15.4 Feeding Value

Feather meal is used to partly replace the costly fish meal in aquaculture diets. However, only few trials have been carried out where the effect of feather meal on the animal's performances could be objectively determined. In most feeding trials, mixtures of animal protein, containing feather meal, blood meal, meat and bone meal and poultry by-product meal, replaced fish meal in the diets for aquatic animals. These mixtures of various animal proteins are also called "fish meal analog". Hence the effectiveness of pure feather meal could not be established.

Fishes

A combination of feather meal and poultry by-product meal (low and high fat content) replaced partially herring meal in the diet for coho salmon (*Oncorhynchus kisutch*). Replacing 35% to 75% of herring meal protein by protein from a mixture of feather meal

and poultry by-product meal did not show any substantial difference in the performance to the herring meal control group. Supplemental methionine may be required at high level replacement of herring meal protein⁽¹⁷⁾.

In diets for the rainbow trout (*Salmo gairdneri*) combinations of feather meal and poultry by-product meal (Table 15-07)⁽¹⁵⁾ or feather meal and blood meal (1:1)⁽²⁷⁾ or feather meal, poultry by-product meal and blood meal (1/3 : 1/3 : 1/3)⁽²⁸⁾ could fully meet the protein requirement of the fish provided the substitutes only may replace half of the available protein in the diet. In addition the diet has to be supplemented with amino acids^(15, 27, 28, 32).

Table 15-07: Replacement of fish meal by feather meal and poultry by-product meal in diets for rainbow trout (*Salmo gairdneri*) (trial period: 88 days)⁽¹⁵⁾

Fish meal	%	70.0	52.5	35.0	-	-
Feather meal	%	-	7.5	15.0	30.0	30.0
Poultry meal	%	-	10.0	20.0	40.0	40.0
Amino acid supplement		-	-	-	-	+ ¹
Crude protein	%	46.1	47.2	50.2	48.1	48.9
Fat	%	12.2	13.3	11.5	12.3	12.8

Weight gain	g	133	142	127	117	126
Feed conversion	1:	1.33	1.24	1.41	1.52	1.37

¹ 1.7% lysine, 0.48% methionine, 0.144% tryptophan

A “fish meal analog” made from equal parts of feather meal, poultry by-product meal, blood meal and meat and bone meal has been used to replace 25%, 50%, 75% or 100% of the fish meal in the diet for rainbow trout fingerlings. Up to 75% of the fish meal could be replaced by fish meal analog without any negative effect on performances. However, full replacement of fish meal resulted in a significant decrease in weight gain of the fish⁽⁷⁾.

Total replacement of fish meal by feather meal in diets for tilapia (*Tilapia mossambicus*) resulted in a reduction in performance (Table 15-08). In this trial with juvenile tilapia, feather meal proved unfeasible, alone or in combination with blood meal (50:50), and as either a partial or total substitute for fish meal⁽⁸⁾.

Channel catfish (*Ictalurus punctatus*) fingerlings were fed isonitrogenous diets containing either maize gluten meal (60% crude protein) alone or in combination with feather meal. While weight gain was not significantly reduced in fish fed feather meal, feed conversion was higher for the feather meal diet. Total sulphur amino acid (TSAA) content was the same for both diets but the TSAA availability tended to be lower for feather meal compared to maize gluten meal (Table 15-09)⁽¹⁾.

Table 15-08: Feather meal and feather meal/blood meal as a substitute for fish meal in diets for tilapia (*Tilapia mossambicus*) (trial period: 49 days)⁽⁸⁾

Fish meal (Chile)	%	47.2	10.8	-	-
Feather meal	%	-	8.8	20.6	8.3
Blood meal	%	-	-	-	8.3
Meat and bone meal	%	-	10.0	10.0	10.0
Crude protein	%	38.8	37.3	39.2	37.1
Fat	%	13.5	13.0	13.0	13.1

Initial weight	g	0.80	0.80	0.82	0.81
Specific growth rate	%	3.71	3.46	2.83	2.90
Daily weight gain	mg	84.0	72.4	50.1	52.0
Feed conversion	1:	2.16	2.32	2.93	2.91
PER		1.20	1.16	0.87	0.93

Table 15-09: Feather meal replaces maize gluten meal in diets for catfish (*Ictalurus punctatus*) (trial period: 42 days)⁽¹⁾

Maize gluten (60%)	%	20.0	10.0
Feather meal	%	-	10.0
TSAA ¹	g/16g N	1.02	1.02

Weight gain	g	42.6	40.7
Feed conversion	1:	2.09	2.26
TSAA ¹ /weight gain		0.021	0.023

¹ Total sulphur amino acids

Crustaceans

In a semi-purified diet for juvenile *Penaeus vannamei* (white shrimp) 2.5%, 5.0% and 10.0% of the diet's protein were replaced by feather meal. There was no difference in the survival rate between the control group and the protein replacement by feather meal. Shrimp growth for the fish meal control diet was better than for the partial fish meal replacement by feather meal. Feather meal at levels of 5.0 to 10.0% of the protein are suitable for shrimp diets as long as the shrimps' requirement for essential amino acids and minerals are met⁽¹⁹⁾.

Molluscs

Feather meal may be an alternative protein source for abalone of the genus *Haliotis*⁽¹²⁾. However, it does not contain phagostimulatory components such as free glutamic acid and aspartic acid⁽⁴⁾. Feather meal as a protein source may also negatively affect water quality and may cause bloat in the abalone ⁽¹²⁾.

15.5 Recommended Inclusion Rates

Feather meal has a high crude protein content but the digestibility of the nutrients is rather low (Table 15-06). It can partly replace fish meal in aquaculture diets but may not perform as well as diets with fish meal as the only protein source. The use of feather meal may require an extra fortification of the diet with amino acids. In commercial aquaculture diets, feather meal may be used at levels of 5.0 to 10.0%.

15.6 Legal Aspects

Feather meal is defined by the “American Feed Control Officials” (AFCO) as: “The product resulting from treatment under pressure of clean, undecomposed feathers from slaughtered poultry, free of additives and/or accelerators. Not less than 75% of the crude protein must be digestible as determined by the Association of Official Analytical Chemists’ pepsin digestibility method 7.048”⁽²⁶⁾.

EU-Directive 92/87 EEC of 26 October, 1992, has listed feather meal as No. 9.06 and is described as a “Product produced from hydrolysed, dried and ground poultry feathers”. The same definition is given by the German feedstuff law (Table 15-10)⁽³⁴⁾.

Table 15-10: Nutritional standards of feather meal required by German feedstuff law⁽³⁴⁾ and NRA⁽²¹⁾

	German feed stuff law	NRA-Standard
Moisture	max. 11.0	max. 10.0
Crude protein	min. 80.0	min. 80.0
Pepsin digestibility	min. 70.0	min. 75.0
Fat	-	max. 6.0
Crude fibre	-	max. 4.0
Ash	max. 3.4	max. 4.0
Phosphorus	-	min. 75.0

15.7 References

1. *Andrews, J.W.* (1991): A comparison of several by-products and plant proteins as sources of essential amino acids for catfish. Director's Digest, No. 12 (Fats and Proteins Res. Found. Bloomington, Ill./USA.
2. *Anonymous* (1987): Byproduct meals may have place in turkey diets. Feedstuffs, 59., (51), 13-14.
3. *Bath, D., Dunbar, J., King, J., Berry, S., Leonhard, R.O., Olbrich, S.* (w/o year): Composition of by-products and unusual feedstuffs (Mimeograph).
4. *Carefoot, T.H.* (1982): Gastropod nutrition. Proc. 2nd Conf. on Aquaculture Nutrition: Biochem. and Physiol. Approaches to Shellfish Nutrition, Rehoboth Beach, Delaware/U.S.A., October, 321-337.
5. *Cho, C.Y.; Slinger, S.J.* (1979): Apparent digestibility measurement in feedstuffs for rainbow trout. Proc. World Symp. on Finfish Nutr. and Fishfeed Techn., Hamburg/Germany, Vol. II, 20-23 June, 1978.
6. *Cho, C.Y., Cowey, C.B., Watanabe, T.* (1985): Finfish nutrition in Asia: Methodological approaches to research and development. IFRC, No. 233e, Ottawa/Canada.
7. *Dabrowski, K. et al.* (1995): Quoted from: *Rowland, R.D.* (1995).
8. *Davies, S.J.; Williamson, J.; Robinson, M.; Bateson, R.I.* (1989): Practical inclusion levels of common animal by-products in complete diets for tilapia (*Oreochromis mossambicus*, Peters). Proc. 3rd Int. Symp. on Feeding and Nutrition in Fish, Toba/Japan, 28.8-1.9, 325-332.
9. *Davis, J.* (1989): Feed from poultry waste - a new process. Poultry International, 28., (3), 40-44.
10. *Dupree, H.K.; Huner, J.V.* (1984): Third report to the fish farmers. Publ. U.S. Fish and Wildlife Service, Washington, D.C.
11. *Evans, M.* (1985): Nutrient composition of feedstuffs for pigs and poultry. Queensland Dept. Primary Ind., Brisbane/Australia (Series Q 185001).
12. *Fallu, R.* (1991): Abalone Farming. Fishing News Books, Oxford/England.
13. *Feltwell, R.; Fox, S.* (1978): Practical poultry feeding. Faber and Faber, London and Boston.
14. *Friesecke, H.* (1984): Handbuch der praktischen Fütterung von Rind, Schaf, Pferd, Schwein, Geflügel und Süßwasserfischen. BLV Verlagsges., München/Germany.
15. *Gropp, J.; Koops, H.; Tiews, K.; Beck, H.* (1976): Ersatz von Fischmehl im Forellenfutter. Arb. Deutscher Fischerei-Verb., No.19, 85-102.
16. *Hepher, B.* (1988): Nutrition of pond fishes. Cambridge University Press, Cambridge/U.K.
17. *Higgs, D.A.; Markert, J.R.; Macquarrie, D.W.; McBride, J.R.; Dojanjh, C.; Hoskins, G.* (1979): Development of practical diets for coho salmon, *Oncorhynchus kisutch*, using poultry by-product meal, feather meal, soybean meal and rape seed meal as major protein sources. Proc. World Symp. on Finfish Nutr. and Fishfeed Techn., Hamburg/Germany, Vol. II, 20-23 June, 1978, 191-216.
18. *Latchaw et al.* (1994): Quoted from: *Rowland, R.D.* (1995).
19. *Lawrence, A.K; Castille, F.* (1991): Nutritive response of a western hemisphere shrimp *Penaeus vannamei*, to meat and bone, feather and poultry by-product meal. Director's Digest, No. 215 (Fats and Protein Res. Found. Bloomington, Ill/USA.
20. *New, M.B.* (1987): Feed and feeding of fish and shrimps - A manual on the preparation and presentation of compound feeds for shrimps and fish in aquaculture. UNDP/FAO/ADCP/REP/87/26, Rome/Italy.
21. *NRA* (1993): Pocket information manual - a buyers guide to rendered products. National Renderers Ass., Inc., Alexandria, Vir./USA.
22. *NRC* (1981): Nutrient requirements of coldwater fishes. National Academy Press, Washington, D.C.
23. *NRC* (1983): Nutrient requirements of warmwater fishes and shellfishes. National Academy Press. Washington, D.C.
24. *Papadopoulos, M.C. et al.* (1985): Quoted from: *Rowland, R.D.* (1995).

25. *Robbins, K.R., Bauer, D.H.* (1980): Studies on the utilization of lysine-alanine and lanthionine. *J. Nutrition*, *110.*, 907-915.
26. *Rowland, R.D.* (1995): Nutrition value of hydrolysed feathers for use in non-ruminant, ruminant and aquaculture feeds. National Renderers Ass., Inc., Alexandria, Virg./USA (Mimeograph).
27. *Schulz, D.; Hartfiel, W.; Greuel, E.* (1982): Verwendung von Nebenprodukten tierischer Herkunft in der Ernährung von Regenbogenforellen (*Salmo gairdneri*). I. Einsatz von Blut- und Federmehl in einer gereinigten Diät. *Z. Tierphysiol., Tierernährung, Futtermittelkd.*, *47.*, 79-85.
28. *Schulz, D.; Hartfiel, W.; Greuel, E.* (1982): Verwendung von Nebenprodukten tierischer Herkunft in der Ernährung von Regenbogenforellen (*Salmo gairdneri*). II. Einsatz von Blut-, Feder- und Geflügelschlachtabfallmehl sowie Gelatine in einer gereinigten Diät. *Z. Tierphysiol., Tierernährung, Futtermittelkd.*, *48.*, 267-275.
29. *Shanks* (164): Quoted from: *NRC* (1981):
30. *Steiner, R.J.; Kellers, R.D.; Church, D.C.* (1983): Feather and hair meals for ruminants. IV. Effects of chemical treatments of feathers and processing times on digestibility. *J. Anim. Sci.*, *57.*, 495.
31. *Stevens, L.* (1991): Genetics and evolution of the domestic fowl. Cambridge University Press, Cambridge/UK.
32. *Tiews, K.; Koops, H.; Beck, H.; Schwalb-Bühling, A.; Gropp, J.* (1981): Entwicklung von Ersatzfutter für die Regenbogenforelle. Bundesforschungsanstalt für Fischerei, Veröffentl. des Inst. für Küsten- und Binnenfischerei, Hamburg/Germany, Publ. No. 75.
33. *Viola, S.* (1977): Energy values of feedstuffs for carp. *Bamidgeh.*, *29.*, 29-30.
34. *Weinreich, O.; Koch, V.; Knippel, J.* (1994): Futtermittelrechtliche Vorschriften. Buchedition Agrimedia, Hamburg/Germany.
35. *Williams, C.M.; Lee, C.G.; Garlich, J.D.; Shih, J.C.H.* (1991): Evaluation of a bacterial feather fermentation product, feather-lysate, as a feed protein. *Poultry Sci.*, *70.*, 85-94.
36. *Wöhlbier, W.* (1977): Keratinhaltige Futtermittel. In: *Kling, M.; Wöhlbier, W.*: Handelsfuttermittel. Verlag Eugen Ulmer, Stuttgart/Germany.

16. FEED CAROTENOIDS

16.1 Rationale

Carotenoids are widely distributed in nature occurring in plants and animals. They are produced by all photosynthetic active microorganisms and plants. In green plants they are covered by chlorophyll and are the cause for the colourful nature in autumn⁽²⁵⁾. About 600 different natural carotenoids have been identified and thereof possibly 10% are precursors of Vitamin A⁽³⁹⁾. Total annual production is estimated at over 100 million MT⁽²⁹⁾. Some examples of tissues whose pigmentation are due to carotenoids are:

- *Corpus luteum*
- Egg yolk
- Pink flesh of salmonids
- Red exoskeleton of boiled crustaceans
- Pink plumage of flamingos

For certain farm animals, feeds are fortified with specific carotenoids in order to obtain the natural colour of animal products⁽¹⁵⁾. The carotenoid content of some plant materials may vary in a wide range and the astaxanthin content of animal origin depends on treatment and processing of the material (Table 16-01).

16.2 Biochemical, Biological and Other Properties

Biochemical Properties

Carotenoids are lipochromes. They are fat soluble, yellow to red polyen-pigments of plant origin, and are classified into⁽¹⁵⁾:

- Carotenes = oxygen-free hydrocarbons:
 - α -carotene
 - β -carotene
 - γ -carotene
 - Lycopine
- Xanthophylls - oxygen-containing hydrocarbons:
 - Astaxanthin
 - Canthaxanthin
 - Cryptoxanthin
 - Zeaxanthin

There are many pigmenting carotenoids but only few of them, astaxanthin and canthaxanthin, are of significant importance for aquaculture feed. Synthetic carotenoids and xanthophylls such as β -apo-8'-carotinal, β -apo-8'-carotene acid-ethylester, capxanthin, citranaxanthin, cryptoxanthin, lutein and zeaxanthin are used as pigmenters in poultry feeds⁽²⁴⁾.

Table 16-01: Xanthophyll content of plant materials⁽³⁵⁾ and astaxanthin content of animal products used in aquatic feed⁽⁵²⁾

Materials		mg/kg
1. Plant Materials		
Alfalfa meal		260 - 330
Alfalfa juice protein		800
Algae meal		2,000 - 4,000
Maize, yellow		17
Maize gluten meal		175 - 290
Marigold petal meal		7,000
Capsicum, Spanish		275
Seaweed		340 - 920
Yeast (<i>Phaffia rhodozyma</i>)		30 - 800
2. Animal Products		
Capelin oil	<i>Mallotus villosus</i>	6 - 94
Copepod	<i>Calanus finmarchicus</i>	39 - 84
Copepod oil	<i>Calanus finmarchicus</i>	- 520
Crab, red	<i>Pleuroncodes planipes</i>	100 - 160
Crab, red, oil extract	<i>Pleuroncodes planipes</i>	1,500
Crab, vacuum dried	<i>Chinochetes opilio</i>	5
Crab, freeze dried	<i>Geryon quinquedens</i>	76
Crayfish, oil extract	<i>Procambrus clarkii</i>	750
Crayfish, meal	<i>Procambrus clarkii</i>	137
Krill	<i>Euphausia pacifica</i>	100 - 130
Krill, co-dried with oil	<i>Euphausia pacifica</i>	200
Krill, oil	<i>Euphausia pacifica</i>	727
Krill	<i>Megannyctiphanes norvegica</i>	46 - 93
Mackerel	<i>Scomber scomburs</i>	6 - 11
Shrimp	<i>Pandalus borealis</i>	20 - 128
Shrimp, vacuum dried ¹	<i>Pandalus borealis</i>	100
Shrimp, steam dried ²	<i>Pandalus borealis</i>	192
Shrimp, oil	<i>Pandalus borealis</i>	1,095

¹Stabilized with antioxidant; ²Freeze-dried caroteno protein

Biological Properties

Aquatic animals cannot bio-synthesise carotenoids *de novo*. They depend entirely on feed for their supply of carotenoids^(4, 16, 48, 57). During metabolism, carotenoids are either converted into other carotenoids or are esterified, saponified, or bound to proteins or glycerides. Utilisation and metabolic transformation of carotenoids are species specific. Lower classes of animals are able to convert carotenoids to a far greater extent than e.g.

birds and mammals⁽¹⁶⁾. The predominant carotenoids in wild salmonids are astaxanthin and canthaxanthin which originate from the food they live on^(25, 48), and are mainly from zooplankton⁽³⁵⁾. The carotenoids in crustaceans are mainly from algae, where the original carotenoid mainly occurs⁽³²⁾. Carotenoid levels in flesh of wild fish varies according to prey, fish size, stage of maturity and specific pigment metabolism as e.g. for some selected species⁽⁵³⁾:

- Sockeye salmon (*Oncorhynchus nerka*) 26-39 mg/kg flesh
- Chinook salmon (*Oncorhynchus tshawytscha*) 8-9 mg/kg flesh
- Rainbow trout (*Oncorhynchus mykiss*) 73 mg/kg flesh

Astaxanthin is absorbed from the digestive tract of fish⁽⁴⁰⁾. In salmonids, absorption of astaxanthin and canthaxanthin is 10 to 20 times better than that of lutein and zeaxanthin⁽⁴³⁾. Apparent digestibility of carotenoids in salmonids is between 39 and 49%⁽⁵³⁾. Free astaxanthin is better absorbed than astaxanthin dipalmitate.

Apparent digestibility of canthaxanthin may be affected by antibiotic supplementation of the feed and levels of dietary fat⁽⁹⁾.

The metabolic pathways of astaxanthin and canthaxanthin are rather complex. Invertebrates such as crustaceans, that feed on plant materials can convert some carotenoids to astaxanthin and canthaxanthin⁽³²⁾. Aside from kuruma prawn (*Penaeus japonicus*) they are capable to directly deposit astaxanthin in their tissues and can transform β -carotene and zeaxanthin to astaxanthin⁽⁵⁷⁾.

The present knowledge does not indicate that carotenoids are toxic when over-supplied. The acute toxicity in the form of LD₅₀ is not uniform and differ between species and form of administration (Table 16-02)⁽¹⁵⁾.

Table 16-02: Acute toxicity of carotenoids⁽¹⁵⁾

Species	Form of administration	LD ₅₀ (mg/kg liveweight)
1. <u>β-Carotene</u>		
Rat	i.m.	more than 1,000
Dog	oral	more than 8,000
2. <u>Canthaxanthin</u>		
Mouse	oral	10,000
Dog	oral	more than 500

To meet consumers' demand for pigmented flesh and exoskeleton, aquaculture diets are fortified with carotenoids⁽²⁶⁾.

Additional functions of carotenoids are: Enhancement of the immune system; ultraviolet protection; Vitamin A precursor; increasing tolerance to environmental stress, necessary in fecundity of broodstock and for better growth and survival^(25, 31, 52).

The efficacy of carotenoids may be affected by certain factors such as:

- Pigment source, form and concentration
- Diet composition
- Dietary fat content and quality

- Fish size and physiological state
- State of sexual maturation
- Genetic background

Carotenoid Stability in Cultured Fish and Crustacean

Carotenoids are labile to light, heat and oxygen. They may fade in flesh of aquatic animals during storage and processing. The stability of carotenoids in salmonid flesh under various processes such as cooking, canning, smoke-curing and storage conditions is important in final product acceptability^(10, 37, 44). Fading of astaxanthin and canthaxanthin in vacuum-packed rainbow trout (*Salmo gairdneri*) fillets during cold storage cannot be excluded^(7, 36, 41).

Other Properties

Astaxanthin, zeaxanthin and canthaxanthin are Vitamin A precursors in aquatic animals. The conversion rate into Vitamin A increases with the age and size of fish^(16, 43).

Astaxanthin is also a powerful antioxidant⁽³⁴⁾. It protects biological membranes from oxidative injury, e.g. Nile tilapia (*Oreochromis nilotica*)⁽²³⁾.

The antioxidant nature of α -carotene differs from the antioxidative property of Vitamin E because α -carotene is most effective at low oxygen pressures and a very efficient single oxygen precursor⁽⁵⁾.

In addition, salmonids having a higher content of astaxanthin are more resistant to bacterial and fungal diseases⁽¹¹⁾ and carotenoids are direct precursors to convert fatty acids to a salmon aroma^(31, 55).

The "blue disease" in farmed tiger prawns is attributed to the lack of astaxanthin^(17, 19). Wild shrimps had 26.3 ppm of total carotenoid in the exoskeleton compared to 4.3 to 1.7 ppm in the "blue diseased" prawns. Low oxygen levels could deplete carotenoid through enhanced fecal release⁽¹⁷⁾.

16.3 Carotenoid Products

Major pigmenting substances used in feeds for cultured aquatic animals are:

- Synthetic astaxanthin,
- Synthetic canthaxanthin,
- Yeast astaxanthin,
- Algal astaxanthin.
- Astaxanthin from crustacean wastes

For pigmenting properties of other feedstuffs such as krill meal and shrimp meal refer to the respective chapters.

16.3.1 Synthetic Astaxanthin and Canthaxanthin

Description

Synthetic astaxanthin and canthaxanthin for feeding purposes are produced on an industrial scale. The basic raw material for the synthesis is crude mineral oil of which

intermediates such as acetone, acetylene and aldehyde are produced. In most cases the starting material for the synthesis is β -ionone⁽⁴⁰⁾.

Properties

Synthetic astaxanthin and canthaxanthin are chemically identical to the naturally occurring compounds in aquatic animals. Pigmentation strength of canthaxanthin is only half of that of astaxanthin. Specifications for synthetic carotenoids, astaxanthin and canthaxanthin are in Table 16-03.

Table 16-03: Specification of synthetic carotenoids¹

			Astaxanthin	Canthaxanthin
Carotenoid content	min.	%	8.0	10.0
Loss of drying	max.	%	8.0	8.0
Appearance			violet-brown to violet-red, free flowing powder	red-violet, free flowing powder
Fineness ²	No. 20	%	100	100
	No. 40	min. %	90	90
	No. 10	max. %	15	15
Shelf-life ³	months		12	36

¹Data from the manufacturers; ²U.S. standard sieves; ³In the unopened container

Feeding Value

Fishes: Pigmentation of salmonids changes throughout life. Generally, fingerlings have limited capacity for carotenoid deposition in the flesh, while significant amounts are deposited in the skin⁽⁴⁸⁾. The carotenoid concentration in the skin of e.g. immature rainbow trout increased until week 49 and decreased thereafter⁽³⁾.

Redness is normally higher for astaxanthin-pigmented flesh than for canthaxanthin-pigmented flesh⁽³⁸⁾. The effect of water salinity on carotenoid concentration in rainbow trout depends most probably on the pigment concentration in the feed. At higher levels of astaxanthin (50 mg/kg) and canthaxanthin (100 mg/kg), respectively, the water salinity had no effect on the carotenoid retention⁽³⁸⁾ while at lower levels of both synthetic pigments 25 mg/kg and 50 mg/kg, respectively, the carotenoid concentration was higher in freshwater than in seawater⁽⁴⁹⁾.

In salmonids, water temperature did not significantly affect total retention of astaxanthin. However, the skin accumulated more carotenoids at 5°C than 15°C water temperature⁽⁵⁰⁾.

The effect of carotenoids in reproduction showed that sexually mature rainbow trout females retained about four times more total carotenoids than males after feeding of astaxanthin and canthaxanthin at levels of 100 mg/kg each for 140 days. Females deposit carotenoids predominantly in the gonads while males show lipid levels in the skin⁽³⁾.

Aside from the efficacy of synthetic astaxanthin and cantaxanthin on their deposition in the flesh and skin and the effect on reproduction, the carotenoids also promote growth and good feed conversion of salmonids^(3, 12, 49).

The positive effect of carotenoids on the reproduction of salmonids is particularly pronounced in eggs exposed to sunlight and kept at elevated water temperature or at low oxygen content of water⁽¹⁶⁾. The number of total eggs doubled when 40 mg/kg canthaxanthin were fed to rainbow trouts and the portion of non-fertile eggs was only 0.1% compared to 4.1% in the control⁽¹²⁾. There is a positive relation between egg mortality and egg astaxanthin content in rainbow trout before hatching⁽³²⁾. With increasing astaxanthin content in the egg, the survival before hatching increases (Table 16-04)⁽²⁸⁾.

Table 16-04: Relation between egg mortality and egg astaxanthin content in rainbow trout (*Salmo gairdneri*)⁽²⁸⁾

Egg colour	Astaxanthin content of eggs mg/kg	Mortality of eggs before hatching %
Bright	1.7	13.2
Less bright	1.3	16.3
Pale	traces	24.4
Very pale	0	36.4

Crustaceans

Pigmentation of crustaceans is very complex and influenced by many factors (Figure 16-01). The main inherent carotenoids in tiger prawn (*Penaeus monodon*) exoskeletons are astaxanthin, astaxanthin esters and β -carotene⁽¹⁹⁾. They are deposited mainly in the head and shells with the exception of farmed tiger prawns where 1/3 of astaxanthin is deposited in the flesh (Table 16-05)⁽²⁾.

Feeding tiger prawns with increasing levels of astaxanthin and cantaxanthin for two months, improved their pigmentation. Astaxanthin was more effective than canthaxanthin or other carotenoids in pigmenting the prawns (Table 16-07)⁽²⁹⁾.

Table 16-05: Distribution of astaxanthin in shrimp (%)⁽²⁾

	Flesh	Shell	Head
Tiger prawn (wild)	13.2	47.2	39.6
Tiger prawn (farmed)	32.4	43.7	23.9
Kuruma prawn	12.2	25.0	62.8
Southern velvet shrimp	13.6	28.8	57.0

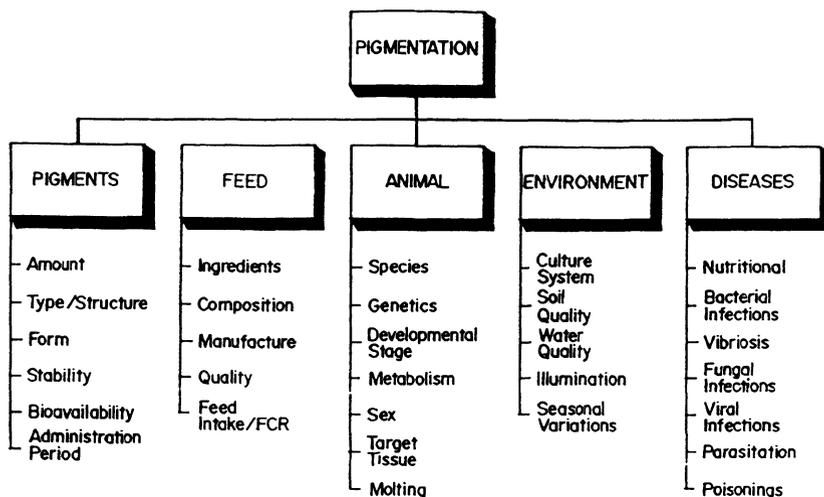


Figure 16-01. Factors that influence pigmentation in crustaceans^(data from: 25).

Contrary to observations in salmonids, in shrimps (*Palaemon serratus*) the variation of the water temperature affects the efficacy of carotenoids⁽⁵⁴⁾.

Similar to fish, females of crustaceans like the sand crab (*Emerita analoga*) contain higher levels of carotenoids than males⁽¹⁴⁾. The reproductive performance of tiger prawn broodstock fed carotenoids alone (astaxanthin) or in combination with natural carotenoid in the form of the green mussel (*Perna viridis*) will improve. Not only significantly more eggs are produced but also hatched and the metamorphosis into the postlarval stage is greater^(30, 42).

In kuruma prawns, it was demonstrated that survival rate is not only improved when carotenoids are in the diet but the survival rate is also positively correlated with pigment concentration in the diet. Levels with more than 100 mg carotenoid may have a negative effect on growth rates (Table 16-06)⁽⁸⁾. In tiger prawns, growth rates improved at the higher levels of carotenoids and feed conversion gets better as the carotenoid content of the diet increases (Table 16-07)⁽²⁹⁾.

Table 16-06: Survival and weight gain of kuruma prawns (*Penaeus japonicus*) fed diets containing various pigment sources at different levels (mg/kg)⁽⁸⁾

Astaxanthin		50	100	200	-	-	-	-	-
β-carotene		-	-	-	50	100	200	-	-
Algal meal		-	-	-	-	-	-	100	-
Control		-	-	-	-	-	-	-	0.9

Survival	%	87	77	63	57	40	53	40	50
Weight gain	g	3.6	4.0	3.7	3.7	5.7	5.0	8.2	0.9

Table 16-07: Pigmentation efficacy of astaxanthin in tiger prawns (*Penaeus monodon*) (Feeding period: 2 months)⁽³⁴⁾

	Carotenoid level in...		Visual scoring ¹	Feed conversion 1:
	Diet mg/kg	Whole prawn mg/kg		
Control	0	3.17	4.0	4.83
Astaxanthin	25	8.02	3.0	3.72
	50	8.75	2.5	3.25
	75	10.80	2.0	2.89
	100	15.18	1.0	2.33

¹Visual scoring of boiled prawns (1=greyish brown; 2=dark violet; 3=light violet; 4=blue)

16.3.2 Yeast Astaxanthin

Description

The yeast *Phaffia rhodozyma* is of commercial interest as a natural supplier of astaxanthin. *Phaffia rhodozyma* was isolated from trees in Japan, Alaska and the former Soviet Union and astaxanthin was identified as the major carotenoid pigment in the yeast⁽²⁰⁾.

Properties

Cultured wild strains of *Phaffia rhodozyma* were found to contain 30 to 800 mcg unesterified astaxanthin per g yeast-dry matter. The wide range of the astaxanthin content depends on the method of culture. The chemical composition of *Phaffia rhodozyma* is listed in Table 16-08. Yeast has a well balanced essential amino acid profile⁽²⁰⁾. Its protein quality improves when supplemented with methionine. The high fat content may promote absorption of carotenoid pigments.

Mutant strains of *Phaffia rhodozyma* that produce up to ten-times as much astaxanthin as wild strains have been isolated⁽¹⁾. In industrial fermentations, yields of 2,000 to 3,000 mg astaxanthin per kg yeast are produced in four to seven days^(20, 33). The commercial yeast astaxanthin can be used at a rather low level. Often an antioxidant is added to prevent oxidation of astaxanthin during processing and storage⁽³³⁾.

Table 16-08: Chemical composition (%) of *Phaffia rhodozyma* compared to that of brewer's yeast⁽²¹⁾

	<i>Phaffia rhodozyma</i>	Brewer's yeast
Crude protein	30.1	54.4
Carbohydrates	40.3	33.4
Lipids	17.0	4.0
Ash	5.6	6.5
Astaxanthin	0.06	0

Feeding Value

Pigmentation trials were carried out in rainbow trout with *Phaffia rhodozyma* prepared by various treatments showed that the entire enzymatic removal of yeast cell wall is superior to all other forms of treatment. The pigmentation was stable for several months. There were no differences between yeast astaxanthin and synthetic astaxanthin but the consistency of the pigmentation of fish fed yeast astaxanthin was more uniform than that achieved with the synthetic astaxanthin⁽²¹⁾.

Yeast astaxanthin is particularly deposited in the carapaces of the lobster (*Homarus americanus*) when fed a preparation of *Phaffia rhodozyma*⁽²²⁾.

16.3.3 Algal Astaxanthin

Description

Most algae are sources of carotenoids. The green algae, *Haematococcus*, can be found in inland waters⁽¹⁸⁾. The microalgae accumulates significant quantities of astaxanthin, particularly in the spore stage of its life cycle and is primarily present as esters of various fatty acids⁽⁴⁵⁾. As an effective pigment source in poultry diets, meals from the sewage-grown algae *Chlorella* and *Micractinium* are used⁽²⁷⁾.

Properties

The biomass of *Haematococcus pluvialis* is a spray-dried free-flowing powder. Spores have to be disrupted to increase the bioavailability of astaxanthin. At least 60% of the cells should be completely disrupted to obtain good pigmentation results⁽⁴⁵⁾.

Feeding Value

Feeding of astaxanthin from micro-algae (*Haematococcus pluvialis*) to rainbow trout for 100 days resulted in significant deposition of total carotenoids and astaxanthin as well as the visual enhancement of flesh colouration in rainbow trouts (Table 16-09).

Table 16-09: Deposition of pigmenters in rainbow trout (*Oncorhynchus mykiss*) flesh fed for 100 days with algal astaxanthin⁽⁴⁵⁾

Algal astaxanthin:					
- intact spores	%	-	-	-	2.7
- disrupted spores	%	-	-	2.7	-
Synthetic astaxanthin	%	-	5.0	-	-
Astaxanthin in the feed	mg/kg	0	40	40	40

Pigmentation of flesh:					
- Astaxanthin	mcg/g	0.01	3.65	2.13	0.82
- Carotenoids	mcg/g	0.17	3.46	2.05	0.84
- Colour score ¹		1.0	4.9	3.6	2.2
Pigment levels in the skin ²	mcg/g	0.81	11.24	9.53	4.56

¹ 1 = no visual pigment; 8 = maximum red; ²total carotenoid (spectro-photometric)

There were no significant differences in the growth of the fish. Best flesh colouration was obtained with the synthetic astaxanthin (positive control) followed by disrupted spores and intact spores. Since intact spores are poorly digested, only algal astaxanthin from disrupted spores is a suitable pigmenter⁽⁴⁵⁾.

Algal astaxanthin from *Dunaliella salina* is not as pigmentation-effective as synthetic astaxanthin and β -carotene carotenoids (Table 16-06)⁽⁸⁾.

16.3.4 Astaxanthin from Crustacean Wastes

Description

Discards from crustacean processing contain useful polymers, carotenoid pigments such as astaxanthin which is the most common and other components that are biologically active⁽⁶⁾.

Shrimp heads, shrimp meals, red crab (*Pleuroncodes planipes*), crawfish (*Procambarus clarkii*) and lobster wastes are sources of astaxanthin which are used as pigmenter in aquaculture feeds^(13, 47, 51).

Various oils such as soybean and fish oils are used in the astaxanthin extraction from freshly ground crustacean waste resulting in a significant concentration in the oil. Astaxanthin levels in the oil phase vary in different crustacean meals (Figure 16-02) and is highest in crawfish waste.

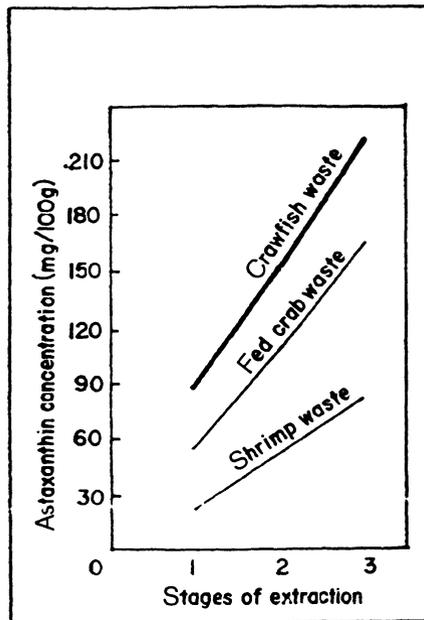


Figure 16-02. Astaxanthin levels in the oil phase from various crustacean meals (re-drawn from: 32).

Properties

Carotenoids from crustacean wastes are unstable. Valuable active components may be derived from crustacean wastes only if they were carefully handled and stored prior to processing. Degradation occurs during the first 15 minutes of extraction (Figure 16-01)⁽⁴⁶⁾. The addition of an antioxidant reduces carotenoid losses during processing substantially. Carotenoid extracts properly stored are stable for at least six months⁽⁴⁶⁾.

Feeding Value

Feeding coho salmon oil extract of red crab (*Pleuroncodes planipes*) showed that the amount of carotenoid deposited in the flesh of the fish was related to the carotenoid of the diet and to the weight of the fish. Salmon fed with 9.0 mg carotenoid/100 g diet from red crab astaxanthin contained significantly more carotenoids than those fed 3.0 mg carotenoid/100 g diet (Figure 16-03)⁽⁴⁶⁾.

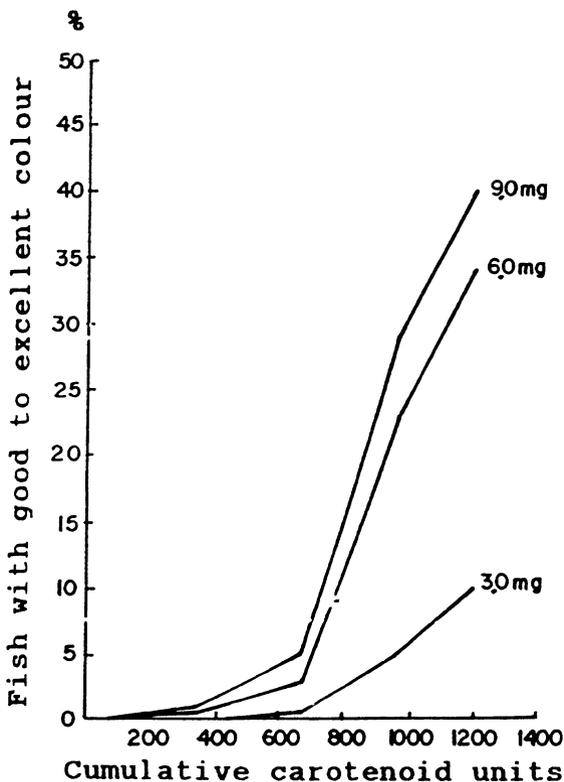


Figure 16-03. Percentage of fish with good to excellent colour after 120 days of feeding 3.0, 6.0 and 9.0 mg carotenoids per 100 grams feed^(data from: 46).

16.4 Recommended Inclusion Rates

A certain quantity of carotenoids is required in the feed to produce the desired flesh and/or exoskeleton colour of aquatic animals. This quantity is comprised of the inherent carotenoid content of the ingredients of the completed feed (Table 16-01) and the added carotenoids such as synthetic astaxanthin and cantaxanthin. The higher the level of inherent carotenoids, less supplemental carotenoids is needed.

The deposition of carotenoids in the organism is cumulative. Fortifying feeds with carotenoids for the entire production period requires lower inclusion rates, but higher inclusion levels are needed when they are supplemented only to the finisher feed. A guideline for supplementation of carotenoids in aquaculture feeds is in Table 16-10.

Table 16-10: Guideline for the application of carotenoids to aquaculture feeds

	Wanted astaxanthin Content in the feed mg/kg	Inclusion rate
Synthetic astaxanthin		50 to 100 mg/kg
Synthetic cantaxanthin		50 to 100 mg/kg
Yeast astaxanthin ¹	30	1.0%
	50	1.7%
	70	2.3%
	100	3.3%
Algal astaxanthin from disrupted spores	40	2.7%
	60	4.1%
	80	5.4%
	100	6.8%
Astaxanthin from red crab crustacean waste	60	1,020 mg/kg
	90	1,550 mg/kg

¹assumes that the yeast contains 53,000 mg astaxanthin/kg

16.5 Legal Aspects and Precautions

Legal Aspects

The use of pigmenting substances in animal nutrition is controlled in the European Union by EU-Directive 70/524 (Table 16-11). In the USA canthaxanthin is considered as a nature-identical synthetic carotenoid and is exempted from certification. While not carcinogenic, it may cause changes in the liver and retina thus, the "Acceptable Daily Intake" (ADI) was not extended by JECFA (Joint Expert Committee on Food Additives) in 1990.

The permission to use carotenoid products in feeds for aquatic animals may differ from country to country and local regulations have to be observed.

Table 16-11: Pigmenters approved by EU-Authorities for the use in feeds for aquatic animals⁽⁵⁶⁾

EWG No.	Name of substance	Approved for...	ppm ¹	Remarks
E 161 g	Canthaxanthin	Salmons	80	Not to be used before the age of six months. Mixing of canthaxanthin and astaxanthin is permitted as long as 100 ppm in the completed feed are not exceeded
	$C_{40}H_{52}O_2$	Trouts	80	
		Ornamental fish	80	
E 161 j	Astaxanthin	Salmons	100	Not to be used before the age of six months. Mixing of canthaxanthin and astaxanthin is permitted as long as 100 ppm in completed feed are not exceeded
	$C_{40}H_{52}O_4$	Trouts	100	
		Ornamental fish	100	

¹max. inclusion rate in diets

Precautions

Excess of carotenoids in the diet may cause an undesirable colour in the fish, e.g. a concentration of 0.6 g carotenoid/g flesh can cause yellow colour of the flesh of channel catfish which is undesirable⁽²⁶⁾.

16.6 References

1. An, G.K.; Schuman, D.B.; Johnson, E.A. (1989): Isolation of *Phaffia rodozyma* mutants with increased astaxanthin content. Appl. Environ. Microbio., 55., 116.
2. Anonymous (1992): Technical Q and A. Infotish International., 6., 55.
3. Bjerkeng, B.; Storebakken, T.; Liaaen-Jensen, S. (1992): Pigmentation of rainbow trout from start feeding to sexual maturation. Aquaculture, 108., 333-346.
4. Brinchmann, H.J. (1967): Quoted from: Meyers, S.P.; Chen, H.M. (1982).
5. Burton, G.W. (1989): Antioxidant action of carotenoids., J. Nutr., 119., 116.
6. Chen, H.M.; Meyers, S.P. (1982): Extraction of astaxanthin pigment from crawfish waste using a soya oil process. J. Food Sci., 47., 892-896 & 900.
7. Chen, H.M.; Meyers, S.P.; Hardy, R.W.; Biede, S.L. (1984): Color stability of astaxanthin pigmented rainbow trout under various packaging conditions. J. Food Sci., 49., 1337.
8. Chien Y.-H.; Jeng, S.C. (1992): Pigmentation of kuruma prawn, *Penaeus japonicus* Bate, by various pigment sources and levels and feeding regimes. Aquaculture, 102., 333-346.
9. Choubert, G.; Noüe, J. de la; Blanc, J.M. (1991): Apparent digestibility of cantaxanthin in rainbow trout effect of dietary fat level, antibiotics and number of *Pyloric caeca*. Aquaculture, 99., 323.
10. Choubert, G.; Blanc, J.M.; Courvalin, C. (1992): Muscle carotenoid content and colour of farmed

- rainbow trout fed astaxanthin or canthaxanthin as affected by cooking and smoke-curing procedures. *Int. J. Food Sci. and Tech.*, *27.*, 277-284.
11. *Czczuga, B.* (1979): Carotenoids in fish. XIX. Carotenoids in the eggs of *Oncorhynchus keta* (Walbaum). *Hydrologia*, *63.*, 45-47.
 12. *Deufel, J.* (1965): Quoted from: *Hencken, H.* (1992)
 13. *D'Abramo, L.R.; Baum, N.A.; Bordner, C.E.; Conklin, D.E.* (1983): Carotenoids as a source of pigmentation in juvenile lobsters fed a purified diet. *Can. J. Fish. Aquat. Sci.*, *40.*, 699.
 14. *Gilchrist, B.M.; Lee, W.L.* (1972): Carotenoid pigments and their possible role in reproduction in the sand crab, *Emerita analoga* (Stimpson, 1857). *Comp. Biochem. Physiol.*, *425.*, 263-294.
 15. *Hanck, A.B.; Kuenzle, C.C.; Rehm, W.F.* (1991): Vitamin A. Verlag Paul Parey, Hamburg and Berlin/Germany.
 16. *Hencken, H.* (1992): Biological properties of feed carotenoids. *Feed Magazine*, (2), 25-28.
 17. *Heralde, F.; Lean, M.; Reyes, A.; Coloso, R.* (1994): A preliminary study in the effect of hypoxia on carotenoid metabolism in tiger shrimp *Penaeus monodon* Fabricius. *Proc. National Seminar-Workshop Fish Nutrition and Feeds*, 1 to 2 June, SEAFDEC/AQD, Tigbauan, Iloilo/The Philippines.
 18. *Hertrampf, J.W.* (1994): Schweden und seine Eierversorgung. *Deutsche Geflügelwirtschaft und Schweineproduktion*, *46.*, (50), 11-12.
 19. *Howell, B.K.; Matthews, A.D.* (1991): Quoted from: *Meyers, S.P.* (1994).
 20. *Johnson, E.A.* (1989): A pigment source in salmonid feed. *Feed Management*, *40.*, 18-21.
 21. *Johnson, E.A.; Villa, T.G.; Lewis, M.J.* (1980): *Phaffia rhodozyma* as an astaxanthin source for salmonid diets. *Aquaculture*, *20.*, 123.
 22. *Johnson, E.A.; Conklin, D.E.; Lewis, M.J.* (1977): The yeast *Phaffia rhodozyma* as a dietary pigment source for salmonids and crustaceans. *J. Fish. Res. Board Canada*, *34.*, 2417.
 23. *Katsuyama, M.; Matsuno, T.* (1988): Quoted from *Meyers, S.P.* (1984).
 24. *Kurunajeewa, H.; Hughes, R.J.; McDonalds, W.M.; Shenstone, F.S.* (1984): A review of factors influencing pigmentation. *WPSA Journal*, *40.*, 52-65..
 25. *Latscha, T.* (1991): Carotenoids in aquatic animal nutrition. *Proc. Aquacult. Feed Processing and Nutr. Workshop. Thailand and Indonesia, Singapore*, 68-79.
 26. *Lee, P.H.* (1987): Carotenoids in the culture of channel catfish. Ph.D. Diss., Auburn Univ., Auburn, Alabama/U.S.A.
 27. *Lipstein, B.; Talpaz, H.* (1984): Sewage-grown algae as a source of pigments for broilers. *British Poultry Sci.*, *25.*, 159-165.
 28. *Longinova, T.A.* (1967): Quoted from: *Hencken, H.* (1992).
 29. *Menasveta, P.; Choosuwan, J.; Buhler, I.I.; Schierl, D.W.; Latscha, T.* (1992): Effect of dietary astaxanthin and cantaxanthin on the pigmentation of giant tiger prawns (*Penaeus monodon*) Fabricius. *Proc. 3rd Asian Fish. Forum.*, 26 to 30 Oct., Singapore, 717-720.
 30. *Menasveta, P.; Choosuwan, J.; Piyattirativorakul, S.; Fast, A.W.; Latscha, T.* (1992): Effect of dietary astaxanthin on gonadal maturation and spawning of giant tiger prawn (*Penaeus monodon*). *Proc. 3rd Asian Fish. Forum*, 26 to 30 Oct., Singapore. 713-716.
 31. *Meyers, S.P.* (1994): Developments in world aquaculture, feed formulations, and role of carotenoids. *Pure and Appl. Chem.*, *66.*, 1069-1076.
 32. *Meyers, S.P.; Chen, H.M.* (1982): Astaxanthin and its role in fish culture. *Proc. Warmwater Fish Culture Workshop. Special Publ. No. 3, Charleston, South Carolina*. 154-164.
 33. *Meyers, S.P.; Sandersonn, G.W.* (1992): Natural pigments for salmon feeds. *Feed Management*, *43.*, 12-20.
 34. *Miki, W.* (1991): Quoted from: *Meyers, S.P.* (1994).
 35. *NRC* (1993): Nutrient requirement of fishes. National Research Council, Nat. Acad. Sci., Washington

D.C./USA.

36. No, H.K.; Storebakken, T. (1990): Pigmentation of rainbow trout with astaxanthin at different water temperatures. *Aquaculture*, *97.*, 203-216.
37. No, H.K.; Storebakken, T. (1990): Color stability of rainbow trout fillets during frozen storage. *J. Food Sci.*, *56.*, 969-972, 984.
38. No, H.K.; Storebakken, T. (1992): Pigmentation of rainbow trout with astaxanthin and cantaxanthin in freshwater and saltwater. *Aquaculture*, *101.*, 123-134.
39. Olson, J.A. (1989): Pro-vitamin A function of carotenoids: The conversion of β -carotene into Vitamin A. *J. Nutr.*, *119.*, 105-111.
40. Olson, J.A. (1984): Vitamin A. In: *Machlin, L.J.* (ed.): *Handbook of vitamins*. Marcel Dekker, Inc., New York and Basle.
41. Pozao, R.; Lavety, J.; Love, R.M. (1988): The role of dietary β -tocopherol (Vitamin E) in stabilising the canthaxanthin and lipids of rainbow trout muscle. *Aquaculture*, *73.*, 165.
42. Quintio, E.T.; Parado-Esteva, F.D.; Millamena, O.M.; Biona, H. (1994): Reproductive performance of captive *Penaeus monodon* fed various sources of carotenoids. Pres. at the National Seminar-Workshop on Fish Nutrition and Feeds, 1 to 2 June, SEAFDEC/AQD, Tigbauan, Iloilo/The Philippines.
43. Schiedt, F.J.; Leuenberges, Vecchi, M.; Glinz, E. (1985): Absorption, retention and metabolic transformations of carotenoids in rainbow trout, salmon and chicken. *Pure Appl. Chem.*, *57.*, 685-692.
44. Skrede, G.; Storebakken, T.; Naes, T. (1990): Color evaluation in raw, baked and smoked flesh of rainbow trout (*Oncorhynchus mykiss*) fed astaxanthin or canthaxanthin. *J. Food Sci.*, *55.*, 1574-1578.
45. Sommer, T.R.; Potts, W.T.; Morrissy, N.M. (1991): Utilisation of microalgal astaxanthin by rainbow trout (*Oncorhynchus mykiss*). *Aquaculture*, *94.*, 79-88.
46. Spinelli, J.; Mahnken, C. (1978): Carotenoid deposition in pen-reared salmonids fed diets containing oil extracts of red crab (*Pleuroncodes planipes*). *Aquaculture*, *13.*, 213-223.
47. Spinelli, J. (1982): Quoted from: *Chen, H.M.; Meyers, S.P.* (1983).
48. Storebakken, T.; No, H.K. (1992): Pigmentation of rainbow trout. *Aquaculture*, *100.*, 209-229.
49. Storebakken, T.; Choubert, G. (1991): Flesh pigmentation of rainbow trout fed astaxanthin and canthaxanthin at different feeding rates in freshwater and saltwater. *Aquaculture*, *95.*, 289-295.
50. Storebakken, T.; Foss, P.; Huse, I.; Wandsvik, A.; Lea, T.B. (1986): Carotenoids in diets for salmonids. III. Utilisation of canthaxanthin from dry and wet diets by Atlantic salmon, rainbow trout and sea trout. *Aquaculture*, *51.*, 245-255.
51. Thibodeaux, P.D. (1981): Crawfish processing waste as a source of astaxanthin in aquatic diet formulations. M.S. Thesis, Dept. of Food Science, Louisiana State Univ., Baton Rouge, L.A.
52. Torrissen, O.J. (1989): Biological activities of carotenoids in fishes. Proc. Third Intern. Symp. Feeding and Nutrition in Fish., Toba/Japan. 387-399.
53. Torrissen, O.J.; Hardy, R.W.; Shearer, K.O. (1989): Pigmentation of salmonids-carotenoids deposition and metabolism critical review. *Aquat. Sci.*, *1.*, 209-225.
54. Vincent, M. (1989): Influence of water temperature on carotenoids and carotenoids metabolism in *Palaemon serratus* (Pennant) (Crustacea: Decapoda). *Biochem syst. Ecology*, *17.*, 319-322.
55. Waagboe, R.; Sandness, K.; Torrissen, O.J.; Sandrin, A.; Lie, O. (1993): Quoted from: *Meyers, S.P.* (1994).
56. Weinreich, O.; Koch, V.; Knippel, J. (1974): Futtermittelrechtliche Vorschriften. Buchedition Agrimedia, Hamburg/Germany.
57. Yamada, S.; Tanaka, Y.; Sameshima, M.; Ito, Y. (1990): Pigmentation of prawn (*Penaeus japonicus*) with carotenoids. I. Effect of prawn dietary astaxanthin, β -carotene and canthaxanthin on pigmentation. *Aquaculture*, *87.*, 323-330.

17. FEED YEAST

17.1 Rationale

The term “yeast” is derived from the old English word “gist” and the German word “gischt” which refers to fermentation. The ancient Egyptians used yeast for making bread, beer and wine⁽⁴⁷⁾.

Yeast is the name for any of the various single celled *Ascomycetes* fungi in which little or no mycelium develops and ordinarily reproduces by budding. Yeast live on sugar solutions, and ferment sugar to form alcohol and carbon-dioxide. It is used in various fermenting industries as well as food and medicine for man.

There are a total of 39 genera of yeast, representing 363 different species, of which 178 species are classified as “true yeast” and 185 species as “false yeast”⁽⁶⁾. One of the most prominent yeast genera is the genus *Saccharomyces* of which the species *Saccharomyces cerevisiae* has the widest applicability. More than 50 strains of this species have been developed and are used as brewer’s yeast, baker’s yeast, wine yeast and others (Figure 17-01).

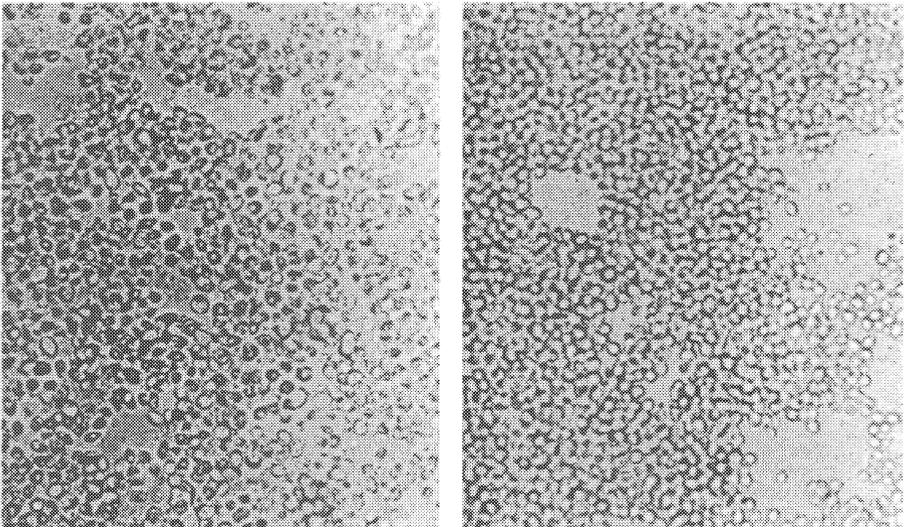


Figure 17-01. Microscopic photos of spray-dried brewer's yeast (left) and molasses yeast (right).

The “Association of American Feed Control Officials, Inc.” (AAFCO) classifies yeast for feeding purposes as:

- Inactive or dead yeast
 - Primary yeast
 - Brewer’s yeast
 - Lactic yeast
 - Grain distillers’ yeast
 - Molasses yeast
 - Torula yeast
 - Alkane (petroleum) yeast
- Active or live yeast
 - Baker’s yeast
 - Yeast culture.

17.2 Inactive Yeast

17.2.1 Definition and Manufacture

Any type of fresh yeast cannot be stored. The wet material has to be spray-dried or drum-dried. In the dried form inactive yeast is a noble feedstuff for aquaculture feed.

Brewer’s Yeast

Brewer’s yeast is one of the by-products of beer brewing. About 1.5 kg dried brewer’s yeast is obtained from 100 kg barley brewed into beer.

Yeast of the type *Saccharomyces cerevisiae* or *Saccharomyces calshbergensis* is added to the wort to activate fermentation. After the fermentation is completed, the yeast dies off and settles to the bottom of the brewing vat. The yeast is separated from the crude beer by centrifugation, washed free of beer, pasteurised, plasmolysed by heat and dried at a relatively high temperature⁽⁵⁶⁾. Drum-dried yeast has to be ground. The cell content is made available by plasmolysis. One gram of yeast contains billions of cells.

A certain degree of bitterness of brewer’s yeast is caused by hops and may affect its palatability (Table 17-01)⁽²⁰⁾. The bitter tasting hop resins and tannins absorbed on the surface of the yeast cells can be removed by washing with an alkaline solution⁽⁵⁵⁾. The resulting product is named “de-bittered brewer’s yeast”.

Table 17-01: Properties of inactive yeasts

Property	Brewer’s yeast	Molasses yeast	Lactic yeast	Torula yeast
Colour	pale brown	gray to dark brown	creamy to light brown	light yellow
Taste	typical yeast (bitter)	soft	like cheese	soft, after taste not bitter
Odour	typical for cheese	pleasant	like cheese	typical for cheese

Molasses Yeast

Molasses yeast is a strain of the species *Saccharomyces cerevisiae*, and is a by-product of industrial alcohol manufacture from sugar-beet or sugar-cane molasses fermentation. Molasses yeast can also be a condensate of baker's yeast cells propagated on molasses⁽⁵⁶⁾. The yeast is separated from its culture medium by centrifugation, filtered and spray- or drum-dried. Drum-dried yeast has to be ground⁽²⁷⁾.

Lactic yeast

Lactic yeast, *Kluyveromyces lactis* and *Kluyveromyces fragilis*, species of the genus *Saccharomyces*, is grown on whey and liquid wastes of milk processing. After fermentation is completed the yeast is separated from the fermentation medium by centrifugation. The crude yeast is washed to remove all fermentation impurities. To burst the cell walls, the yeast is plasmolysed, pasteurised and spray-dried⁽¹⁸⁾.

Torula Yeast

Torula yeast, also called fodder yeast, belongs to the genus *Candida* which is grown specifically for animal feed. *Torulopsis utilis* is a yeast-like fungi that reproduces by budding and grows rapidly. Torula yeast is cultivated predominantly on wood saccharides, a waste liquor from the production of pulp for paper manufacture. It can be grown also on citrus pulp, molasses and other organic wastes. Torula yeast cultured on cellulose waste waters may contain up to 10% ligninsulphonates^(56, 67)

Candida ingens, a yeast high in protein and ashes has been developed in Australia for the treatment of animal wastes⁽²⁰⁾.

Alkane Yeast

Alkanes are saturated hydrocarbons of the methane series. They are components of most mineral crude oils. Strains of yeast, like *Candida lipolytica* have been selected because they can be cultivated on mineral crude oil. Colloquially, alkane yeasts are named "single cell protein". This is incorrect because alkane yeast contains not only protein but also other nutrients. Petro-protein and petroleum yeast are other names for this type of yeast⁽²²⁾.

17.2.2 Chemical, Physiological and other Properties

Chemical Properties

Yeast is both a protein and an energy source. Nucleic acid nitrogen, mostly in the form of ribonucleic acid, constitutes about 20% of the protein in the yeast⁽⁶²⁾. Glutathione, a peptide of yeast cells is also found in yeast. Crude fibre content is low but ash content appears to be high (Table 17-02).

The methionine content is low (Table 17-03). When compared to chicken egg protein, which is considered an excellent protein source for animals, the methionine and cystine content of torula yeast has an index (based on chicken egg protein) of only 48 (max. 100) which is seriously limiting⁽⁵⁰⁾. Torula yeast has also 0.5% linoleic acid (18:2n-6)⁽²⁰⁾.

Table 17-02: Mean chemical composition of different types of inactive, dry yeasts (as fed)

	Brewer's yeast (16,20,22, 24,50,53,+)	Torula yeast (20,53, +)	Molasses yeast (+)	Lactic yeast (+)	Alkane yeast ⁵ (8,72,74,+)
Dry matter %	92.2	92.3	94.8	91.8	94.0
Crude protein %	46.3	45.9	42.5	48.1	66.0
Crude fat %	1.7	4.2	2.8	4.4	0.9
Ash %	6.8	8.1	8.8	8.3	7.3
Crude fibre %	2.4	2.2	0.5	1.0	0.1
N-free extract %	35.0	31.9	40.2	30.0	19.7

(+) inclusive of manufacturers data

Table 17-03: Essential amino acid profile of different types of inactive dry yeasts (g/16 g N)

	Brewer's yeast ¹	Torula yeast ¹	Molasses yeast ¹	Lactic yeast ¹	Alkane yeast ¹
Arginine	2.22	3.59	2.27	2.40	5.18
Histidine	1.38	1.57	1.11	0.95	1.64
Isoleucine	2.50	3.11	2.70	2.28	3.17
Leucine	3.61	4.98	3.89	3.40	3.30
Lysine	3.61	4.99	3.76	3.60	6.15
Methionine	0.70	0.91	0.84	0.80	0.77
Phenylalanine	2.07	3.17	2.46	1.75	2.02
Threonine	2.56	3.38	2.82	2.33	3.09
Tryptophan	0.70	0.82	0.59	0.55	0.96
Valine	2.83	3.75	2.97	2.35	3.45

¹ for references see Table 17-02

The minerals are embedded in the yeast cell and are available in an assimilable form (Table 17-04). The sodium content is low but does not need to be supplemented in diets for sea and brackish water cultured animals⁽¹²⁾.

Yeast is a major natural source particularly of B-vitamins^(20, 50) which are stable and readily available⁽⁵³⁾. Brewer's yeast is very rich in Vitamin B₁ (Table 17-05). The vitamins are in conjugated form as they occur in nature, hence are less likely to leach into the water⁽⁵³⁾.

Table 17-04: Macro and trace mineral contents of different types of inactive dry yeasts

		Brewer's yeast ¹	Torula yeast ¹	Molasses yeast ¹	Lactic yeast ¹	Alkane yeast ¹
Calcium	%	0.25	0.45	0.45	0.35	0.46
Phosphorus	%	1.26	1.42	0.65	1.45	-
Sodium	%	0.15	0.02	1.58	0.75	-
Potassium	%	1.66	1.60	2.75	2.05	-
Magnesium	%	0.20	0.16	0.20	0.15	-
Chlorine	%	0.07	0.02	0.10	-	-
Sulphur	%	0.42	0.55	0.25	-	-
Manganese	mg/kg	18.18	10.4	7.0	0.5	-
Iron	mg/kg	143.40	134.10	92.50	60.0	-
Zinc	mg/kg	48.20	96.10	370.10	45.00	-
Copper	mg/kg	22.40	13.20	37.00	25.00	-
Selenium	mg/kg	0.46	1.00	-	-	-

¹ for references see Table 17-02

Table 17-05: Vitamin contents of different types of inactive, dry yeasts (1,000 g, as fed)

		Brewer's yeast ¹	Torula yeast ¹	Molasses yeast ¹	Lactic yeast ¹
Vitamin E	mg	3.80	58.90	-	45.00
Vitamin B ₁	mg	122.30	5.13	5.25	15.50
Vitamin B ₂	mg	33.50	39.20	40.00	47.59
Vitamin B ₆	mg	33.30	17.27	24.90	9.75
Vitamin B ₁₂	mcg	71.40	3.90	10.00	-
Vitamin C	mg	-	-	-	700.00
Biotin	mcg	743.20	660.00	680.00	-
Folic acid	mg	9.81	9.82	25.75	-
Nicotinic acid	mg	377.40	515.47	675.00	115.0
Panthothenic acid	mg	81.70	54.30	49.00	95.00
Choline	g	3.14	2.96	8.30	-
Inositol	g	2.08	-	3.00	-

¹ for references see Table 17-02

The viability of the cells of active fresh and dry baker's yeast is high at after 10 hours but much lower after 42 hours, particularly for dry yeast (Table 17-06).

Table 17-06: Properties of baker's yeast⁽⁴³⁾

		Fresh yeast	Dry yeast
Dry matter	%	29.0	90.0
Cell diameter	µm	5.0 to 7.0	5.0 to 7.0
Cells per g	nos.	1.10 x 10 ¹⁰	3.08 x 10 ¹⁰
Vitality	%	99.0	85.0
Cell viability:			
- after 10 hours	%	92.6	90.1
- after 42 hours	%	62.9	37.4

Physiological Properties

The mean metabolisable and digestible energy differs insignificantly between *Saccharomyces* yeasts and torula yeast as found in rainbow trout (*Salmo gairdneri*) (Table 17-07).

Table 17-07: Energy values of different inactive, dry yeasts in rainbow trout (*Salmo gairdneri*)

Type of yeast		Mean	Range	Reference
1. Metabolisable energy				
<i>Saccharomyces</i> sp.	kcal/kg	3,110	2,465 - 3,950	(15,53,62.
yeasts	MJ/kg	13.0	10.3 - 16.5	70,71)
Torula yeast	kcal/kg	3,326	3,090 - 3,362	(53,71)
	MJ/kg	13.5	12.9 - 14.1	
2. Digestible energy				
<i>Saccharomyces</i> sp.	kcal/kg	3,436	2,723 - 4,116	(16,62,70)
yeasts	MJ/kg	14.4	11.4 - 17.2	(71)
Torula yeast	kcal/kg	3,367	-	(71)
	MJ/k1	4.1	-	

The apparent protein digestibility of yeast is generally high (Table 17-08). However, the kind of treatment of yeast affects the digestibility. Disruption or homogenisation of the yeast cell wall markedly increased the apparent digestibility of the yeast protein in rainbow trout but energy digestibility was only slightly increase, indicating that salmonid fishes have limited amounts of enzymes capable of digesting cell walls (Table 17-09)⁽⁶²⁾.

Table 17-08: Apparent digestibility (%) of inactive, dry yeasts by various fish species

Species	Dry matter	Crude protein		Energy		Reference
		Mean	Range	Mean	Range	
1. Brewer's yeast						
Salmonids	76.0	78.8	60.4 - 91.0	72.9	60.6 - 84.2	(15,16,34,66,70,71)
2. Torula yeast						
Salmonids	-	82.3		-		(70)
3. Alkane yeast						
Salmonids	-	91.6		-		(34)
Common carp	-	90.9		-		(34)

Table 17-09: Effect of *Saccharomyces* sp. treatment on the apparent digestibility by rainbow trouts (*Salmo gairdneri*)⁽⁶²⁾

Yeast treatment	Apparent digestibility (%)	
	Crude protein	Energy
Intact cells	63.2	62.6
Disrupted cells	84.7	68.6
Disrupted yeast without cell walls	80.5	77.0
Yeast nucleo-protein complex	83.4	69.5
Yeast protein isolate	87.3	70.5

The phosphorus of alkane yeast has an availability of 99% for the common carp (*Cyprinus carpio*) and 91% for the rainbow trout⁽⁷⁴⁾.

Brewer's dried yeast promotes the rate of phagocytosis in fish. Oral application of brewer's dried yeast to rhesus monkeys significantly improved the resistance to seasonal respiratory and enteritis infections, and in mice to chronic infections⁽⁴⁾.

Contrary to many mammals and avians, salmonids can use the nucleic acid (RNA) nitrogen of yeast almost as efficiently as they use protein/amino acid nitrogen⁽⁶²⁾ because of the presence of the hepatic enzyme "uricase"⁽⁴⁰⁾.

Brewer's yeast is particularly rich in glutathione. It is a common component of all cells. The sulphurous tripeptide glutathione, which is found in yeast, is an exogenous transporter and contributes to most of the body's enzymatic reactions⁽⁵⁸⁾.

Other Properties

Brewer's dried yeast is also considered to be a source of UGF⁽⁵⁶⁾ (see chapter 44).

17.2.3 Feeding Value

17.2.3.1 Fishes

Saccharomyces Yeasts

Rainbow trout responded negatively to feed containing 5.0 to 15.0 brewer's yeast as compared to the control fed solely with fresh herring (*Clupea harengus*)⁽⁵⁹⁾ or when brewer's yeast was the primary source of protein (more than 25%). Meager growth was associated with poor feed conversion^(35, 49, 73). Yeast should be used in feeds for spawners and as a source of B-vitamins for fingerlings^(41, 53). Red sea bream (*Chrysophrys major*) larvae were fed successfully with rotifers packed with yeast⁽⁴⁴⁾.

On the other hand, baker's yeast protein can replace up to 50% of the total protein in the diet for the lake trout (*Salvelinus namaycush*) without performance depressing effects, if the yeast cell wall is disrupted to release the intracellular protein (Table 17-10)⁽⁶⁴⁾.

Table 17-10: Differently treated dry baker's yeast (*Saccharomyces cerevisiae*) in the diet for the lake trout (*Salvelinus namaycush*)⁽⁶³⁾

Intact yeast	%	-	32.4	-	-	-	-	-
Intact yeast ¹	%	-	-	32.4	-	-	-	-
Intact yeast ²	%	-	-	-	32.4	-	-	-
Disrupted yeast	%	-	-	-	-	32.4	-	-
Disrupted yeast ¹	%	-	-	-	-	-	32.4	-
Disrupted yeast ²	%	-	-	-	-	-	-	32.4

Final weight	g	12.9	12.0	11.2	11.1	12.6	12.1	12.8
Weight gain	g	10.7	9.7	9.0	8.9	10.4	9.9	10.6
Feed conversion	1:	0.94	1.01	1.07	1.08	0.97	1.00	0.96

¹ yeast washed with saline (0.9% NaCl in distilled H₂O); ² unwashed yeast

Alkane Yeast

Alkane grown yeast as a sole protein source in rainbow trout diets depressed growth. But adding cystine and arginine enhanced fish growth while addition of methionine had no effect^(11, 12, 51, 52, 77). A discolouration of the livers in the yeast-fed fish was also observed^(11, 12, 77).

However, positive effects have been observed when 30 g rainbow trouts were fed with alkane yeast as a sole protein source. Results were comparable to a fish meal diet as the control (Table 17-11)⁽⁹⁾. The combination of alkane yeast with other protein sources in diets for rainbow trouts had no adverse effect on growth rate^(3, 12, 20, 68, 69).

Increasing the levels of alkane yeast (25, 50, 75, 100%) as replacement for fish meal in the diet for coho salmon (*Oncorhynchus kisutch*) (liveweight 30 g) caused a decline in relative feed conversion from 95 to 90, 85 and 76%, respectively. Nevertheless, yeast may replace 25% of fish meal without negatively affecting growth and feed conversion.

Adding l-methionine to the yeast diets did not significantly improve performances (Figure 17-02)⁽⁷²⁾.

Alkane yeast, *Candida lipolytica*, as a first sole nutrient for the coldwater vendace (*Coregonus albula*) fry is a suitable first food. Survival rate was 22% better than that of the control on natural food⁽⁸⁾.

Table 17-11: Performances of rainbow trout (*Salmo gairdneri*) (initial liveweight: 30 g) on diets with alkane yeast and fish meal as the sole protein source⁽⁹⁾

	Fish meal	Alkane yeast
Specific growth rate	1.36	1.30
PER (protein efficiency ratio)	1.91	2.01
NPU (net protein utilisation)	0.38	0.42
BV (biological value)	0.41	0.46

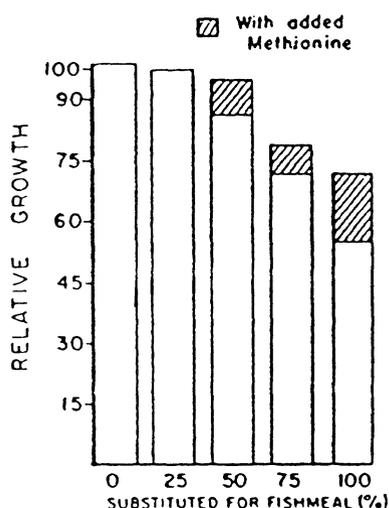


Figure 17-02. Replacement of fish meal by alkane yeast with and without l-methionine in diets for coho salmon (*Oncorhynchus kisutch*)⁽⁷²⁾.

Other Yeasts

Feeding lactic yeast (*Kluyveromyces fragilis*) at a level of 1.0% notably improved the growth of the yellowtail (*Seriola quinqueradiata*) (Figure 17-03). Also eel fry (*Anguilla japonica*) responded favourably on lactic yeast⁽³⁰⁾.

Inconsistent results were obtained when the yeasts *Candida utilis* and *Endomycopsis fibuliger* grown on starch as replacement for animal protein, were fed at levels of 50% and 67% to Atlantic salmon (*Salmo salar*)⁽¹³⁾.

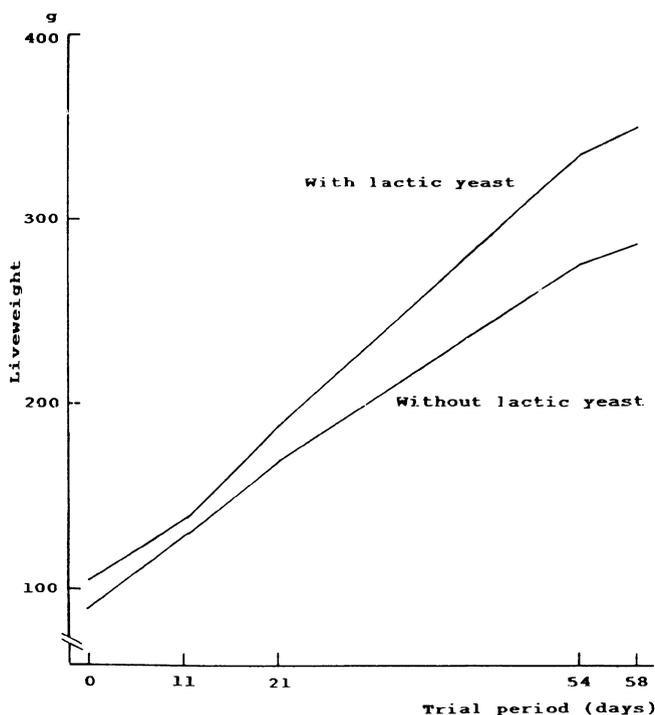


Figure 17-03. Development of the body weight of yellowtail (*Seriola quinqueradiata*) after feeding lactic yeast (data from⁽³⁰⁾).

17.2.3.2 Crustaceans

Saccharomyces Yeasts

Larvae of the kuruma prawn (*Penaeus japonicus*) and tiger prawn (*Penaeus monodon*) were fed the marine yeast (*Saccharomyces cerevisiae*) to obtain high survival rates, particularly at the zoea stage^(10, 23). But the combination of yeast and several algae species in varying proportions gave better survival rate than feeding yeast or algae alone⁽¹⁰⁾.

Replacing algae with active dry baker's yeast as feed for blue shrimp (*Penaeus stylirostris*) larvae gave quite successful results⁽⁴⁸⁾.

Lactic yeast

Replacing fish meal by lactic yeast (*Kluyveromyces fragilis*) at a level of 13% in diets for tiger prawns improved performances (Table 17-12)⁽³⁰⁾. Under field conditions in Japan squid meal was replaced successfully by 10 to 15% lactic yeast in diets for kuruma prawns⁽¹⁸⁾.

Table 17-12: The effect of lactic yeast (*Kluyveromyces fragilis*) on performances of tiger prawn (*Penaeus monodon*)⁽³⁰⁾

Lactic yeast	%	-	13.0
Fish meal	%	62.0	54.0
Daily weight gain	g	0.5	1.2
Feed conversion	1:	4.80	1.96
Feed efficiency		0.21	0.51

17.2.3.3 Molluscs

Growth was severely retarded when more than 50% torula yeast was used in the diet for bivalve molluscs in combination with the cultured algae *Thalassiosira pseudonana* or *Isochrysis galbana* (Table 17-13)^(2, 19, 78). Brewer's yeast at levels of 2.0 to 5.0% in diets for juvenile abalone of the genus *Haliotis* performed well but not as good as natural food^(42, 54, 65).

Table 17-13: Response of bivalves on algae and torula yeast and combinations thereof (parameter: final dry weight of soft tissues [mg]; test period: 28 days)⁽¹⁹⁾

Algae	%	100	75	50	25	0
Torula yeast	%	0	25	50	75	100
Argopecten bay scallop (<i>Argopectan irradians</i>)	mg	228.9	193.9	259.5	162.2	69.1
American oyster (<i>Crassostrea virginica</i>)	mg	49.4	43.9	35.8	27.9	21.2
Hard clam (<i>Mercenaria mercenaria</i>)	mg	23.2	21.8	21.4	17.5	11.0
Blue mussel (<i>Mytilus edulis</i>)	mg	168.1	146.1	144.9	87.3	55.3

The decline in growth with increasing levels of yeast is most probably due to the fact that bivalves are less able to digest the yeast, particularly its cell wall^(2, 19). This finding also corroborates the "assimilation efficiency" used as a parameter for determining the diet's effectiveness (Table 17-14)^(2, 29). Minor processing is needed to disrupt the yeast cell wall to make the nutrients better available for utilisation by molluscs⁽²¹⁾.

17.2.3.4 Zooplankton

In rotifer (*Brachionus plicatilis*) mass culture baker's yeast (*Saccharomyces cerevisiae*) is used as a mono-diet to replace algae, the organism's natural food. Unexpected decrease of production or suppressed growth of rotifers may be caused by nutrient deficiency of the yeast and pollution of the water by the yeast itself^(36, 37). The reproductive rate also declines, if rotifers are fed on yeast only⁽⁴⁴⁾.

The response of rotifers to fresh baker's yeast is slightly better than to dry baker's yeast. The former has higher vitality of the yeast cells and reduced sedimentation. In general, the combination of baker's yeast with other components does not show additional effects (Table 17-15)⁽⁴³⁾.

The essential fatty acid composition of rotifers grown on fresh baker's yeast and algae does not seem to meet the requirements of marine fish larvae, may be because the yeast is an inadequate essential fatty acid source^(17, 25, 84). However, when baker's yeast is grown on a medium supplemented with fish oil or cuttle fish liver oil, both of which are rich in PUFA of the n-3-series, the PUFA content of rotifers is altered⁽⁸¹⁾.

One million rotifers are produced with a mean in-put of 1.13 g dry baker's yeast (variation: 0.73 to 2.55 g)⁽⁴³⁾.

Table 17-14: Assimilation efficiency¹ (%) of the algae *Isochrysis galbana* and torula yeast for the American oyster (*Crassostrea virginica*) and the hard clam (*Mercenaria mercenaria*)⁽²⁾

	American oyster		Hard clam	
	Algae	Yeast	Algae	Yeast
Organic matter	76.4	67.6	78.3	80.1
Carbohydrates	74.4	63.7	85.6	75.8
Crude protein	78.5	70.5	90.3	78.4

¹ "Assimilation Efficiency" is a parameter to determine the effectiveness of a diet. It is the difference between the ingested and egested quantity of the diet and is similar to digestibility.

Table 17-15: Different preparations of baker's yeast on performances of the rotifer *Brachionus plicatilis*⁽⁴³⁾

Type of preparation	GR ¹	PR ²
Dry baker's yeast (control)	0.321	41.6
Fresh baker's yeast	0.331	43.6
Dry baker's yeast (activated) ⁵	0.315	39.5
Dry baker's yeast + Vitamin B ₁₂	0.325	42.4
Dry baker's yeast + extract ³	0.330	43.6

¹ GR = population growth rate of rotifer; ² PR = production of rotifers per ml;

³ macro-algal extract with unspecified composition; ⁴ microencapsulated commercial product; ⁵ with sugar

17.3 Active Yeast

17.3.1 Definition and Production

Definition

The “Association of American Feed Control Officials, Inc.” (AAFCO) have defined live (active) yeast as follows:

“Yeast culture is the product composed of yeast and the media on which it was grown, dried in such a manner as to preserve the fermenting activity of the yeast. The media must be stated on the label.”⁽³²⁾.

The major difference of yeast culture to inactive yeast and baker’s yeast (an active yeast, too) is its bio-regulating properties on the intestinal flora and possibly an antagonistic effect towards pathogenic germs^(38, 39).

Yeast culture has a wide range of names as shown below:^(32, 60).

- Yeast feed,
- Live yeast feed,
- Cereal yeast,
- Live cell yeast culture,
- Special yeast culture,
- Active yeast culture,
- Dried feed microbials.

Production

In the manufacture of yeast culture selected strains of *Saccharomyces cerevisiae* alone or in combination with *Kluyveromyces fragilis* are used⁽⁵⁾. Yeast cells used for yeast culture have to be modified by “substrate induction” which changes the yeast cells from sugar fermenters into cereal grains digesters⁽⁶⁾. AAFCO recognises 43 different micro-organisms for producing yeast culture^(1, 60).

The manufacturing process of yeast culture, the ingredients used and their effectiveness vary greatly. Cereals are the major substrate but other materials are also used. Three different production methods are known⁽³²⁾:

- Dry mixes of cereal grains and active dry yeast without culturing;
- Culture of yeast and cereals which has varying degrees of fermentation and are frequently dried at high temperatures killing the fermenting activities;
- Yeast and cereals carefully cultured together and dried in a manner to retain the activity and the metabolites of the fermentation.

17.3.2 Chemical and other Properties

Chemical Properties

The chemical composition of yeast culture is not as impressive as inactive yeast. Yeast culture is much lower in protein than inactive yeast. The mean nutrient content of yeast culture (as fed) is as follows⁽⁵⁶⁾ and the essential amino acids, minerals and vitamin contents are in Tables 17-16 and 17-17.

- Dry matter: 88.5%
- Crude protein: 14.0%
- Crude fat: 2.5%
- Crude fibre: 8.0%
- Ash: 4.0%
- N-free extract: 60.0%

Table 17-16: Essential amino acid profile of yeast culture (g/16 g N)⁽⁵⁶⁾

	Mean	Variation
Arginine	6.35	4.00 - 9.00
Histidine	3.33	2.00 - 4.80
Isoleucine	4.70	3.00 - 5.00
Leucine	11.25	7.00 - 15.00
Lysine	7.15	5.00 - 11.00
Methionine	2.28	1.00 - 3.00
Phenylalanine	5.00	4.00 - 6.00
Threonine	4.93	4.00 - 6.00
Tryptophan	1.25	0.70 - 1.80
Valine	5.03	4.00 - 6.00

Table 17-17: Mineral and vitamin contents of yeast culture ^(56, 1)

Minerals			Vitamins (per 1,000 g)		
Calcium	%	0.26	Vitamin A	IU	6,600
Phosphorus	%	0.65	Vitamin E	mg	39.70
Potassium	%	1.50	Vitamin B ₁	mg	4.50
Magnesium	%	0.39	Vitamin B ₂	mg	4.38
Sulphur	%	0.15	Vitamin B ₆	mg	6.60
Manganese	mg/kg	34.95	Vitamin B ₁₂	mg	0.01
Iron	mg/kg	75.00	Biotin	mg	0.40
Zinc	mg/kg	48.50	Folic acid	mg	0.60
Copper	mg/kg	6.47	Nicotinic acid	mg	49.33
Selenium	mg/kg	0.04	Pantothenic acid	mg	49.30
Cobalt	mg/kg	0.11	Choline	g	1.40

¹ inclusive of manufacturers data

Other Properties

Digestibility values for yeast culture have been determined in terrestrial animals only and are as follows:

- Metabolisable energy: 3,252 kcal/kg (13.6 MJ/kg) (pigs)
- Metabolisable energy: 3,098 kcal/kg (13.0 MJ/kg) (poultry)
- Digestible energy: 3,175 kcal/kg (13.3 MJ/kg) (horses).

The count of live cells ranges from 1.5×10^8 to 6.5×10^9 cells per gram dry yeast culture^(60, 80) and is used for the identification and analysis of yeast culture. However, measuring the viability of live cells is not yet precise⁽⁶⁰⁾.

The thermostability of yeast culture is insufficient. The temperature of pelletising, extrusion and expansion of feed together with moisture and pressure affects the viability of the live cells and losses can amount to 95%⁽⁶⁰⁾. But there are claims that although the live cells may die by heating, the metabolic activity of the yeast culture remains. Only temperatures greater than 70°C and exposure to such temperature for longer than five minutes can reduce the metabolic activity of yeast culture⁽³³⁾.

Mode of Action

It is still impossible to precisely define the metabolic consequences of using yeast culture in animal feeding^(28, 60, 83). However, three models may explain the mode of action of yeast culture⁽²⁶⁾:

- Live yeast cells may actively eliminate *Escherichia coli* by preventing its fixation onto the cells of the intestinal epithelium;
- Live yeast cells eliminate the coli enterotoxin when fixed onto the cell wall;
- Live yeast cells produce a lethal toxin which kills *Escherichia coli*.

It is also presumed that yeast cells contain numerous enzymes which are released into the intestine and supplement the endogenous enzymes of the animals, thus supporting dry matter digestion⁽³⁸⁾. For instance yeast culture in poultry upgraded the utilisation of phytate phosphorus^(75, 76) and in post-weaning piglets the feed conversion of high fibre diets was improved⁽⁷⁾. It is also possible that yeast culture contains UGF that could cause its effectiveness as a feedstuff^(6, 45).

17.3.3 Feeding Value

The feeding value of yeast culture has been studied extensively in terrestrial animals. Ruminants responded positively to the yeast culture^(28, 31, 83), the effects achieved in pigs were variable⁽¹⁴⁾ and results from trials in poultry were not very promising^(46, 80).

Studies on yeast culture in aquatic animals are rare. Yeast culture at levels of 0.125, 0.25 and 0.50% in diets of channel catfish (*Ictalurus punctatus*) fingerlings fed for 12 weeks did not significantly ($P > 0.05$) improve growth, feed conversion and survival⁽⁶¹⁾. Unless the thermostability of yeast culture is improved it cannot be successfully used in pelletised feed for aquatic animals⁽⁶⁰⁾.

17.4 Recommended Inclusion Rates

Inactive Yeast

High protein content and high digestibility are the characteristics of yeasts as a feedstuff. However, trials have proven that yeast cannot replace animal protein completely. Supplementation with amino acids may be needed. Recommended inclusion rates of yeast for aquaculture feed are:

- Fishes: 5.0 to 10.0%
- Shrimps: 2.0 to 5.0%
- Lobsters: 8.0 to 12.0%.

Active Yeast

Manufacturers recommend 0.1 to 1.0% yeast culture for aquaculture feeds⁽³⁸⁾.

17.5 Legal Aspects

Saccharomyces cerevisiae yeast is considered as Generally Recognised As Safe (GRAS) by the U.S.A authorities⁽³⁸⁾. Lacto yeast, distiller's yeast and alkane (petroleum) yeast are not approved by the U.S.A authorities. The only petroleum derived yeast approved is *Pichia pastoris* yeast. Also yeast culture is not an approved feedstuff⁽⁵⁷⁾.

In Germany, the following yeast products are approved as a single feedstuff:

- Brewer's yeast
- Yeast, extracted
- Yeast, liquid
- Yeast, dried.

They have to be produced from the yeast families *Saccharomycetaceae*, *Endomycetaceae* and *Cryptococaceae*. All yeast cells of the product have to be dead (inactive). Yeast produced from species of the genus *Candida* and cultured on n-alkane are not approved as a feedstuff⁽⁸²⁾.

17.6 References

1. AAFCO (1995): Official publication 1995. Ass. of American Feed Control Officials (Publisher), Sacramento, CA/USA.
2. Alatalo, P. (1980): Yeast utilization in oysters and clams. M.S. Thesis, University of Delaware, Newark/U.S.A.
3. Andruetti, S.; Vigliani, E.; Ghittino, P. (1973): Possibel uso nei per trota die proteine da lieviti coltivati su idrocarburi (proteine BP). Riv. Ital. Piscic/Gtiopatol, 8., (4), 97-100.
4. Anonymous (1989): Increasing immunity by the oral administration of brewer's yeast. Israeli Inst. of Biological Res., University Medical School, Tel Aviv/Israel (Mimeograph).
5. Anonymous (1990): Yeast culture products. Agritek & Gateway Monthly Newsletter, 4., (12).
6. Anonymous (1992): What is yeast culture "live"? (Mimeograph).
7. Anonymous (1993): Yeast offsets fibre. Pig International, 23., (8), 26.

8. *Appelbaum, S.* (1970): The suitability of alkane-yeast (hydro-carbon grown yeast) as a first nutrient for *Coregonus albula* (L.) fry. Proc. World Symp. on Finfish Nutr. and Fishfeed Techn., Hamburg/Germany, Vol. I, 20-23 June, 1978.
9. *Atack, T.; Matty, A.J.* (1979): The evaluation of some single-cell proteins in the diet of rainbow trout. II. The determination of net protein utilisation, biological values and true digestibility. Proc. World Symp. on Finfish Nutr. and Fishfeed Techn., Hamburg/Germany, Vol. I, 20-23 June, 1978.
10. *Aujero, E., J.; Tech, E., Javellana, S.* (1985): Nutritional value of marine yeast fed to larvae of *Penaeus monodon* in combination with algae. Proc. 1st Intern. Conf. on Culture of Penaeid Prawns and Shrimps, Iloilo City/The Philippines, 4-7 December (Abstr.).
11. *Beck, H.; Gropp, J.; Koops, H.; Tiews, K.* (1979): Single cell proteins in trout diets. Proc. World Symp. on Finfish Nutr. and Fishfeed Techn., Hamburg/Germany, Vol. II, 20-23 June, 1978.
12. *Beck, H.; Koops, H.; Tiews, K.; Gropp, J.* (1977): Weitere Möglichkeiten des Fischmehl-Ersatzes im Futter für Regenbogenforellen: Ersatz von Fischmehl durch Alkanhefe und Krillmehl. Arch. Fischerei Wiss., 28., (1), 1-17.
13. *Borgström, E.* (1979): Experiments on the use of single cell proteins in Atlantic salmon diets. Proc. World Symp. on Finfish Nutr. and Fishfeed Techn., Hamburg/Germany, Vol. II, 20-23 June, 1978.
14. *Castaldo, D.* (1993): More sophisticated pig feeds. Feed International, 14., (5), 18-26.
15. *Cho, C.Y.; Slinger, S.J.* (1979): Apparent digestibility measurement in feedstuffs for rainbow trout. Proc. World Symp. on Finfish Nutr. and Fishfeed Techn., Hamburg/Germany, Vol. II, 20-23 June, 1978.
16. *Cho, C.Y.; Cowey, C.B.; Watanabe, T.* (1985): Finfish nutrition in Asia: Methodological approaches to research and development. IDRC, Ottawa/Canada, 233e.
17. *Dendrinis, P.; Thorpe, J.P.* (1987): Experiments on the artificial regulation of the amino acid and fatty acid contents of food organisms to meet the assessed nutritional requirements of larval, post-larval and juvenile Dover sole (*Solea solea*, L.). Aquaculture, 61., 121-154.
18. *Derome, O.* (1992): Private communication.
19. *Epifanio, C.E.* (1979): Comparison of yeast and algal diets for bivalve molluscs. Aquaculture, 16., 187-192.
20. *Evans, M.* (1985): Nutrient composition of feedstuffs for pigs and poultry. Queensland Dept. of Primary Ind., Brisbane/Australia, Info, Series Q 185001.
21. *Fallu, R.* (1991): Abalone Farming. Fishing News Books, Oxford/England.
22. *Friesecke, H.* (1984): Handbuch der praktischen Fütterung von Rind, Schaf, Pferd, Schwein, Geflügel und Süßwasserfischen. BLV Verlagsges. München/Germany.
23. *Furukawa, I.; Hidaka, K.; Hirano, K.* (1973): Production of larvae of *Penaeus japonicus* Bate with marine yeast. Bull. Fac. Agric. Miyazaki University, 20., (1), 93-110.
24. *Gaede, E.A.* (1979): Bierhefe ersetzt Sojaschrot. Der Tierzüchter, (7), 283-285.
25. *Gatesoupe, F.J.; Millinaire, C. le* (1984): Dietary value adaptation of live food organisms for covering the nutritional requirements of marine fish larvae. Proc. Norwegian-French Shop on Aquaculture, Brest/France.
26. *Gedek B.R.* (1980): Interaktionen zwischen lebenden Hefezellen und darmpathogenen *Escherichia coli* Keimen im ökosystem Darm. In: Müller, J.; Ottenjan, R.; Seifert, J. Morphologie, Mikrobiologie, Immunologie. Springer Verlag, Berlin/Germany.
27. *Go, A.* (1994). Private communication.
28. *Gray, W.R.; Ryan, J.P.* (1988): A study of the effect of yeast culture on ruminant fermentation in sheep. In: Lyons, T.P. (ed.) Biotechnology in the feed industry. Alltech Techn. Publications, Nicholasville/USA, 129-150.
29. *Gropp, J.; Koops, H.; Tiews, K.; Beck, H.* (1976): The replacement of dietary fish meal in trout feeding. Proc. FAO Techn. Conf. on Aquaculture, Kyoto/Japan.
30. *Guillaume, P.* (1991): Private communication.

31. Günther, K.-D. (1980): Yeast culture's success under German dairy conditions. In: Lyons, T.P. (ed.) Biotechnology in the feed industry. Alltech Techn. Publications, Nicholasville/USA, 39-46.
32. Hartung, K.L. (1990): Marketing yeast culture. Feed Management, 41., (10), 17.
33. Headon, D.R. (1992): Selecting stable yeast cultures. Feed Management, 43., (7), 36-44.
34. Hopher, B. (1988): Nutrition of pond fishes. Cambridge University Press, Cambridge/England.
35. Higuera, M. de la; Sanchez-Munz, F.J.; Mataix, F.J.; Varela, G. (1981): Nitrogen utilization by rainbow trout fed on the yeast *Hansenula anomala*. Comp. Biochem. Physiology, 69A., 583-586.
36. Hirata, H. (1980): Culture methods of the marine rotifer *Brachionus plicatilis*. Min. Re. Data File Fish. Research, 1., 27-46.
37. Hirayama, K. (1987): A consideration of why mass culture of the rotifer *Brachionus plicatilis* with baker's yeast is unstable. Hydrobiologica, 147., 269-270.
38. Jonvel, S. (1993): Use of yeast in monogastrics. Feed Mix, 1. (4).
39. Jonvel, S. (1993): Interest of living yeast as a feed additive for animal feed. Proc. Feed Production Tomorrow, Bangkok/Thailand, 25-27 October.
40. Kinsella, J.E.; German, B.; Shetty, J. (1985): Uricase from fish liver: Isolation and some properties. Comp. Biochem. Physiology, 82B., (4), 621.
41. Koch, W.; Bank, O.; Jens, G. (1976): Fischzucht (4th ed.). Verlag Paul Parey, Hamburg and Berlin/Germany.
42. Koike, Y.; Flasch, J.P.; Mazurier, J. (1979): Biological and ecological studies on the propagation of the ormer, *Haliotis tuberculata* Linnaeus. II. Influence of food and density on the growth of juveniles. La Mer, 17., 43-52.
43. Komis, A. (1991/92): Improved production and utilization of the rotifer *Brachionus plicatilis* Müller, in European sea bream (*Sparus aurata* Linnaeus) and sea bass (*Dicentrarchus labrax* L.) larviculture. Dr. thesis, University Gent/Belgium.
44. Landau, M. (1992): Introduction to aquaculture. John Wiley & Sons, Inc., New York/USA.
45. Lyons, T.P. (1990): Yeast cultures. Feed Management, 41., (10), 16-35.
46. McDaniel, G. (1991): Effect of Yea-Sacc¹⁰²⁶ on reproductive performance of broiler breeder males and females. In: Lyons, T.P. (ed.): Biotechnology in the feed industry. Alltech techn. Publications, Nicholasville/USA, 413-415.
47. Miller, Jones, J. (1992): Food safety. Eagan Press, St. Paul, Minnesota/USA.
48. Mock, C.R.; Revera, D.B.; Fontaine, C.T. (1980): The larval culture of *Penaeus stylirostris* using modifications of the Galveston laboratory technique. Proc. World Mariculture Soc., 11., 102-117.
40. Murray, A.P.; Marchant, A. (1986): Nitrogen utilisation in rainbow trout fingerlings (*Salmo gairdneri*) fed mixed microbial biomass. Aquaculture, 54., 263-275.
50. New, M.B. (1987): Feed and feeding of fish and shrimps - A manual on the preparation and presentation of compound feeds for shrimps and fish in aquaculture. UNDP/FAO/ADCP/REP/87/26, Rome/Italy.
51. Nose, T. 1974): Effects of amino acids supplemented to petroleum yeast on growth of rainbow trout fingerlings. I. A preliminary experiment. Bull. Freshwater Fish. Res. Laboratory, Tokyo, 24., (1), 57-63.
52. Nose, T. 1974): Effects of amino acids supplemented to petroleum yeast on growth of rainbow trout fingerlings. II. Methionine and cystine. Bull. Freshwater Fish. Res. Laboratory, Tokyo, 24., (2), 101-110.
53. NRC (1983): Nutrient requirements of warmwater fishes and shellfishes. National Academy Press. Washington, D.C.
54. Ogino, C.; Kato, N. (1964): Studies on the nutrition of abalone. II. Protein requirements for the growth of abalone *Haliotis discus*. Bull. Jap. Soc. Sci. Fisheries, 30., 523-526.
55. Peppler, H.J. (1979): Production of yeasts and yeast products. In: Peppler, H.J.; Periman, D. (eds.): Microbial technology, Vol. 1. Academic Press, Inc., Orlando, Florida/USA.

56. *Peppler, H.J.; Stone, C.W.* (1976): Feed yeast products. *Feed management*, 27. (reprint).
57. *Price, W.D.* (1995): Private communication.
58. *Raipf, F.; Kautzmann, R.; Lüiers H.; Lindemann, M.* (eds.) (1960): *Die Hefen in der Wissenschaft*. Verlag Hans Carl Nürnberg.
59. *Rasmussen, C.J.* (1967): *Handbog i Ørredopdræt*. Rhodos forlag, Copenhagen/Denmark.
60. *Risley, C.* (1993): Yeast and pelleting. *Feed Management*, 44., (4), 46-47.
61. *Robinette, H.R.; Young,.* (1988): Catfish fingerling feeding study. Mississippi State University, Mississippi/USA (Mimeograph).
62. *Rumsey, G.L.* (1988): Fish farming as a form of animal agriculture. Recent advances in fish nutrition. In: *Lyons, T.P.* (ed.): *Biotechnology in the feed industry*. Alltech Techn. Publications, Nicholasville/USA, 235-248.
63. *Rumsey, G.L.; Smith, R.R.* (1990): Lecithin with diatomaceous earth works well in fish feed. *Feedstuffs*, 62., 30.7., 11-13.
64. *Rumsey, G.L.; Hughes, S.G.; Kinsella, J.L.* (1990): Use of dietary yeast *Saccharomyces cerevisiae* nitrogen by the lake trout. *J. World Aquaculture Soc.*, 21., 3, 205-209.
65. *Sagara, J.; Sakai, K.* (1974): Feeding experiments of juvenile abalone with four artificial diets. *Bull. Tokai Reg. Fish. Res. Laboratory*, 71., 1-5.
66. *Shanks* (164): Quoted from: *NRC* (1981):
67. *Shiio, I.* (1992): Microbial production of nucleotides. Central Res. Laboratory, Ajinomoto Co., Kawasaki/Japan (unpublished manuscript).
68. *Shimma, Y.; Nakada, M.* (1974): Utilisation of petroleum yeast for fish feed. I. Effect of supplemental oil. *Bull Freshwater Fish. Res. Laboratory, Tokyo*, 24., (1), 47-63.
69. *Shimma, Y.; Shimma, H.* (1976): Utilisation of petroleum yeast for fish feed. IV. Plasma cholesterol content of fatty acid composition of erythrocytes of rainbow trout. *Bull Freshwater Fish. Res. Laboratory, Tokyo*, 26., (2), 71-78.
70. *Smith, R.R.* (1976): Metabolisable feedstuffs for trouts. *Feedstuffs*, 48., (23), 16-17.
71. *Smith, R.R.; Peterson, M.C.; Allred, A.C.* (1980): The effect of leaching on apparent digestion coefficients in determining digestibility and metabolizable energy of feedstuffs for salmonids. *Prog. Fish Culturist*, 42., 699-718.
72. *Spinelli, J.; Mahken, C.; Steinberg, M.* (1979): Alternate sources of proteins for fish meal in salmonid diets. *Proc. World Symp. on Finfish Nutrition and Fishfeed Techn.*, Hamburg, 20-23 June, Vol. II.
73. *Tacon A.G.J.; Cooke, D.J.* (1980): Nutritional value of dietary nucleic acids in trout. *Nutrition Rep. Int.*, 22., 631-640.
74. *Takeda, M.; Ogino, C.* (1975): Quoted from *Nose, T.* (1979).
75. *Thayer, R.H.; Jackson, C.D.* (1975): Improving phytate phosphorus utilization by poultry with live yeast culture. *Anim. Sci. Research M.P.* 94, April (Oklahoma State University and USDA).
76. *Thayer, R.H.; Burkitt, R.F.; Morrison, R.D.; Murray, E.E.* (1978): Efficiency of utilization of dietary phosphorus by caged turkey breeder hens when fed rations supplemented with live yeast culture. *Bull. M.P.-103, Oklahoma State University, Stillwater/USA*.
77. *Tiews, K.; Koops, H.; Beck, H.; Schwab-Büttling, M.; Gropp, J.* (1981): Entwicklung von Ersatzfuttern für die Regenbogenforelle. *Veröffl. Inst. Küsten- und Binnenfischerei, Hamburg*, No. 75/1981.
78. *Urban, E.R.* (1982): Yeast and vitamins as supplements in the diet of *Crassostrea virginica* (Gmelin). *Proc. 2nd Int. Conf. on Aquaculture Nutrition: Biochemical and Physiological Approaches to Shellfish Nutrition, Lewes/Rehoboth Beach-Delaware/USA*, October.
79. *Valentin, C.C.* (1978): Nitrogen balance of the American oyster *Crassostrea virginica* (Gmelin). *M.S.*

Thesis, University of Delaware/USA.

80. *Vogt, H.; Matthes, S.* (1991): Der Einfluß lebender Hefekulturen Yea-Sacc^(R) auf die Mastergebnisse von Broilern. *Landbauforschung Völkenrode*, 41., (2), 90-93.
81. *Watanabe, T.* (1981): Dietary value of rotifers for fish larvae. Proc. XII. Int. Congr. of Nutrition, San Diego, 16-21 August (Abstr. 174).
82. *Weinreich, O.; Koch, V.; Knippel, J.* (1994): Futtermittelrechtliche Vorschriften. Buchedition Agrimedia, Hamburg/Germany.
83. *Williams, P.E.V.* (1988): Undertaking of biochemical mode of action of yeast culture. In: *Lyons, T.P.* (ed.): *Biotechnology in the feed industry*. Alltech Techn. Publications, Nicholasville/USA, 79-99.
84. *Witt, U.; Quantz, G.; Kuhlmann, D.; Kattner, G.* (1984): Survival and growth of turbot larvae *Scophthalmus maximus* L. reared on different food organisms with special regard to long-chain polyunsaturated fatty acids. *Aquaculture Engineering*, 3., 177-190.

18. FISH MEAL

18.1. Rationale

Historical Background

Fish by-products have been used for feeding animals for many centuries ago. As early as 800 AD, herring was utilised as a raw material in Norway. The oil was pressed with wooden boards and stones for human consumption and the remains were used as feed. In the travels of Marco Polo as written in the 14th century, a primitive form of fish meal was already described and fed to animals⁽⁶⁰⁾. In the past, in Great Britain and Japan, fish meal and fish solubles were used as fertiliser and first of all as animal feed because of its high nutritional value⁽³⁵⁾. Fish meal of high grade quality is used also for human consumption in countries where there is a lack of protein in malnourished children's diets. Fish meal manufacture is now the largest operation in the world. Around 12% of the world production of fish meal is used in aquaculture feeds⁽⁴⁴⁾. In addition, production of fish meal and fish silage (Chapter 20) is a good way of managing waste from fish processing, thus, protecting the environment.

Sources

Most commercial fish meals are produced from a mixture of various fish species such as fish meal from small oily fishes of the herring family, anchovy which is fished off Peru and Chile, menhaden, which is obtained in large amounts off the East coast of the U.S.A. and the Gulf of Mexico and sardines caught in waters off Nordic countries, Japan and Russia. Generally a meal produced from a defined fish species can be declared as pure if more than 50% of the raw material is from only one species⁽⁵⁹⁾. Occasionally meal from the following species may also be available:

- Anchovy (false) (*Stolephorus commersonii*)
- Anchovy (true) (*Engraulidae* spp.)
- Bream/Redfish (*Sebastes* spp.)
- Cod (*Gadus morhua*)
- Conger (*Conger conger*)
- Capelin (*Mallotus villosus*)
- Carp (*Cyprinus carpio*)
- Chilean hake (*Merluccius geyi*)
- Croaker (*Sciaenidae* spp.)
- Haddock (*Melanogrammus aeglefinus*)
- Halibut (*Hippoglossus hippoglossus*)
- Herring (*Clupea harengus*)
- Horse mackerel (*Trachurus* spp.)
- Mackerel (*Scomber scombrus*)

- Menhaden (*Brevoortia* spp.)
- Pilchard (*Sardina pilchardus*)
- Pollack (*Pollachius pollachius*)
- Sand eel (*Ammodytidae* spp.)
- Shark (order *Squaliformes*)
- Tuna (*Thunnus* spp.)

Commercially produced fish meal are labelled according to:

- Country of origin (Alaskan, Canadian, Danish, Peruvian, Thailand fish meal)
- Procedure of manufacture (steam dried, sun-dried, low temperature dried, flame dried, freeze dried)
- Fish species (e.g. Herring, Menhaden, Pollack, Anchovy)
- Colour (white or brown fish meal)

The raw material used in Danish fish meals normally consists of small fish not for human consumption such as sand eels (*Ammodytes*), Norway Pout (*Trisopterus esmarki*) and sprat (*Spratus spratus*)⁽³⁰⁾. Peruvian fish meal comes mostly from anchovy.

Type of fish meals produced by some exporting countries are listed in Table 18-01.

Table 18-01: Types of fish meals produced by some fish meal exporting countries⁽²⁵⁾

Country	Types of meal	Drying process
Canada	Herring	Steam
Chile	Anchovy and horse mackerel	Flame/steam
Iceland	Herring and Capelin	All low temperature
Japan	Sardine	-
Norway	Herring and Capelin	All low temperature
Peru	Anchovy	-
South Africa	Pilchard	-
U.S.A.	Menhaden (mostly in the South)	Flame/steam

In Great Britain, “white fish meal” is defined as containing not more than 6.0% oil and 4.0% salt. In Norway distinction is made between herring meal and fish meal. The former is only from herring while the latter is from cod and fish offal and is of lower quality⁽⁵⁾. Fish meal containing 65 to 70% crude protein is generally called “herring meal” in Denmark while “fish meal” has a lower protein content.

18.2 Manufacture and Processing

The principle in fish meal processing is the separation of the solids from water and oils. The quality of fish meal depends on several factors which are:

- Temperature at the time the fish are caught;
- Temperature at which the fish is stored prior to processing;
- Length of storage prior to processing;

- Type or composition of fish catch;
- Method of catching the fish.

Fish meal has to be processed as soon as the fish is caught in the ship offshore or at shore. A by-product of fish meal manufacture is fish oil⁽³²⁾ (Chapter 29).

There are two principal ways of producing fish meal: Direct drying which is an old process and cooking before drying⁽⁶⁾. With the latter, a higher quality fish meal is obtained⁽³²⁾.

Wet Reduction Process

Fish is cooked in a long steam jacketed cylinder or steam is injected into the cooking material. Undercooking and overcooking has to be avoided (Figure 18-01). The pressing stage removes the major portion of the oil and water followed by drying.

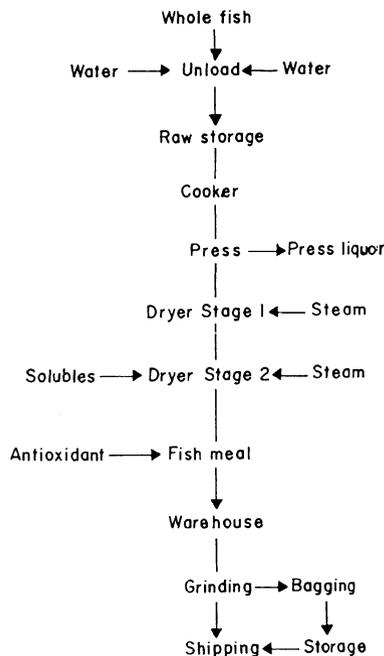


Figure 18-01. Flow diagram in the processing of fish meal⁽⁵⁰⁾.

In the direct drying process, very hot air of up to 500°C is passed over the material as it is tumbled rapidly in a drum. Direct drying is a quick method but the nutrients of the finished product can be easily heat damaged.

There is less damage to the nutrients if the fish meal is processed by indirect steam drying which is also termed “indirect fired” “steam dried” or “low temperature” fish meal process. Hereby a steam jacket or steam heated discs are used⁽³⁵⁾. Compared to steam-drying, air-drying reduces the protein content by 10.5% and the fat level by 0.6%⁽³⁹⁾.

Returning the fish solubles (see Chapter 21) to the press cake prior to drying gives fish meal known as “whole meal”.

Heat Transfer Process

The heat transfer method (HTM) was developed in the USA. Oil is added to a slurry of the raw material which acts as a heat transfer medium. In another process, the oil is removed by solvent extraction rather than by pressing and centrifuging the liquid material⁽³²⁾.

Artisanal Process

In developing countries fish meal is produced by artisanal methods such as cooking, draining, sun-drying and mechanically grinding the fish. The quality of “cooked” fish meal is higher than that of “raw-salted” fish meal⁽³⁴⁾. Small-scale processing under local conditions does not produce a quality compared to industrial fish meals⁽¹¹⁾.

18.3 Chemical, Physiological and Other Properties

Chemical Properties

Fish meal is a high quality protein feedstuff. The chemical composition, particularly the protein content varies widely and depends on fish species used for fish meal manufacture (Tables 18-02), season, and the latitude where the fish are caught. Fish meal is also an excellent source of essential amino acids (Table 18-03).

Table 18-02: Chemical composition of fish meal (% in dry matter)

Meal from... ¹	Dry Matter	Crude protein	Crude fat	Ash	Crude fibre	N-free extract
1. Fish meal from defined species^(51, 59)						
Anchovy (true)	92.0	70.7	5.3	16.9	-	7.1
Anchovy (false)	93.0	78.0	9.0	12.5	-	0.5
Bream	93.0	63.2	10.3	25.2	-	1.3
Capelin	91.1	72.6	9.3	10.6	4.7	2.8
Chilean hake	81.6	83.3	2.4	14.3	-	-
Cod	89.7	68.6	3.8	26.0	-	1.6
Croaker	94.0	63.1	10.9	20.2	0.9	4.9
Haddock	93.4	65.9	4.7	26.5	-	2.9
Halibut	-	53.2	13.1	32.8	-	0.9
Herring	90.0	74.4	9.0	15.0	-	1.6
Horse Mackerel	95.4	70.9	13.7	-	-	-
Mackerel	92.0	66.4	10.3	21.1	-	2.2
Menhaden	92.6	66.6	11.1	20.9	-	1.4
Pilchard	91.8	66.5	7.6	20.4	-	5.5
Pollack	94.8	65.5	17.7	14.1	-	2.7
Sandeel	91.0	72.6	8.3	10.6	-	8.5
Sardine	93.0	65.2	5.0	19.8	1.0	9.0
Shark	92.0	72.3	17.9	-	-	-
Tuna	-	64.0	10.1	23.6	-	2.3
2. Fish meal from unspecified fish^(9, 16, 20, 23, 35, 37, 40, 41, 51, 56)						
White fish meal	91.5	65.8	8.5	19.5	1.4	4.8
Brown fish meal	91.3	69.0	6.0	14.8	-	10.2
Fish waste meal	90.0	49.2	9.0	34.4	-	7.4

¹For scientific names of fish species see Chapter 18.1

Table 18-03: Essential amino acid profile of fish meal (g/16 g N)⁽⁵⁹⁾

Leucine	Arginine	Histidine	Isoleucine	Leucine	Lysine	Methionine	Phenylalanine	Threonine	Tryptophan	Valine
1. Defined fish species⁽⁵⁹⁾										
Anchovy (true)	5.9	2.5	4.7	7.7	8.0	2.9	4.2	4.4	1.2	5.4
Anchovy (false)	5.1	3.4	5.2	8.0	9.5	3.7	4.5	4.7	1.2	5.8
Bream	6.4	2.3	3.7	5.7	6.6	3.0	4.0	4.1	1.0	4.5
Capelin	5.4	2.0	4.2	7.2	6.9	2.9	3.5	4.1	-	4.6
Cod	6.6	2.0	4.8	8.1	7.2	3.0	3.8	5.2	1.0	5.3
Haddock	5.3	1.7	5.1	7.4	.2	2.6	3.2	4.2	0.9	-
Herring	6.6	2.4	4.7	7.5	7.7	2.8	3.9	4.2	1.1	5.8
Horse Mackerel	6.6	2.7	4.3	7.1	8.0	2.4	3.4	4.0	0.7	4.9
Menhaden	6.1	2.5	4.3	7.0	7.7	2.8	3.9	4.0	1.1	5.1
Pilchard	5.7	2.9	4.1	7.4	7.4	2.7	3.8	4.3	1.2	5.6
Pollack	9.0	3.0	5.1	8.4	11.9	2.4	4.1	4.9	0.9	5.8
Shark	6.6	2.2	5.6	8.5	7.1	2.5	4.3	4.7	1.4	5.5
Tuna	6.5	3.3	4.5	7.2	7.2	2.7	4.1	4.3	1.0	5.3
2. Unspecified fish^(10, 16, 20, 29, 37, 38, 42)										
White fish meal	5.3	1.8	3.5	6.4	6.3	2.4	2.1	2.2	0.8	2.6
Brown fish meal	4.6	2.0	3.0	5.5	6.2	1.6	3.2	3.1	2.3	3.2

The fat content of fish meal is species specific (Table 18-02). Normally, fish meal is de-oiled. Nevertheless, fish meal from oily fish species may contain up to 9.0% oil⁽¹⁵⁾. The residual oil in fish meal is rich in PUFA, predominantly of the n-3 family (Table 18-04).

Fish meal has a high ash content and is particularly high when made mainly from fish frames (Tables 18-02). Generally, the higher the ash content, the higher the calcium, phosphorus and magnesium content which are predominantly from the fish bones (Table 18-05). Fish meal is a source of selenium which is of good availability⁽¹⁵⁾.

Fish meal is rich in water soluble vitamins but the content of fat soluble vitamins is insignificant (Table 18-06).

Table 18-04: Important fatty acids in lipids of fish meal (%)⁽¹⁵⁾

Fatty acid		White fish meal	South American fish meal	Herring-type fish meal
Tetradecanoic	14:0	3.2	6.3	4.9
Hexadecanoic	16:0	11.0	19.9	14.8
Octadecanoic	18:0	1.7	4.8	2.1
Hexadecenoic	16:1	6.8	7.3	5.8
Octadecenoic	18:1	16.9	11.4	14.4
Eicodenoic	20:1	9.7	3.0	10.9
Docosanoic	22:1	9.1	1.8	11.9
Eicosapentaenoic	20:5n-3	12.0	14.6	10.1
Docosahexaenoic	22:6n-3	19.2	17.4	15.4

Total n-6-PUFA		3.4	4.1	3.5
Total n-3-PUFA		35.5	34.3	27.1

Table 18-05: Macro and micro mineral contents of some typical fish meals ⁽¹⁵⁾

Mineral		White fish meal	South American fish meal	Herring type fish meal
Calcium	%	8.00	4.00	2.0
Phosphorus (total)	%	4.80	2.60	1.90
Phosphorus (available)	%	4.80	2.60	1.90
Potassium	%	0.90	0.70	1.20
Chlorine	%	2.00	1.82	1.03
Magnesium	%	0.15	0.25	0.11
Sodium	%	1.30	0.87	0.70
Iron	mg/kg	300	246	150
Copper	mg/kg	7.0	11.0	5.0
Manganese	mg/kg	10.0	2.0	10.0
Zinc	mg/kg	100	111	120
Selenium	mg/kg	1.50	1.40	2.20

Table 18-06: Vitamin content of some typical fish meals (per 1,000 g)⁽¹⁵⁾

Vitamin		White fish meal	South American fish meal	Herring-type fish meal
Vitamin A	IU	-	3.9	8.9
Vitamin E	mg	9.8	3.4	4.0
Vitamin K ₃	mg	-	-	2.4
Vitamin B ₁	mg	1.8	1.9	0.7
Vitamin B ₂	mg	6.5	6.60	7.3
Vitamin B ₆	mg	3.3	3.5	3.7
Vitamin B ₁₂	mcg	70	180	250
Biotin	mcg	80	260	420
Folic acid	mcg	500	160	500
Nicotinic acid	mg	50	95	126
Pantothenic acid	mg	15.0	9.3	30.6
Choline	mg	4,400	4,400	4,400

Physiological Properties

The energy content of fish meal depends on the protein and oil content. The data on the digestible energy found in aquatic and terrestrial animals do not differ much from each other when quality of the fish meal is considered (Table 18-07).

Table 18-07: Metabolisable and digestible energy content of fish meals in aquatic and terrestrial animals

	Metabolisable energy		Digestible energy		Reference
	kcal/kg	MJ/kg	kcal/kg	MJ/kg	
<u>Chinook salmon</u>					
- Herring meal	-	-	4,876	20.4	(24)
- Herring/Capelin meal ¹	-	-	4,661	19.5	(24)
- Anchovy meal	-	-	4,827	20.2	(24)
- Menhaden meal	-	-	4,063	17.0	(24)
<u>Channel catfish</u>					
- Fish meal ²	-	-	3,906	16.3	(36)
<u>Pigs</u>					
- Herring-type meal	-	-	4,804	20.1	(15)
<u>Poultry</u>					
- Fish meal ²	3,460	14.5	3,650	15.3	(16)

¹organic matter; ²from unspecified matter

The protein digestibility of fish meal is highest for grass carp (*Ctenopharyngodon idellus*) and chinook salmon (*Oncorhynchus tshawytscha*) and lowest for milkfish (*Chanos chanos*) and yellowtail (*Seriola quinqueradiata*) (Table 18-08). Other digestibility data are rare.

Table 18-08: Apparent digestibility (%) of fish meals in various aquatic species^(7, 13, 19, 21, 24, 26, 31, 38, 49)

	Protein	Fat	Fibre	Dry matter	Energy
Salmonids (general)	81.8	89.2	-	88.2	91.7
Atlantic salmon (<i>Salmo salar</i>)	88.5	-	-	-	-
Chinook salmon (<i>Oncorhynchus tshawytscha</i>)	89.9	-	-	86.7	89.2
Rainbow trout (<i>Salmo gairdneri</i>)	86.0	-	-	-	-
(Common carp) (<i>Cyprinus carpio</i>)	86.4	-	-	-	-
Grass carp (<i>Ctenopharyngodon idella</i>)	90.8	90.0	100.0	68.1	83.4
Channel catfish (<i>Ictalurus punctatus</i>)	85.5	-	-	-	84.5
Tilapia (<i>Oreochromis</i> spp.)	87.5	-	-	-	-
Milkfish (<i>Chanos chanos</i>)	61.5	-	-	-	-
Sea bass (<i>Dicentrachus labrax</i>)	88.3	-	-	-	-
Yellowtail (<i>Seriola quinqueradiata</i>)	62.0	-	-	-	-
Tiger prawn (<i>Penaeus monodon</i>)	66.4	-	-	-	-

The bioavailability of minerals in fish meal varies among species. Phosphorus bioavailability appears to be correlated with the presence of gastric juice in the stomach and is low in stomachless fish like the common carp (*Cyprinus carpio*) and high in fish with stomach such as rainbow trout (*Salmo gairdneri*)⁽⁵⁶⁾.

Zinc and manganese availability is related to the fish meal's content of calcium-phosphate as found in rainbow trout^(4, 46).

The bioavailability of magnesium in white fish meal is very low. Utilisation of magnesium might be distorted by an undefined substance in white fish meal. Supplementation of the diet, therefore, has to be considered⁽⁴⁶⁾. Selenium in fish meal has low availability (47.5%)⁽⁴⁾.

Other Favourable Properties

High quality fish meals are a good source of phospholipids. Unspecified fish meals may contain 2.47% phospholipids⁽²⁸⁾. Tuna meal has a phospholipid content of only 0.5⁽⁵⁹⁾. Fish meal has chemo-attractant properties most probably due to its high content of glutamic acid. Glutamic acid, although a non-essential amino acid is abundant in fish meal ranging from 11.8 to 14.9 g/16 g N and may be one of the reasons why fish meal can serve as a chemo-attractant.

The pelletising ability of fish meal according to CPM is rated “medium” for both pelletising ability and abrasiveness⁽²⁷⁾.

Unfavourable Properties

Fish meal produced from improperly handled raw fish may contain histamine (β -imidazoleethylamine) ($C_5H_9N_3$) which is a N-containing heterocyclic biogen amine, produced by microbial decarboxylation of the amino acid histidine. The toxin can be produced in just three to four hours when fish is kept at a room temperature of 18° to 22°C. The normal histamine level of fish is less than 1.0 mg% but histamine levels as high as 430 mg% were found in yellowtail⁽³³⁾. The toxin can cause allergic reactions, lowers the blood pressure by dilating the blood vessels and stimulates gastric secretion (enteritis). Histamine is heat stable but the enzyme histaminase, found in the digestive system, is capable of inactivating histamine^(33, 53, 58).

18.4 Feeding Value

In feeding cultured aquatic animals two types of fish meal are used: White fish meal and brown fish meal. White fish meal is of higher nutritional value than brown fish meal. About 2/3 of protein in aquatic diets come from fish meal⁽³²⁾ and its fish feeding value has caused its extensive use in aquaculture diets. Of the total fish meal used in aquaculture feeds, 93.2% was consumed by carnivorous species⁽⁵¹⁾. Fish meal is also used as the sole source of protein in the determination of protein requirements of various aquatic species.

Fishes

Fish meal is the major protein source of fish diets. Its replacement by less expensive components were the target of many experiments. The differences in the feeding value of meal of defined fish species were also tested (see Chapter 18.1).

For salmonids such as chinook salmon and rainbow trout insignificant differences were found when various meals of defined fish species were tested (Table 18-09)^(3, 12, 22). Insignificant differences in performances also were found when different meals of defined fish species were fed to turbot (*Scophthalmus maximus*)⁽¹⁴⁾, red sea bream (*Pagrus major*) and the Japanese eel (*Aguilla japonica*)⁽⁴¹⁾.

Intensive culture of channel catfish (*Ictalurus punctatus*) requires diets with a high level of fish meal (Menhaden). Replacement of all fish meal by soybean meal on isonitrogenous basis resulted in poor fish development for juvenile blue catfish (*Ictalurus furcatus*). A minimum of 13.0% fish meal in a diet containing 34.0% crude protein has been established⁽²⁾.

Table 18-09: Response of rainbow trout (*Salmo gairdneri*) fingerlings on feeding diets with tilapia or herring meal (feeding period: 12 weeks⁽²²⁾)

Herring meal	%	26.7	-
Tilapia meal	%	-	30.6
Crude protein	%	42.1	40.1
Crude fat	%	7.4	9.6
Gross energy	kcal/kg	4,680	4,560
	MJ/kg	19.6	19.1
Initial weight	g	23.0	23.0
Mean weight gain	g	36.0	39.0
Daily weight gain	g	0.429	0.464
Carcass composition (in dry matter):			
- Dry matter	%	22.6	21.5
- Protein	%	67.1	69.0
- Lipid	%	19.5	17.9
- Ash	%	10.7	11.5
- Energy	kcal/kg	5,460	5,440
	MJ/kg	22.8	22.8

The rather frugal tilapia (*Oreochromis* spp.) responded better to a diet containing fish meal than blood meal⁽⁵⁵⁾. Replacing all fish meal by soybean meal in a diet (24% crude protein) for male tilapia significantly reduced performances. Adding of methionine to the soybean diet was ineffective⁽⁴⁸⁾.

Mudfish (*Clarias anguillaris*) fingerlings performed best when fish meal was the only protein source instead of a mixture of fish meal, blood meal and ground nut cake⁽¹⁷⁾. White fish meal is a better protein source than herring meal in diets for the European eel (*Anguilla anguilla*)⁽²⁹⁾. The growth of milkfish fry is improved substantially, when 30% of dietary protein from maize gluten meal is replaced with white fish meal (Table 18-10)⁽⁴⁷⁾.

Table 18-10: Growth response of milkfish (*Chanos chanos*) fry fed white fish meal and/or maize gluten meal⁽⁴⁷⁾

Maize gluten meal	%	52.3	45.4	38.1
White fish meal	%	-	8.3	17.0

Weight gain	%	312	862	1,275
Survival	%	14.2	56.0	63.0
Feed conversion	1:	4.9	1.8	1.5

Crustaceans

Shrimp need fish meal in their diets. In post-larvae (2.0 to 3.0 g) tiger prawn (*Penaeus monodon*) the highest survival rate was attained with fish meal as the sole protein source, but the best growth rate was obtained with the combination of fish meal and shrimp head

meal (1:1)⁽⁴³⁾. Brown fish meal based diets can sustain good growth and high survival of the larval kuruma prawn (*Penaeus japonicus*) and is comparable to live food⁽⁵⁴⁾.

Molluscs

The phagostimulatory properties of dietary white fish meal has been tested in gastropod molluscs. White fish meal can be the major protein source in artificial diets for abalone (*Haliotis* spp.)⁽⁸⁾.

It seems that it is the most desirable protein source for abalone⁽¹⁸⁾. The amino acid profile and the lipids of fish meal are easily digestible at abalone's body temperature. The high concentration of PUFAs are also of value to abalone⁽¹⁸⁾.

18.5 Recommended Inclusion Rate

The cost of fish meal limits its application level in diets for cultured aquatic animals. The mean and optimal inclusion rates of fish meal are as follows^(51, 52):

Carnivores	50.0%
Omnivores/herbivores	25.0%
Penaeid shrimps	25.0%
Other crustaceans	20.0%

18.6 Legal Aspects

According to EU-Regulation 92/87 of 26 October 1992, fish meal has the No. 10.01 and is defined as "a product processed from fishes or parts of them of which the oil has been partly extracted and the fish solubles may be added to the product". Products with more than 75% crude protein may be declared as "high protein fish meal". Quality requirements of fish meals according to German feedstuff legislation are in Table 18-11.

In the U.S.A. fish meal (AAFCO No. 51.14) is defined as "the clean, dried ground tissue of undecomposed whole fish or fish cuttings, either or both with or without extraction of part of the oil". It must contain not more than 10.0% moisture. If it contains more than 3.0% salt (NaCl), the amount of salt must be labelled. In no case must the salt content exceed 7.0%⁽¹⁾. The requirement for fish residue meal (AAFCO No. 51.24), which is the residue from the manufacture of glue from non-oily fish, is the same as for fish meal⁽¹⁾.

Undesirable substances may reduce the value of a fish meal. The German feedstuff law permits undesired substances in fish meal only at the following levels⁽⁵⁷⁾:

• Aflatoxin B ₁	max.	0.05 mg/kg
• Arsenic	max.	10.00 mg/kg
• Cadmium	max.	2.00 mg/kg
• Fluorine	max.	500.00 mg/kg
• Mercury	max.	0.50 mg/kg

Table 18-11: Quality requirements (%) of fish meals according to German feedstuff legislation⁽⁵⁷⁾

		Fish meal standard type		
		55	60	64
Moisture	max.	12.0	12.0	12.0
Crude protein	min.	55.0	60.0	64.0
Digestible protein ¹	min.	88.0	88.0	88.0
Crude fat	max.	12.0	12.0	12.0
Ash	max.	2.2	2.2	2.2
Sodium-chloride	max.	5.0	4.0	4.0
Calcium-chloride	max.	2.7	2.5	2.0

1. <u>Compulsory declaration on labels</u>				
Crude protein		+	+	+
Crude fat		+	+	+
Sodium-chloride		+	+	+
2. <u>Voluntary declaration on labels</u>				
Moisture		+	+	+
Calcium-carbonate		+	+	+
Phosphorus		+	+	+

¹Pepsin-hydrochloric test

18.7 References

1. *AAFCO* (1995): Official publication 1995. Ass. of American Feed Control Officials (publisher), Sacramento, USA. p.548.
2. *Andrews, J.W.; Page, J.W.* (1974): Growth factors in the fish meal component of catfish diets. *J. Nutr.*, 104., 1091-1096.
3. *Anonymous* (1980): Fish meal: wide range of raw fish and a high quality are the keynotes. *World Fishing*, 29., 13-15.
4. *Bell and Cowey.* (1989): Digestibility and bioavailability of dietary selenium from fish meal, selenomethionine and selenocystine in atlantic salmon (*Salmo salar*). *Aquaculture*, 81., 61-68.
5. *Baelum, J.* (1962): El pescado y los productos pesqueros en la alimentacion de las aves. In: *Heen, E. and Kruezer, B.* (eds.): *Fish in Nutrition*. FAO, Rome.
6. *Bredon, R.M.; Marshall, B.* (1954): Small-scale fish meal production under tropical conditions. *The East African Agric. J.*, Oct., 98-101.
7. *Brown, P.B.; Strange, R.J.; Robbins, K.R.* (1985): Protein digestibility coefficients for yearling channel catfish fed high protein feedstuffs. *Prog. Fish. Cult.*, 47., 94-97.
8. *Carefoot, T.H.* (1982): Gastropod nutrition. *Proc. 2nd International Conf. on Aquaculture Nutrition*:

- Biochemical and Physiological Approaches to Shellfish Nutrition. 27-29 Oct. 1981. Louisiana State Univ., Baton Rouge Louisiana. 321-337.
9. *Cho, C.Y.; Cowey, C.; Watanabe, T.* (1985): Finfish nutrition in Asia: Methodological approaches to research and development. IDRC, 233e. Ottawa/Canada.
 10. *Chou, R.* (1985): Performance of various fish meal diets in young sea bass (*Lates calcarifer* Bloch). In: *Cho, C.Y.; Cowey, C.B.; Watanabe, T.* (eds.): Finfish Nutrition in Asia: Methodological approaches to research and development. IDRC 233, Ottawa, Canada.
 11. *Coulibaly, M.; Diambra, O.; Bangare, K.* (1989): Chemical and nutritional characteristics of fish meal related to processing techniques. Proc. FAO Expert Consultation on Fish Technology in Agricra Abidjan, Cote D' Ivoire, 25 to 28 April 1988. FAO Comm. From Inland Fisheries of Latin America, Rome, Italy, 1989. No. 400 pp. 199-202.
 12. *Crawford, D.L.; Law, D.K.; McKee, T.B.; Westgate, J.W.* (1994): Nutritional characteristics of Oregon pellet rations containing meals of different fish species. Prog. Fish. Cult., 36., 3-7.
 13. *Cruz, E.M.* (1975): Determination of nutrient digestibility in various feedstuffs for channel catfish. Ph.D. dissertation. Auburn Univ., Alabama/U.S.A.
 14. *Danielssen, D.S.; Gulbrandsen, K.E.; Hjertnes, T.* (1989): Fish meal quality in dry feed for turbot (*Scophthalmus maximus* L.). Paper pres. at Intern. Aquaculture Conf. Bordeaux/France, 2-4 Oct.
 15. *De Boer, F.; Bickel, H.* (1988): Livestock feed resources and feed evaluation in Europe. Elsevier Sciences Publishers, Amsterdam/The Netherlands.
 16. *Evans, M.* (1985): Nutrient composition of feedstuff for pigs and poultry. Queensland Dept. of Primary Industries, Information Series Q185001, Brisbane/Australia.
 17. *Eyo, A.A.* (1991): The utilization of isonitrogenous feed mixtures containing blood meal, fish meal, groundnut and soyabean meal by fingerling mudfish *Clarias anguillarus*. Annu. Rep. Nat'l. Freshwater Fish. Res., Nigeria. 1990, 96-103.
 18. *Fallu, R.* (1991): Abalone farming. Fishing News Books, Oxford/ England.
 19. *Feed Development Section* (1994): Feeds and feeding of milkfish, Nile tilapia, Asian sea bass and tiger shrimp. SEAFDEC Aquaculture Dept., Tigbauan, Iloilo, Phil.
 20. *Feltwell, R.; Fox, S.* (1978): Practical poultry feeding. Faber and Faber, London and Boston.
 21. *Ferraris, R.P.; Catacutan, M.R.; Mabellin, R.L.; Jazul, A.P.* (1986): Digestibility in milkfish, *Chanos chanos* (Forsskal): Effects of protein source, fish size and salinity. Aquaculture, 59., 93-105.
 22. *Foltz, J.W.* (1982): Evaluation of tilapia meal for fish diets. Prog. Fish. Cult., 44., 8-11.
 23. *Friesecke, H.* (1984): Handbuch der praktischen Fütterung. BLV Verlagsgesellschaft München/Germany.
 24. *Hajen, W.E; Higgs, D.A.; Beames, R.M.; Dosarojh, B.S.* (1993): Digestibility of various feedstuffs by post-juvenile Chinook salmon (*Oncorhynchus tshawytscha*) in seawater. 2. measurement of digestibility. Aquaculture, 112., 333-348.
 25. *Hardy, R.W.; Masumoto, T.* (1991): Specifications for marine by-products for aquaculture. Proc. Aquaculture Feed Proc. and Nutrition Workshop, Thailand and Indonesia, 19-25 Sept. 1991. American Soybean Asso., Singapore, 99-108.
 26. *Hepher, B.* (1988): Nutrition of pond fishes. Cambridge Univ. Press, Cambridge.
 27. *Hertrampf, J.W.* (1992): On the water durability of aquaculture feed pellets - A review. Advances in Feed Technology, (7), 18-38.
 28. *Hertrampf, J.W.* (1996): Inherent phospholipids of raw material (an update). Lecithin-Trends 40/96, October, (Lucas Meyer GmbH & Co., Hamburg/Germany).
 29. *Higuera, M. de la; Garcia-Gallego, M.; Sanz, A.; Hidalgo, M.C.; Suarez, M.D.* (1989): Utilization of dietary protein by the eel (*Anguilla anguilla*): Optimum dietary protein levels. Aquaculture, 79., 53-61.

30. Jensen, N.C. (1990): Quality fish meal: Specifications and use in aquaculture and for farming. Making profits out of seafood wastes. Proc. International Conf. On Fish By-Products. Anchorage, Alaska. 25 to 17 April. 127-130.
31. Lee, D.L. (1971): Study on digestion and absorption of protein in artificial feeds by four species of shrimps. Collected Reprints. Tungkuang Marine Lab., Taiwan (1): 77-84.
32. McCoy, H.D. II (1990): Fish meal - the critical ingredient in aquaculture feeds. Aquaculture Magazine, Mar/April, 43-50.
33. Miller-Jones, J. (1992): Food safety . Eagen Press, St. Paul/USA.
34. Motta, H. (1988): Fish meal production by artisanal methods. Proc. FAO Expert-Consultation on Fish Technology in Africa. Abidjan, Cote D'Ivoire, 25 to 28 April, 213-217.
35. Murayama, S.; Yanase, M., Masaki, Y (1962): Nutritive constituents of fish meal and fish solubles. In: Heen, E.; Kruezer, B. (eds.). Fish in Nutrition. FAO, Rome, 320-323.
36. NRC (1977): Nutrient requirement of warmwater fishes. Nat. Academy Press, Washington D.C./USA.
37. NRC (1983): Nutrient requirement of warmwater fishes and shellfishes. Nat. Academy Press, Washington D.C./USA.
38. NRC (1993): Nutrient requirement of fish. Nat. Academy Press, Washington D.C./USA.
39. Nehring, K. (1955): Lehrbuch der Tierernährung und Futtermittelkunde (Edition 5). Neumann Verlag, Radebeul and Berlin/Germany.
40. New, M.B. (1987): Feeds and feeding of fish and shrimp - A manual on the preparation and presentation of compound feeds for shrimp and fish in aquaculture, ADCP/Rep/87/26 UNDP, FAO, Rome.
41. Park, C.W. (1989): Effect of sardine meal on growth and mineral contents of red sea bream, *Pagrus major* and Japanese eel, *Anguilla japonica*. Ocean Res. Korea, 11., 9-13.
42. Peñaflores, V.D. (1989): An evaluation of indigenous protein sources as potential component in the diet formulation for tiger prawn, *Penaeus monodon*, using essential amino acid index (EAAI). Aquaculture, 83., 319-330.
43. Piedad-Pascual, F.; Destajo, W. (1978): Growth and survival of *Penaeus monodon* post-larvae fed shrimp head meal and fish meal as primary sources of protein. Fish. Res. J. Phil., 4., 23.
44. Pike, I.H. (1990): Fish meal and oil in farm diets. Fish Farming International, 17., 64.
45. Rumsey, G. (1993): Fish meal and alternate sources of protein in fish feeds update 1993. Fisheries, 18., 14-19.
46. Satoh, S.; Takeuchi, T.; Watanabe, T. (1991): Availability of manganese and magnesium contained in white fish meal to rainbow trout *Oncorhynchus mykiss*. Nippon Suisan Gakkaishi Bull. Jap. Soc. Sci. Fish., 57., 99-104.
47. Seneriches, M.M.; Chiu, Y.N. (1988): Effect of fish meal on the growth, survival and feed efficiency of milkfish (*Chanos chanos*) fry. Aquaculture, 71., 61-69.
48. Shiau, S.Y.; Kwok, C.C.; Kwang, J.-Y.; Chen, C.M.; Lee, S.L. (1989): Replacement of fish meal with soybean meal in male tilapia (*Oreochromis niloticus* x *O. aureus*) fingerling diets at sub-optimal protein level. J. World Aquacult. Soc., 20., 230-235.
49. Smith, R.R.; Peterson, M.S.; Alfred, A.C. (1980): Effect of leaching on apparent digestion coefficient of feedstuffs for salmonids. Prog. Fish Cult., 42., 195-199.
50. Stansby, M.E.; Schlenk, H.; Gruger, E.G. (1990): Fatty acid composition of fish. In: Stansby, M.E. (ed.): Fish oils in nutrition. Van Nostrand Reinhold, New York/USA.
51. Tacon, A.G.J. (1993): Feed ingredients for warm water fish, fish meal and other processed feedstuffs. FAO Fisheries Circular No. 856. FAO, Rome. 64.
52. Tacon, A.G.J. (1993): Feed ingredients for crustaceans natural foods and processed feedstuffs. FAO Fisheries Circular No. 866, FAO, Rome.

53. Täufel, A.; Ternes, W.; Tunger, L.; Zobel, M. (1993): Lebensmittel-Lexicon. Behr's Verlag, Hamburg/Germany.
54. Teshima, S.; Kanazawa, A.; Yamashita, M.; Koshio, S. (1991): Rearing of larval prawn *Penaeus japonicus* with brown fish meal based diets. Nippon Suisan Gakkaishi Bull. Jap. Soc. Sci. Fish., 57., 175.
55. Ufodike, E.B.C.; Ugwuzor, G.N. (1985): Effects of fish meal, cow blood meal and sorghum diets on good utilization and growth of cage-cultured *Oreochromis niloticus*. Biol. Afr., 2., 69-74.
56. Watanabe, T.; Satoh, S.; Takeuchi, T. (1988): Availability of minerals in fish meal to fish. Asian Fish. Sci., 1., 175-195.
57. Weinreich, O.; Koch, V.; Knippel, J. (1994): Futtermittelrechtliche Vorschriften. Buchedition Agrimedia, Hamburg/Germany.
58. West, G.P. (1992): Blacks veterinary dictionary. A & C Black, London, 17th edition.
59. Wöhlbier, W.; Jäger, F. (1977): Futtermittel aus Meerestieren. In: Kling, M.; Wöhlbier, W.: *Handelsfuttermittel*. Verlag Eugen Ulmer, Stuttgart/Germany.
60. Windsor, M.L. (w/o year): Fish meal. Torry Research Station, Torry Advisory Note No. 49.

19. FISH PROTEIN CONCENTRATE (HYDROLYSED)

19.1. Rationale

Hydrolysed fish protein concentrate (HFPC) is produced from by-products of the fishery industry. It is a feed ingredient of the new generation of feedstuffs, characterised by its extraordinarily high protein content and the conversion of insoluble fish protein into polypeptides and amino acids by enzymatic hydrolysis. The soluble fish protein forms chelates with minerals.

The manufacture of HFPC utilises the experiences from the food processing industry, which since the 1960's utilises the advantages of the enzymatic hydrolysis to get a better protein solubility⁽²⁾.

19.2. Manufacture and Processing

Raw materials for HFPC are fish and fish frames from filleting plants. The location of the processing plant determines the fish species used as raw materials. In Europe prevailing fish species for the manufacture of HFPC are:

- Cod (*Gadus morhua*)
- Haddock (*Melanogrammus aeglefinus*)
- Mackerel (*Scomber spp.*)
- Pout (*Trisopterus luscus*)
- Whiting (*Merlangus merlangus*)

The fresh raw material is minced in order to obtain a large surface area for a better and faster enzymatic hydrolysis. In the hydrolysis process, temperature, time and pH have to be strictly controlled for producing the wanted short-chain polypeptides.

After completion of hydrolysis the insoluble matter such as bones, scales and other undigestible solids is removed. The liquid product is de-fatted, concentrated, pasteurised and spray-dried (Figure 19-01). To control any oxidation during transport and storage an antioxidant may be added⁽⁷⁾.

19.3. Chemical, Physiological and other Properties

Chemical Properties

Hydrolysed fish protein concentrate (HFPC) is characterised by its high crude protein content (Table 19-01). The dry matter content is 95 to 97%. Fat and crude fibre content is negligible. However, the small amount of fat has a high level of unsaturated fatty acids as shown below:

- Saturated fatty acids: 22.29% (of total fat)
- Mono-unsaturated fatty acids: 42.95%
- Poly-unsaturated fatty acids: 21.83%

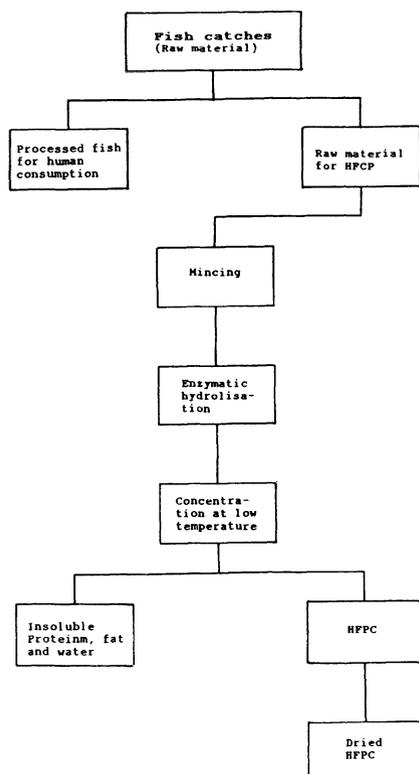


Figure 19-01. Diagram of the production of Hydrolysed Fish Protein Concentrate (HFPC).

Table 19-01: Chemical composition (%) of hydrolysed fish protein concentrate (HFPC) in comparison to soybean meal (from de-hulled beans) and herring meal⁽⁶⁾

	HFPC	Soybean-meal	Herring meal
Crude protein	80.0	48.0	70.0
Crude fat	0.3	0.5	10.0
Crude fibre	1.0	3.0	1.0
Calcium	3.5	0.2	2.0
Methionine + Cystine	4.7	1.5	2.9

HFPC is rich in sulphur-containing amino acids (Table 19-02). The taurine content is remarkably high. It is ten times higher than fish meal made from anchovies (7,900 ppm and 790 ppm, respectively)⁽¹⁰⁾. Information on calcium content vary widely (Tables 19-01, 19-03) and depends on whether the raw material processed is whole fish or fish frames.

Table 19-02: Essential amino acid profile of hydrolysed fish protein concentrate (HFPC) (g/16 g N)⁽⁷⁾

Arginine	6.4 - 7.1
Histidine	1.8 - 2.1
Isoleucine	3.7 - 4.3
Leucine	6.0 - 7.1
Lysine	6.9 - 7.5
Methionine	2.6 - 2.9
Phenylalanine	2.7 - 3.7
Threonine	3.5 - 3.9
Tryptophan	0.8 - 1.0
Valine	4.2 - 4.9

Table 19-03: Mineral and vitamin contents of hydrolysed fish protein concentrate (HFPC)⁽⁷⁾

Minerals			Vitamins (in 1,000 g)		
Calcium	%	0.33	Vitamin A	I.U.	1,400
Phosphorus	%	0.60	Vitamin E	mg	700
Potassium	%	1.30	Vitamin B ₁	mg	13.0
Magnesium	%	0.01	Vitamin B ₂	mg	10.0
Sodium	%	1.00	Vitamin B ₁₂	mcg	140
Manganese	mg/kg	5.0	Biotin	mg	0.2
Iron	mg/kg	85.0	Folic acid	mg	0.2
Copper	mg/kg	4.0	Pantothenic acid	mg	30.0
Zinc	mg/kg	15.0	Choline	mg	3,000
Selenium	mg/kg	1.0			

Physiological Properties

The energy content of HFPC has been determined for salmonids (Table 19-04). Enzymatic hydrolyses is a kind of “pre-digestion”. The apparent digestibility, therefore, is high. In rainbow trout (*Salmo gairdneri*) the digestibility of crude protein, dry matter and energy of HFPC is 95.1%, 77.9% and 79.0%, respectively^(5, 6).

Table 19-04: Energy content of hydrolysed fish protein concentrate (HFPC) determined in salmonids^(5, 6)

	kcal/kg	MJ/kg
Gross energy	6,090	25.5
Metabolisable energy	4,490	18.8
Digestible energy	4,110	17.2

Other Properties

Hydrolysed fish protein concentrate has also chemo-attractant properties as found in crustacean feeding^(4, 9).

19.4 Feeding Value

Fishes

HFPC is a high-class protein source for aquaculture feed. First feeding Atlantic salmon fry (*Salmo salar*) performed better on a LT-fish meal diet than on a HFPC diet, while mortality rate was almost the same. However, HFPC-fed fishes performed better than fish fed other fish meal sources (Table 19-05)⁽⁸⁾.

Table 19-05: The effect of starter feed containing various marine protein sources on the development of first feeding Atlantic salmon (*Salmo salar*)⁽⁸⁾

HFPC	%	90.8	-	-	-
LTF-meal	%	-	90.8	-	-
Menhaden fish meal	%	-	-	90.8	-
Herring meal	%	-	-	-	51.2
Shrimp meal	%	-	-	-	5.0
Crude protein	%	65.9	64.8	57.9	56.6
Crude fat	%	13.9	15.7	14.7	14.6

Final weight	g	0.97	1.06	0.81	0.77
Weight gain	g	0.78	0.87	0.62	0.58
Losses	%	1.6	1.3	8.5	28.9

Juvenile Atlantic salmon as well as juvenile chinook salmon (*Oncorhynchus tshawytscha*) responded significantly better on HFPC diets than on LT-fish meal containing feed. More than 5.0% HFPC in the diet, however, did not improve the performance of the fish (Table 19-06)⁽⁵⁾.

Rainbow trouts (*Salmo gairdneri*) of an initial weight of 8.0 g grew about 15.0% better on HFPC diet than on a LT-fish meal diet as the control⁽⁵⁾.

Table 19-06: Effect of hydrolysed fish protein concentrate (HFPC) in juvenile chinook salmon (*Oncorhynchus tshawytscha*) (trial period: 9 weeks)⁽⁵⁾

HFPC	%	-	5.0	8.0	11.0
Fish meal	%	45.0	40.0	37.0	34.0
Crude protein	%	49.8	49.9	50.0	49.8
Crude fat	%	19.8	19.9	19.9	19.9
Digestible energy	kcal/kg	4,828	4,852	4,852	4,852
	MJ/kg	20.2	20.3	20.3	20.3

Weight gain/ 100 g fish	g rel.	305 100.0	377 123.6	332 108.9	373 122.3
Feed conversion	1: rel.	0.85 100.0	0.75 88.2	0.82 96.5	0.75 88.2

Crustaceans

Increasing levels of HFPC as partial replacement for fish meal in diets for tiger prawn (*Penaeus monodon*) juveniles showed no significant differences between the different inclusion rates. More than 3.0% HFPC did not further improve performances (Table 19-07, Figure 19-02)^(3, 4).

Table 19-07: Feeding tiger prawn (*Penaeus monodon*) juveniles with hydrolysed fish proteion concentrate (HFPC) for 60 days^(3, 4)

HFPC	%	-	3.0	5.0	8.0
Fish meal	%	31.8	27.8	25.5	22.0
Crude protein	%	43.4	45.6	44.9	44.6
Crude fat	%	9.6	8.6	9.4	9.4

Mean initial weight	g	0.92	0.94	0.94	0.84
Mean final weight	g	3.01	4.37	4.20	3.87
Relative growth	%	227.5	365.4	348.1	360.7
Feed conversion rate	1:	4.30	3.05	3.05	2.90
Survival rate	%	75.0	76.7	81.7	75.0

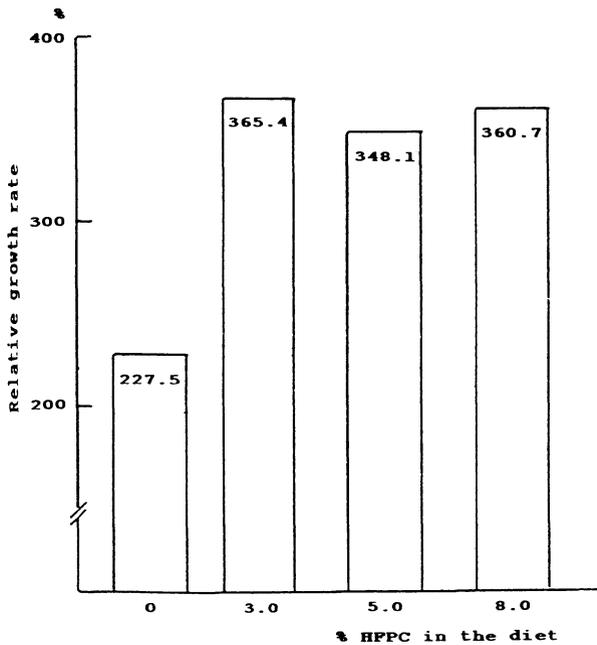


Figure 19-02. Relative growth rate of tiger prawn (*Penaeus monodon*) juveniles fed with increasing levels of HFPC^(data from: 5)

19.5 Recommended Inclusion Rates

HFPC is a valuable high protein source for aquaculture feed. It has to be used at restricted levels because beyond a certain inclusion rate there is no further improvement in performance. Recommended inclusion rates for HFPC are 2.0 to 5.0% for fishes and 2.0 to 4.0% for crustaceans.

19.6 Legal Aspects

HFPC is a natural as well as safe product. The EU-Directive 92/87/EEC does not list the feedstuff. According to AAFCO⁽¹⁾ the product is named “dried fish protein digest” and in Germany the term is “fish meal, partly hydrolysed”. The legal requirements for hydrolysed fish protein concentrate are in Table 19-08.

Table 19-08: Legal requirements (%) for hydrolysed fish protein concentrate (HFPC)

		Germany ⁽¹⁾	U.S.A ⁽¹⁾
Listed as	No.	-	15.12
Moisture	max.	7.5	10.0
Crude protein	min.	85.0	80.0
Water solubility of crude protein	min.	75.0	-
Crude fat	min.	2.5	-

19.7 References

1. AAFCO (1995): Official publication 1995. Ass. of American Feed Control Officials (publisher), Sacramento, CA/USA.
2. Adler-Nissen, J. (1976): Enzymatic hydrolysis of proteins for increased solubility. *J. Agric. Food Chem.*, 24., (6), 1090-1093.
3. Anggawati, A.M. (1992): Fish protein in juvenile tiger shrimp diets. *Feed Magazine*, (2), 22-24.
4. Anggawati, A.M.; Jovita, T.M.; Endang Sri, H. (1990): The use of hydrolyzed protein concentrate in practical diets for *Penaeus monodon* juveniles. Research Report, Nov.
5. Anonymous (1991): Results of experimental trials. Sapropeche, F - 62204 Boulogne-sur-mer, France (Mimeograph).
6. Cho, C.Y.; Owey, C.; Watanabe, T. (1985): Finfish nutrition in Asia: Methodological approaches to research and development. IDRC, Ottawa/Canada, 233e.
7. Hertrampf, J.W. (1992): Hydrolysiertes Fischprotein - ein hochwertiger Eiweißträger. *Allg. Mühlenmarkt*, 93., (1689/1690), 127-130.
8. Hughes, S.G.; Rumsey, G.L. (1991): Starter salmon diets. *Feed Management*, 42., (4), 58-62.
9. Pascual, F.P.; Saclauso, C.A. (1991): Hydrolyzed fish protein concentrate in practical diets for *Penaeus monodon*. Trial Report (Manuscript).
10. Picone, T.A. (1987): Taurin update: Metabolism and function. *Nutrition today*, July/Aug., 16-20.
11. Weinreich, O.; Koch, V.; Knippel, J. (1994): Futtermittelrechtliche Vorschriften. Buchedition Agrimedia, Hamburg/Germany.

20. FISH AND OTHER MARINE SILAGES

20.1 Rationale

Fish and other silages are liquid feeds, manufactured from trash fish and by-products and wastes of fish, crustacean and amphibia (frogs) processing. This is a suitable method to preserve marine materials for months of storage^(30, 39).

Silage making is suitable for utilising marine products when quantities of by-products and wastes are too small for a viable operation of a fish meal plant⁽³³⁾. It is a useful animal feed in areas close to the point of manufacture⁽³¹⁾ and convenient for tropical conditions because the added acids completely arrests putrefaction even at high environmental temperature. The technology of silage making is relatively simple and does not require substantial investments (Figure 20-01)⁽³³⁾.

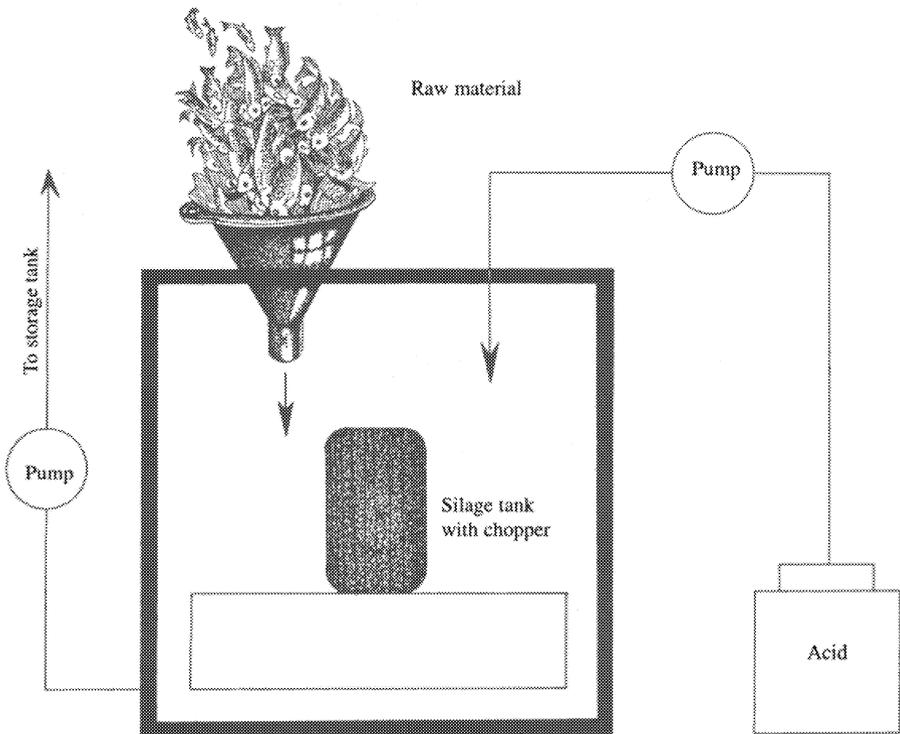


Figure 20-01. Diagram of batch production of acid fish silage.

20.2 Manufacture and Processing

The fresher the raw materials used for silage making, the better the quality of the end-product⁽¹¹⁾. Fish and fish material with low fat content is more suitable for silage preparation than material with a high fat content⁽⁴⁴⁾. The material has to be minced and the preservative agent is added. The whole has to be mixed thoroughly^(30, 33). Preservative agents for ensiling are acids, alkali and fermentable sugars.

20.2.1 Acid Silage

Fish Silage

Formic and propionic acids are most commonly used organic acids. Inorganic acids such as sulphuric acid and hydrochloric acid are also utilised because they are less expensive^(30, 33). To quickly reach a pH of 3.8 to 4.0 about 2.5 % (by weight) of acid is required. Single acids or combinations of two or more acids can be used⁽¹¹⁾.

Fish material gradually liquefies as the tissue structures are broken down by enzymes present in the raw material. Fish guts and whole pelagic fish will liquefy very fast, while processing waste without the guts will hardly autolyse^(6, 15 33, 34). The rate and degree of autolysis depends on the activity of the digestive enzymes, the pH and the temperature⁽³³⁾.

When autolysis is completed, the oil of the raw material floats to the top of the silage and bones and the undissolved portion settles at the bottom as a sludge⁽³³⁾. The liquid silage can be concentrated to bring the moisture content from about 80% to 50%⁽³¹⁾. Acid fish silage can be stored for months. A mould inhibitor should be added to prevent mould development and an antioxidant could be useful to avoid oxidation of the fat/oil^(10, 33).

Crustacean Silage

Usable wastes (head and carapace [exoskeleton]) from shrimp processing amounts to 70% of the whole shrimp⁽²⁸⁾. The rapid decomposition of the fresh material and its valuable nutrients can be preserved by acid treatment.

The method used is similar to that of making fish silage. However, due to the high ash content (CaCO₃) of shrimp shells more acid is needed for stabilising the silage. The acid treatment rapidly solubilises the calcium salt structure of the shells⁽⁹⁾. The use of an antioxidant is helpful^(41, 42).

The liquefaction process is completed after two to three days. The liquid is separated from the solid sediment by centrifugation. About 60 to 70% of the wet weight are liquid which contains half the protein. Over 85% of the chitin remains in the sediment. By removing the insoluble chitin the silage can be processed to a pure end-product⁽¹⁷⁾. The acid silage should be neutralised prior to feeding.

20.2.2 Alkaline Silage

Alkali hydroxides have been used as preservatives in fish silage. The advantages of this silage treatment are good gelling, water binding property and low degree of autolysis. But there are also risks such as the formation of lysino-alanine, racemisation of amino acids and lower storage stability. Actually, alkaline silage making is not practised⁽³³⁾.

22.2.3 Fermented Silage

Fish Silage

Fermented silage is also called “biological fish silage”. It is prepared by adding a fermentable sugar, such as molasses (10 to 12%), and a starter culture of e.g. 200 million lactic acid bacteria per m³ silage, which rapidly converts the sugars to lactic acid. The initial temperature is 21° to 25°C and the pH 6.0 to 6.2 which should decline to 4.5 within 48 hours. Fermented silage autolyses and liquefies in the same way as acid silage^(30, 33, 44).

Crustacean Silage

Lactic acid fermentation of shrimp material is the basis for many fermented pastes and sauces found in South-East Asia such as “belachan” (Malaysia), “trassi-udang” (Indonesia) and “pla-ra” (Thailand).

The principles are the same as for fermented fish silage. Instead of molasses starchy products such as fermented rice, cooked rice and tapioca (cassava) can be also used. However, the starch must be broken down into single sugars for its use by lactic acid bacteria⁽¹⁷⁾.

20.3 Chemical, Physiological and other Properties

20.3.1 Chemical Properties

Fish Silage

Silage of marine materials is a protein source but the crude protein content in the dry matter varies widely. The nitrogen fraction comprises short peptides, amino acids, ammoniac, non-protein nitrogen (NPN) as well as urea (about 20 to 30% of the total N content) (Table 20-01)^(5, 21, 22). The latter is neither beneficial nor detrimental to the metabolism of salmonid fishes. But urea nitrogen must be subtracted when comparing protein values of silage and fresh marine wastes⁽⁵⁾. Total volatile nitrogen (TVN) of about 1.0% is the sum of trimethylamine (TMA), ammoniac and biogenic amines (histamine, putrescine, cadaverine, tyramine) and their levels are an indicator for the freshness of the raw material at the time of ensiling^(10, 33).

Table 20-01: Chemical composition of fish silage (in dry matter)
(10, 26, 30, 44, 45, 46)

		Mean	Variation
Dry matter	%	24.9	20.0 - 47.6
Crude protein	%	58.3	28.2 - 74.4
Crude fat	%	16.0	2.1 - 50.6
Ash	%	14.7	9.6 - 19.5
Crude fibre	%	3.6	1.0 - 6.1
N-free extract	%	28.9	7.7 - 50.0
NPN	g/100 g N	72.9	64.0 - 80.5

The amino acid profile of fish silage is not significantly different from that of dried fish (Table 20-02). Due to the degradation of protein, the level of free amino acids in fish silage is high. In general, they are stable but tryptophan, methionine and histidine are most sensitive for decomposition by storage⁽²⁶⁾.

Table 20-02: Essential amino acid profile of fish silage (g/16 g N)^(11, 26, 28, 44, 45)

	Fish silage		Fish meal
	Mean	Variation	
Arginine	4.9	1.7 - 6.2	5.3
Histidine	1.8	1.2 - 3.0	2.7
Isoleucine	3.2	2.4 - 3.9	3.9
Leucine	5.7	4.2 - 7.5	6.6
Lysine	6.6	4.8 - 9.2	7.7
Methionine	2.5	1.4 - 4.4	2.9
Phenylalanine	2.9	1.6 - 4.0	3.1
Threonine	3.1	2.0 - 4.8	3.8
Tryptophan	1.1	0.1 - 2.0	N/D ¹
Valine	4.3	3.3 - 4.8	4.1

¹ Not determined

The fat content of fish silage depends on the fat content of the raw material used. Fish silage from lean fish had a fat content of 14.9 % while fat fish silage had 50.6%. The catching season also affects the fat content of the fish and consequently that of the silage⁽⁴⁴⁾. The fat of whiting (*Merlangus merlangus*) is rich in unsaturated fatty acids⁽¹⁶⁾:

- Saturated fatty acids: 38.05% (of total fat)
- Mono-unsaturated fatty acids: 39.77%
- Poly-unsaturated fatty acids: 20.33%

The content of water soluble vitamins of fish silage per 1,000 g dry matter is documented as follows⁽⁴⁴⁾:

- Vitamin B₁: 4.0 mg
- Vitamin B₂: 1.0 mg
- Vitamin B₁₂: 15.0 mcg
- Nicotinic acid: 20.0 mg
- Pantothenic acid: 2.0 mg

Fish silage made from fish waste has a higher ash content than those prepared from whole fish. It contains^(26, 30):

- Calcium: 3.1% (0.7 to 4.8%)
- Phosphorus: 1.9% (1.55 to 2.6%).

Storage does not affect the nutrient content of fish silage. The dry matter content and TVN may increase with storage time^(10, 11, 37).

Other Marine Silages

The crude protein content of shrimp head silage and squid viscera silage is lower than in the fresh material. On the contrary the dry matter content of the silages is higher than in the raw material (Table 20-03)⁽⁸⁾. The chemical composition of shrimp wastes and squid viscera vary significantly, reflecting the nature of the shrimp or viscera wastes⁽²⁸⁾. In general, the content of most essential amino acids is higher in shrimp head silage than in shrimp head meal (Table 20-04). Acid silage from shrimp waste is also a source of carotenoids⁽²⁸⁾.

Table 20-03: Chemical composition of shrimp head and squid viscera silage compared to the fresh material (in dry matter)⁽⁸⁾

		Squid viscera		Shrimp head	
		Silage	Fresh	Silage	Fresh
Dry matter	%	19.9	17.8	21.0	19.4
Crude protein	%	60.8	75.3	45.6	54.8
Crude fat	%	7.3	7.4	4.8	2.7
Ash	%	9.5	6.8	24.3	27.4
Calcium	%	0.4	0.1	6.0	8.1
Phosphorus	%	1.0	1.1	1.6	2.0
Free fatty acids	%	4.3	1.9	1.2	50.3

Table 20-04: Essential amino acid profiles of shrimp head silage and shrimp head meal (g/16 g N)⁽²⁸⁾

	Shrimp head silage	Shrimp head meal
Arginine	6.2	5.4
Histidine	3.4	1.4
Isoleucine	3.9	3.0
Leucine	5.8	5.0
Lysine	6.0	5.2
Methionine	1.9	1.9
Phenylalanine	3.2	3.5
Threonine	2.9	3.0
Tryptophan	3.4	2.6
Valine	4.4	3.8

20.3.2 Physiological Properties

The energy values of fish silage for fishes are 5,432 kcal/kg (22.7 MJ/kg) for gross energy, 2,871 kcal/kg (12.0 MJ/kg) for digestible energy and 3,394 kcal/kg (14.2 MJ/kg) for metabolisable energy^(5, 30, 46).

The apparent digestibility of fish silage ranges from 31.9% to 84.4%. The utilisation of fish silage by the eel is low and declines when the percentage in the diet increases (Table 20-05). The protein efficiency ratio (PER) varies from 0.34 for the European eel (*Anguilla anguilla*) to 1.30 for the Atlantic salmon (*Salmo salar*). Silage made from waste of frog processing showed a protein digestibility of 72.0%⁽³⁹⁾.

Table 20-05: Apparent digestibility (%) of fish silage

Species	Silage in diet %	Apparent digestibility				Reference
		All	Dry matter	Crude protein	Crude fat	
Rainbow trout (<i>Salmo gairdneri</i>)	55.0	-	84.4 ¹	-	-	(5)
Atlantic salmon (<i>Salmon salar</i>)	45.0 ²	78.6	-	-	-	(10)
	45.0 ³	79.4	-	-	-	
Nile tilapia (<i>Oreochromis niloticus</i>)	N/S ⁴	-	81.1	84.6	74.4	(12)
European eel (<i>Anguilla anguilla</i>)	10.0	38.8	-	-	-	(16)
	15.0	41.9	-	-	-	
	20.0	31.9	-	-	-	
Rats	100.0 ²	-	82.0 ¹	-	-	(11)
	100.0 ³	-	82.3 ¹	-	-	
Pigs	N/S ⁴	-	83.0	95.0	89.0	(44)

¹ Nitrogen digestibility; ² Silage stored for five months; ³ Silage stored for two months; ⁴ Not stated

The mean apparent digestibility of amino acids of fish silage from dogfish (*Squalus acanthias*) tested in rainbow trout (*Salmo gairdneri*) is 89.1%. Storage of fish silage for more than 30 days slightly reduces but insignificantly the amino acid digestibility as found in rats (Table 20-06).

Table 20-06: Apparent digestibility (80%) of essential amino acids of fish silage

	Rainbow trout ⁽⁵⁾	Rats ⁽¹¹⁾	
		Silage stored for ...	
		30 days	180 days
Arginine	93.6	91.3	91.4
Histidine	86.3	93.4	90.9
Isoleucine	87.4	85.7	83.7
Leucine	88.8	87.6	86.1
Lysine	93.0	90.8	87.4
Methionine	89.2	89.4	87.8
Phenylalanine	87.5	86.5	84.1
Threonine	88.9	82.4	79.6
Valine	87.4	86.7	83.7

20.3.3 Other Properties

Positive Properties

Silage from marine material has chemo-attractant properties due to free amino acids⁽⁴⁴⁾. In particular shrimp silage has shown to exhibit feeding stimulatory properties to a variety of fish species⁽²⁷⁾. Fish silage may also contain unidentified growth factors⁽⁴⁴⁾ (see chapter 44).

The carotenoid, astaxanthin, in shrimp head silage is quite stable at pH 4.0. Rainbow trouts (*Salmo gairdneri*) well absorbed astaxanthin of silage made from the processing waste of the deepwater prawn *Pandalus borealis* and accumulated it in the fish muscle⁽⁴²⁾.

Negative Properties

Fish silage may contain high levels of mercury (*Batterham et al.* [1983]) which is accumulated in the body tissues and could produce fish carcasses that are not fit for human consumption⁽⁷⁾. Fish silage containing more than 0.5 mg/kg mercury is unfit as feed^(26, 43).

The relatively high content of fluoride found in silage made from dogfish (*Squalus acanthias*) does not seem to limit its use in diets for salmonids^(5, 36).

Oxidised oils of fish silage may also cause the destruction of fat soluble vitamins which in extreme cases could result in a vitamin deficiency⁽²⁶⁾. Thiamine (Vitamin B₁) may be destroyed by the enzyme thiaminase which is present in fish silage at high levels⁽¹⁾.

20.4 Feeding Value

Fishes

Commonly moist silage feeds are made by mixing the liquid silage with a dry binder meal in about equal proportions by weight⁽³³⁾.

Fresh fish silage of various fish species and fish processing waste prepared with formic acid (2.2% to 2.5%) has successfully replaced fresh and frozen fish, respectively, in diets for Atlantic salmon (*Salmo salar*) and rainbow trout (*Salmo gairdneri*). No negative effects were observed in weight gain, health and the quality of the fish meat (Table 20-07)^(2, 3, 4, 5, 19, 20, 23, 24, 35). Silage in the diet at a level of 47% is equal to 30% of the diet's total nitrogen⁽⁴⁾. But it has been found that growth rates of the Atlantic salmon are significantly reduced, if more than 15% of the total protein came from fish silage. At a level of 20% of the total protein from the silage a slightly off-flavour was observed⁽³³⁾.

Table 20-07: Dogfish (*Squalus acanthias*) offal silage as feed for Atlantic salmon (*Salmo salar*) (feeding period: 92 days)⁽⁵⁾

Industrial frozen fish	%	50.0	-
Dogfish silage	%	-	47.0
Dry matter	%	58.9	59.1
Crude protein	%	46.3	47.9
Non-urea protein	%	46.3	44.9

Initial weight	g	702	702
Weight gain	g	490	483
Daily growth rate	%	0.58	0.58
Dressing percentage		88.1	87.6
Pigmentation of flesh	Points	1.8	1.8
Taste	Points	3.9	4.0

When fresh saithe (*Pollachius virens*) and silage made from offal of the same fish species were fed to Atlantic salmon no differences in performances were observed when the silage was stored for two months. But a storage time of five months has negatively affected fish performances (Table 20-08) although the silage was fortified not only with formic acid (2.2%), potassium sorbate (0.2%) and an antioxidant (200 ppm)⁽¹⁰⁾. Rainbow trout grew slower, compared to a fish meal diet, when the fish silage was stored for only one month^(18, 38). It is concluded that the quality of acid fish silage significantly declines when stored for more than 90 days^(10, 11).

Mirror carp (*Cyprinus carpio*) fingerlings responded negatively on acid fish silage, stored for six months, compared to LT-fish meal. Both silage and fish meal were prepared from whole whiting (*Merlangus merlangus*). Poor diet palatability and loss of nitrogen by leaching most probably are the limiting factors to the growth of carp fed fish silage diets⁽⁴⁵⁾.

Feeding lactic acid fish silage to juvenile Nile tilapia (*Oreochromis niloticus*) and cat fish (*Clarias gariepinus*) at increasing levels of silage as replacement for herring meal

showed no significant differences to the control for all parameters and at all levels (Table 20-09). There were also no differences in the carcass composition and no morphological defects were observed⁽¹²⁾.

In diets for the European eel (*Anguilla anguilla*) acid fish silage gradually replaced meat and fish meal. There was a statistically significant improvement in weight gain and feed conversion as compared to the control at all silage levels (Table 20-10)⁽¹⁶⁾.

Table 20-08: The influence of storage time of saithe (*Pollachius virens*) offal silage on performance of Atlantic salmon (*Salmo salar*)⁽¹⁰⁾

Raw minced fish	%	45.0	-	-
Silage/2 months stored	%	-	45.0	-
Silage/5 months stored	%	-	-	45.0
Dry matter	%	55.6	58.6	62.6
Crude protein ¹	%	44.8	44.8	46.2

Final live weight	g	478	484	444
Weight gain	g	153	154	122
	%	100.0	100.7	79.3
Feed conversion	1:	1.7	1.7	2.4
	%	100.0	100.0	141.2
Protein efficiency	%	1.36	1.30	0.94

¹ In dry matter

Table 20-09: Increasing levels of lactic acid tilapia silage in diets for juvenile Nile tilapia (*Oreochromis niloticus*) in replacement for herring meal (feeding period: 70 days)⁽¹³⁾

Fish silage ¹	%	-	13.4	26.8	40.1
Herring meal	%	40.0	30.0	20.0	10.0
Crude protein	%	31.0	31.3	31.2	31.3
Crude fat	%	3.5	3.6	3.6	3.6

Initial weight	g	8.2	8.2	8.2	8.2
Final weight	g	52.7	52.3	52.2	52.2
Daily weight gain	g	0.63	0.63	0.63	0.63
PER		2.02	2.00	2.01	2.01
Feed conversion	1:	1.59	1.60	1.60	1.59

¹ A mixture of fish silage and soybean meal (50:50)

Table 20-10: Increasing levels of fish silage from a blend of sardine (*Sardina pilchardus*) and whiting (*Merlangius merlangius*) on the development of European eel (*Anguilla anguilla*) fingerlings (feeding period: 4 months)⁽⁶⁾

Fish silage	%	-	9.0	12.8	17.0
Meat meal	%	21.0	12.6	11.7	10.5
Fish meal	%	39.5	37.8	34.5	31.5
Crude protein	%	49.8	49.7	49.9	49.4
Lipids	%	9.1	9.5	9.4	9.8

Weight gain	g	2.15	2.42	2.56	2.57
SGR/day	%	0.17	0.28	0.29	0.29
Feed conversion		8.87	6.00	6.26	6.10
PER	%	0.24	0.34	0.34	0.34

Crustaceans

Information on silage of marine material as a protein source in feed for crustaceans are scarce. In studies with the common prawn (*Palaemon serratus*) up to 40% of a silage made from *Macroramphosus scolopax* has been used⁽²⁵⁾. Freshwater fish silage was successfully fed to the giant freshwater prawn *Macrobrachium rosenbergii*⁽⁴¹⁾. Lack of comprehensive research does not mean that fish silage is not used as an ingredient for shrimp feed⁽³⁰⁾.

20.5 Recommended Inclusion Rates

High levels of acid fish silage in diets may have an adverse effect. The use of acid fish silage, therefore, should be restricted to not more than 20% of the protein content of the diet. The use of low levels of fish silage seems to be necessary to avoid a disagreeable taste and odour of cultured fish. However, if the autolytic process is arrested at an early stage by heating before ensiling or just thereafter, there seems to be no nutritional limits⁽³³⁾.

It is advisable to add vitamins at a level which is higher than normal because of the negative effect of rancid oil in the silage and the enzyme thiaminase on vitamins.

There are no quality requirements for fish silage. Based on the requirements for raw materials for fish meal, it is suggested that the content of total volatile nitrogen (TVN) should be below 40 mg N/100 g of the raw material for making silage⁽³³⁾.

20.6 Legal Aspects and Precautions

Legal Aspects

Regulations restricting the use of fish silage for feeding aquatic animals are unknown. Existing legislation and regulations with regard to the application of acids to feed have to be duly considered.

In U.S.A. all common organic and inorganic acids have the GRAS-status when used in accordance with food manufacture or feeding practices⁽¹⁴⁾. In the EU all common acids used for preservation of feeds and feedstuffs may be used without any restriction at permitted levels⁽⁴³⁾. Thailand has limited the use of acids in finished aquaculture feeds to not more than 0.1%⁽³²⁾.

Precautions

Fish silage may contain mercury and fluorine which can accumulate in the fish body. In single feedstuffs (min. 88% dry matter) from the processing of aquatic animals, in Germany mercury and fluorine is restricted to not more than 0.5 mg and 500 mg/kg, respectively⁽⁴³⁾. The 0.5 mg/kg mercury limit applies also to fish or fish produce for human consumption⁽⁴⁰⁾. The “provisional tolerate weekly intake” (PTWI), set by WHO/FAO is limited to 0.3 mg mercury per person or 0.005 mg per kg body weight and the safe and adequate fluorine level for man amounts to 2.0 to 10.0 mg⁽²⁹⁾.

20.7 References

1. *Anglesa, J.O.; Jackson, A.J.* (1985): Thiaminase activity in fish silage and moist fish feed. *Anim. Feed Sci. Technology*, *13.*, 39-46.
2. *Anonymous* (1995): Dogfish processing waste in salmon diets. *Infotish International*, (3), 60.
3. *Åsgård, T.* (1981): Syrekonservering - kan avfall bli inntektskjelde? *Norsk Fiskeoppdrett*, *6.*, (5/6), 30.
4. *Åsgård, T.* (1984): Pigghåavfall in fôr til laksefisk. *Norsk Fiskeoppdrett*, *9.*, (2), 42-43.
5. *Åsgård, T.; Austreng, E.* (1985): Dogfish offal, ensiled or frozen, as feed for salmonids. *Aquaculture*, *49.*, 289-305.
6. *Backhoff, H.P.* (1976): Some chemical changes in fish silage. *J. Food Technology*, *11.*, 353-363.
7. *Batterham, E.S.; Gorman, T.B.; Chojka, R.* (1983): Nutritive value and mercury content of fish silage for growing pigs. *Anim Feed Sci. Technology*, *21.*, 43-56.
8. *Carver, L.A.; Akiyama, D.M.; Dominy, W.G.* (1989): Processing of wet shrimp heads and squid viscera with soy meal by a dry extruder process. *Proc. World Congr. on Vegetable Protein Utilization in Human Foods and Animal Feedstuffs*, Singapore, October, 167-170.
9. *Chen, H.M.; Meyers, S.P.* (1983): Ensilage treatment of crawfish waste for improvement of astaxanthin pigment extraction. *J. Food Sci.*, *48.*, 1516-1520 and 1555.
10. *Espe, M.; Haaland, H.; Njaa, L.R.* (1992): Autolysed fish silage as a feed ingredient for Atlantic salmon (*Salmo salar*). *Comp. Biochem. Physiol.*, *103A.*, (2), 369-372.
11. *Espe, M.; Raa, J.; Njaa, L.R.* (1989): Nutritional value of stored fish silage as a protein source for young rats. *J. Sci. Food Agric.*, *49.*, 259-270.
12. *Fagbenro, O.; Jauncy, K.* (1995): Water stability, nutrient leaching and nutritional properties of moist fermented fish silage diets. *Aquaculture Engineering*, *14.*, 143-153.
13. *Fagbenro, O.; Jauncy, K.; Haylor, G.* (1994): Nutritive value of diets containing dried lactic acid fermented fish silage and soybean meal for juvenile *Oreochromis niloticus* and *Clarias gariepinus*. *Aquatic. Living Res.*, *7.*, 79-85.
14. *FDA* (1994): Food additives permitted in feed and drinking water of animals. *Food and Drug Admin.*, 21 CFR Ch.I (4-1-94 ed.), 514, 582.
15. *Gildberg, A.* (1982): Autolysis of fish tissue - General aspects. *Dr. scient. thesis*, University Tromsø/Norway.

16. *Gonçalves, J.F.; Santos, S.; Pereira, V.S.; Baptista, I.; Coimbra, J.* (1989): The use of fish silage as an ingredient for eel fingerling nutrition. *Aquaculture*, 80., 135-146.
17. *Hall, G.M.; Silva, S. de* (1994): Shrimp waste ensilation. *Infofish International*, (2), 27-30.
18. *Hardy, R.W.; Shearer, K.D.; Stone, F.D.; Wieg, D.H.* (1983): Fish silage in aquaculture diets. *J. World Mariculture Soc.*, 14., 695-703.
19. *Heras, K.; McLeod, C.A.; Ackmann, R.G.* (1994): Atlantic dogfish silage vs. herring silage in diets for Atlantic salmon (*Salmo salar*): growth and sensory evaluation of fillets. *Aquaculture*, 125., 93-106.
20. *Jackson, A.J.; Kerr, A.K.; Bullock, A.M.* (1984): Fish silage as a dietary ingredient for salmon. II. Preliminary growth findings and nutritional pathology. *Aquaculture*, 40. 283-291.
21. *Kjos, N.P.* (1994): Fiskeensilasje som fôr til slaktekylling og verpehøns. *Faginf. fra SFFL*, No. 6, Husdyrforsksmøtet, 366-370.
22. *Kjos, N.P.* (1994): Fiskeensilasje som fôr til drøvtyggare. *Faginf. fra SFFL*, No. 6, Husdyrforsksmøtet, 218-220.
23. *Lall, S.P.* (1991): Nutritional value of fish silage in salmonid diets. *Bull. Aquaculture Assoc. Canada*, 91. (1), 63-74.
24. *Lie, O.; Waagbø, R.; Sandnes, K.* (1988): Growth and chemical composition of adult Atlantic salmon (*Salmo salar*) fed dry and silage based diets. *Aquaculture*, 69., 343-353.
25. *Luis, O.J.; Batista, I.* (1990): The influence of protein quality and lipid composition from two Portuguese fish meals on growth of early juveniles of *Palaemon serratus* (Crustacea, Decapodes). *Biol. Inst. National Fish. Investigation of Portugal*, 15. 5-14.
26. *Lunen, T.A. van* (1990): Fish silage. In: *Thacker, P.A.; Kirkwood, P.N.*: Nontraditional feed sources for use in swine production. Butterworths Publisher, Stoneham, MA/USA.
27. *Mackie, A.M.* (1982): Identification of the gustatory feeding stimulants. In: *Hara T.J.* (ed.): Chemoreception in fishes. Elsevier Publ. Co., Amsterdam/The Netherlands.
28. *Meyers, S.P.; Benjamin, G.* (1987): Feeding value of crustacean wastes can be improved through proper ensilage treatment. *Feedstuffs*, 30 March, 12-13.
29. *Miller Jones, J.* (1992): Food safety. Eagan Press, St. Paul, Minnesota/USA.
30. *New, M.B.* (1987): Feed and feeding of fish and shrimps - A manual on the preparation and presentation of compound feeds for shrimps and fish in aquaculture. UNDP/FAO/ADCP/REP/87/26, Rome/Italy.
31. *OECD* (1984): Multilingual dictionary on fish and fish products. Fishery News Books Ltd., Farnham/England.
32. *Prasert, S.* (1993): Feed ingredients and quality control. In: *New, M.B.; Tacon, A.G.J.; Csava, I.* (eds.): Farm made aquafeeds. RAP Publication 1993/18, AADCP/PROC/5, Bangkok/Thailand, 75-86.
33. *Raa J.* (1994): Fish silage: Successes and limitations as feed ingredient in aquaculture. *Proc. Fish Nutrition Workshop*, Singapore, 25-27 October.
34. *Raa, J.; Gildberg, A.* (1976): Autolysis and proteolytic activity of cod viscera. *J. Food Technology*, 11., 619-628.
35. *Rungruansak, K.; Utne, F.* (1981): Effect of different acidified wet feeds on protease activities in the digestive tract and on growth rate of rainbow trout (*Salmo gairdneri*). *Aquaculture*, 22., 67-79.
36. *Søvik, T.; Brækkan, O.R.* (1981) The fluoride content in some Norwegian fish products and other marine products. *Fiskeri Dir. Skrifter. Ser. Ernæring*, 2., 1-6.
37. *Stone, F.E.; Hardy, R.W.* (1986): Nutritional value of acid stabilised silage and liquefied fish protein. *J. Sci. Food Agric.*, 37., (8), 797-802.
38. *Stone, F.E.; Hardy, R.W.; Shearer, K.D.; Scott, T.M.* (1989): Utilization of fish silage by rainbow trout (*Salmo gairdneri*). *Aquaculture*, 76., 109-118.

39. *Suparno; Poernonto, A.* (1992): Fish waste utilisation in Indonesia. *ASEAN Food J.*, 7., (2), 67-72.
40. *Täufel, A.; Ternes, W.; Tunger, L.; Zobel, M.* (1993): *Lebensmittel-Lexikon*. Behr's Verlag, Hamburg/Germany.
41. *Tideman, E.; Raa, J.; Stormo, B.; Torrissen, O.* (1984): Processing and utilization of shrimp waste. In: *McKenna* (ed.): *Engineering and Food*, Vol. 2. Elsevier Publ. Co., Amsterdam/The Netherlands, 583-591.
42. *Torrissen, O.; Tideman, E.; Hansen, F.; Raa, J.* (1981/1982): Ensiling in acid - A method to stabilize astaxanthin in shrimp processing by-products and improve uptake of this pigment by rainbow trout (*Salmo gairdneri*). *Aquaculture*, 26., 77-83.
43. *Weinreich, O.; Koch, V.; Knippel, J.* (1994): *Futtermittelrechtliche Vorschriften*. Buchedition Agrimedia, Hamburg/Germany.
44. *Wöhlbier, W.; Jager, F.* (1977): *Futtermittel aus Meerestieren*. In: *Kling, M.; Wöhlbier, W.*: *Handelsfuttermittel*. Verlag Eugen Ulmer, Stuttgart/Germany.
45. *Wood, J.F.; Capper, B.S.; Nicolaidis, L.* (1985): Preparation and evaluation of diets containing fish silage, cooked fish preserved with formic acid and low-temperature-dried fish meal as protein source for mirror carp (*Cyprinus carpio*). *Aquaculture*, 44., 27-40.
46. *Zaher, M.; Mazid, M.A.* (1993): *Aquafeeds and feeding strategies in Bangladesh*. In: *New, M.B.; Tacon, A.G.J.; Csava, I.* (eds.): *Farm made aquafeeds*. RAPA Publication 1993/18, AADCF/PROC/5, Bangkok/Thailand, 75-86.

21. FISH SOLUBLES (DE-HYDRATED)

21.1 Rationale

Fish solubles is a by-product of fish meal manufacture. Industrial fish processed into fish meal comprises 22.0% solids, 6.0% fish oil and 72.0% water. The water phase is rich in soluble protein, soluble minerals and vitamins of the B-group. But fresh material decays easily and cannot be stored and handling is difficult due to the content of gluey substances. Most of the solubles, therefore, are condensed and added back to the fish cake prior to drying, resulting in “full fish meal”⁽⁵⁾. By de-hydration fish solubles can be converted into a first class feedstuff.

21.2 Manufacture and Processing

Cooked fish produces two products “press-cake” (fish meal) and “press liquor”. The press-liquor or press-water passes a vibrating screen for the removal of remaining solids, followed by centrifuge to separate the fish oil from the press-liquor (Figure 21-01)⁽⁴⁾. Vacuum evaporation concentrates the press-water to a content of 50% solids. This material is de-hydrated, today mostly by spray-drying. The latest spray-drying technology does not alter the chemical composition of the final product⁽²⁾. The fine yellow-brownish powder is hygroscopic and has to be handled with care.

21.3 Chemical, Physiological and other Properties

Chemical Properties

De-hydrated fish solubles have a high crude protein content (Table 21-01). The variation of the protein content is caused by the fishing season and the fish species processed. Fish solubles are also a useful source of essential amino acids (Table 21-02).

The fat level of fish solubles is affected by the intensity of the separation of the fat from the press-liquor. The total fat content is composed of around 77.0% unsaturated fatty acids of which 21.4% are polyunsaturated fatty acids (PUFA)⁽²⁾.

A high ash content is an indicator that the press-liquor comes from processing of fish waste having a high content of bones. The solubility of macro and micro minerals of fish solubles is high (Table 21-03). Fish solubles is probably the richest source of natural selenium⁽⁷⁾. It is also a good source of water soluble vitamins (Table 21-03).

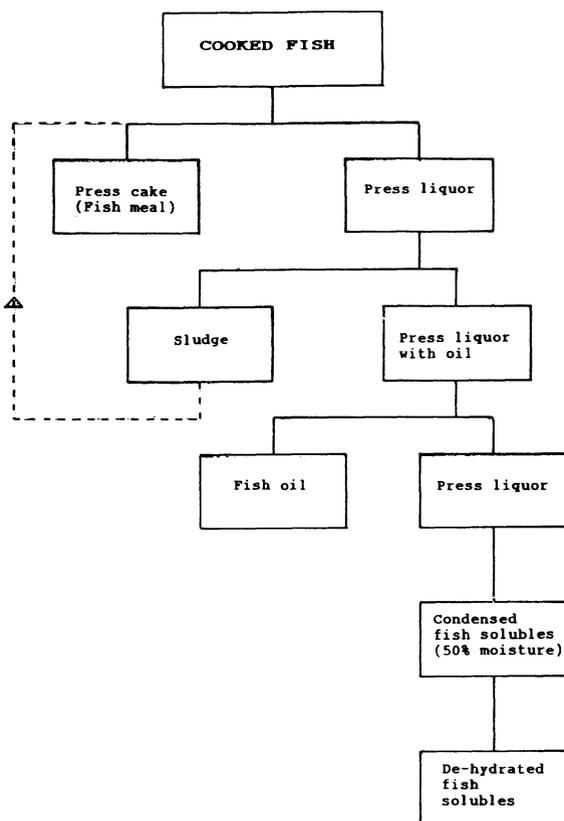


Figure 21-01. Flow diagram of the processing of de-hydrated fish solubles.

Table 21-01: Chemical composition (%) of de-hydrated fish solubles and condensed fish solubles (as fed)^(2, 3, 8, 9, 12, 13)

	Fish solubles, de-hydrated		Condensed fish solubles
	Mean	Variation	
Dry matter	94.0	89.0 - 96.0	50.0
Crude protein	71.0	62.0 - 80.0	32.7
Crude fat	4.0	3.0 - 8.2	5.6
Ash	13.5	12.0 - 16.0	-
Crude fibre	0.9	0.3 - 1.4	0.5
Salt	5.0	3.5 - 6.0	-

Table 21-02: Essential amino acid profile of de-hydrated fish solubles (g/16 g N)^(2, 3, 8, 13)

	Mean	Variation
Arginine	2.74	2.44 - 3.05
Histidine	1.21	0.75 - 2.10
Isoleucine	1.74	1.52 - 2.05
Leucine	3.27	2.97 - 3.50
Lysine	3.27	2.24 - 3.87
Methionine	1.04	0.75 - 1.18
Phenylalanine	1.47	1.41 - 1.53
Threonine	1.25	0.09 - 1.81
Tryptophan	0.38	0.16 - 0.59
Valine	2.16	2.10 - 2.20

Table 21-03: Macro and trace minerals and vitamin contents of de-hydrated fish solubles

Minerals ^(9, 13, 15)			Vitamins (per 1,000 g) ^(9, 13, 15)		
Calcium	%	0.36	Vitamin E	mg	4.8
Phosphorus	%	1.22	Vitamin B ₁	mg	4.7
Sodium	%	1.27	Vitamin B ₂	mg	13.4
Potassium	%	1.78	Vitamin B ₆	mg	17.1
Magnesium	%	0.21	Vitamin B ₁₂	mcg	530
Manganese	mg/kg	19.1	Biotin	mg	0.48
Iron	mg/kg	337.3	Folic acid	mg	0.93
Zinc	mg/kg	46.7	Nicotinic acid	mg	266
Copper	mg/kg	24.2	Pantothenic acid	mg	39.5
Selenium	mg/kg	3.5	Choline	g	4.70
			Inositol	mg	352

Physiological Properties

De-hydrated fish solubles have a high crude protein content but much of it is non-protein nitrogen⁽¹¹⁾. The protein digestibility in rainbow trout (*Salmo gairdneri*) is only 60%⁽¹⁴⁾. A similar low digestibility rate is reported for pigs (70.8%). The organic matter digestibility for poultry is 81.0%⁽⁸⁾.

The metabolisable and the digestible energy of fish solubles has been determined for rainbow trouts and is 3,345 kcal/kg (14.0 MJ/kg) and 3,684 kcal/kg (15.4 MJ/kg), respectively⁽¹⁴⁾.

Other Properties

De-hydrated fish solubles is an efficient chemo-attractant due to its high solubility of about 90%^(3, 11) which also means faster leaching of chemo-attractant components and loss of nutrients. It was found that after one hour of seawater immersion 21% of the protein was lost⁽⁶⁾.

Fish solubles is also a source of unidentified growth factors (UGF)^(7, 11, 15) (see chapter 44). The binding capacity of de-hydrated fish solubles is medium according to pelletising tests by CPM⁽¹⁰⁾.

21.4 Feeding Value

De-hydrated fish solubles is a protein source, an attractant, a supplier of UGF and can serve as a pellet binder. However, it appears that the significant improvement of the diet’s palatability is the most important contribution of fish solubles to aquaculture feeds⁽³⁾.

Reports on comparative trials are missing. In finisher diets for the tiger prawn (*Penaeus monodon*) 4.0% and 5.0% fish solubles were used⁽¹⁶⁾. However, the diets were not isonitrogenous and the composition is not comparable (Table 21-04).

Table 21-04: Fish solubles in diets for tiger prawn (*Penaeus monodon*)⁽¹⁶⁾

Fish solubles	%	-	5.0	4.0
Squid meal	%	35.0	-	-
Shrimp head meal	%	15.0	-	-
Small shrimp meal	%	-	40.0	10.0
Fish meal	%	-	15.0	20.0
Crude protein	%	37.2	35.1	30.2

Initial weight	mg	1.52	1.52	1.52
Final weight	mg	34.21	32.14	31.14
	%	100.0	93.9	91.0
Survival rate	%	57.0	55.3	54.3

21.5 Recommended Inclusion Rates

The value of de-hydrated fish solubles is established as an ideal combination of essential amino acids that are nutritionally known as feeding stimulants for aquatic organisms. For all species and types of feed, de-hydrated fish solubles as an attractant should be used at levels of 2.0% to 5.0%^(3,17).

21.6 Legal Aspects

De-hydrated fish solubles should be free of any kind of pathogens. AAFCO⁽¹⁾ rules that fish solubles, de-hydrated, (No. 51.7) should contain not less than 60% crude protein and condensed fish solubles (No. 51.6) not less than 30%. In the EU-Directive 92/87/EEC only condensed fish solubles (No. 10.02) is listed. The German feedstuff legislation is more specific (Table 21-05).

Table 21-05: Legal requirements for fish solubles in the Federal Republic of Germany⁽¹⁸⁾

		Fish solubles, de-hydrated %	Fish solubles, condensed %
Moisture	max.	8.0	-
Crude protein	min.	60.0	32.0
Pepsin solubility	min.	90.0	-
Salt (NaCl)	max.	10.0	5.0

21.7 References

1. *AAFCO* (1995): Official publication 1995. Ass. of American Feed Control Officials (publisher), Sacramento, CA/USA.
2. *Anonymous* (1990): Description of spray-dried fish solubles. Dan-Spray APS, Hvide Sande/Denmark.
3. *Anonymous* (w/o year): Spray-dried fresh whole-fish solubles protein attractants and binder for aqua feed. HVISA fiskemelsfabrikken, Hvide Sande/Denmark (FPr/4).
4. *Bimbo, A.P.* (1990): Production of fish oil. In: *Stansby, M.E.*: Fish oils in nutrition. Van Nostrand Reinhold, New York.
5. *Christensen, S.* (1978): Control of decanters and separators. IAFMM News Summary, 44., 104-119.
6. *Cuzon, G.; Hew, M.; Cognie, D.; Soletchnik, P.* (1982): Time lag effect of feeding on growth of juvenile shrimp *Penaeus japonicus* Bate. *Aquaculture*, 29., 33-44.
7. *Feltwell, R.; Fox, S.* (1978): Practical poultry feeding. Faber and Faber, London and Boston.
8. *Friesecke, H.* (1984): Handbuch der praktischen Fütterung von Rind, Schaf, Pferd, Schwein, Geflügel und Süßwasserfischen. BLV Verlagsgesellschaft, München/Germany.
9. *Hansen, P.* (1993): Private communication.
10. *Hertrampf, J.W.* (1992): On the water durability of aquaculture feed pellets - A review. *Advances in Feed Technology*, (7), 18-38.
11. *New, M.B.* (1987): Feed and feeding of fish and shrimp. A manual on the preparation and presentation of compound feeds for shrimp and fish in aquaculture. UNDP/FAO/ADCA/REP/87/26, Rome/Italy.
12. *NRC* (1981): Nutrient requirements of coldwater fishes (No. 16). National Academy Press, Washington, D.C.
13. *NRC* (1983): Nutrient requirements of warmwater fishes and shell fishes. National Academy Press, Washington, D.C.
14. *Smith, R.R.; Peterson, M.C.; Allred, A.C.* (1980): The effect of leaching on apparent digestion coefficients in determining digestibility and metabolizable energy of feedstuffs for salmonids. *Prog. Fish Culturist*, 42., 699-718.
15. *Soares, J.; Miller, D.; Cuppett, S.; Bauersfeld, P.* (1971): A review of the chemical and nutritive properties of condensed fish solubles. *Fishery Bull.*, 71., 255-265.
16. *Sumeru, S.U.* (1988): Status of shrimp feed development at BADC Jepara, Indonesia. Paper pres.

Workshop on Shrimp and Finfish Feeds Dev., 25-29 Oct, Johore Bahru/Malaysia.

17. *Tacon, A.G.J.* (1993): Feed ingredients for crustaceans natural foods and processed feedstuffs. FAO Fisheries Circular No. 866, Rome/Italy (FIRI/C866).
18. *Weinreich, O.; Koch, V.; Knippel, J.* (1994): Futtermittelrechtliche Vorschriften. Buchedition Agrimedia, Hamburg/Germany.

22. IMMUNOSTIMULATORY SUBSTANCES

22.1 Rationale

Immunity is the power of the organism to resist infections or actions of certain poisons. The immunity can be either inherited, acquired naturally or acquired artificially⁽¹⁷⁾. Strengthening the immunity of cultured aquatic animals is an important task since bacterial and viral diseases are a major threat to aquaculture. While fish have both “non-specific” and “specific” immunity⁽¹²⁾, shrimps lack a specific immune system and are apparently entirely dependent on non-specific immune mechanism to resist infections⁽¹⁵⁾.

Contrary to vaccination immunostimulants or “immuno-modulatory substances”⁽¹¹⁾ influence the immune system of cultured aquatic animals through feeding via feed⁽⁸⁾. This is particularly of interest in shrimp farming since vaccination of shrimps is unrealistic and impractical. On the contrary big fish can be vaccinated or orally intubated, such as salmon (*Salmo salar*, *Oncorhynchus* spp.) and turbot (*Psetta maxima*).

22.2 Substances with Immunostimulatory Effect

There are compounds which have the ability to activate cells in the immune system. Presently, the chemical nature or biological origin of immunostimulatory preparations may not be defined clearly. Nevertheless, immunostimulants have been classified as follows⁽¹²⁾:

- Bacterial products,
- Products from mycelial fungi,
- Yeast glucans,
- Yeast nucleotides,
- Soluble and particle bound β -1,3-glucans,
- Immunostimulatory glycans,
- Peptides from animal extracts,
- Synthetic compounds,
- Cytokines.

Influencing the immune systems of cultured aquatic animals is a relatively new way to combat diseases. The cited product groups have immunostimulatory properties but reports on the immunostimulatory effect in aquatic animals are rare.

22.3 Glucans

Glucans appear to be the most promising substances for enhancing the physiological defence mechanism of cultured aquatic animals.

Occurrence

Beta (β)-glucans are polysaccharides and are extracted from grains and yeast, particularly baker's yeast (*Saccharomyces cerevisiae*). They are present in the inner cell wall and are important for the structural strength of the cells^(2, 3, 4). The β -glucan content of grains varies with the variety, location and climate (Table 22-01)⁽⁵⁾.

Table 22-01: β -glucan content of grains (% in dry matter)⁽⁶⁾

Species	Whole grain	Endosperm only
Barley	4.2	4.1
Oats	3.9	1.8
Rye	2.5	1.7
Wheat	0.6	0.3

Production

The composition of a yeast glucan preparation varies with the extraction procedure and the treatment of the crude extract. The extraction and preparation technique will also affect the chain length of the branches and the relative proportion of β -1,3- and β -1,6-linked side chains (Figure 22-01)⁽¹²⁾.

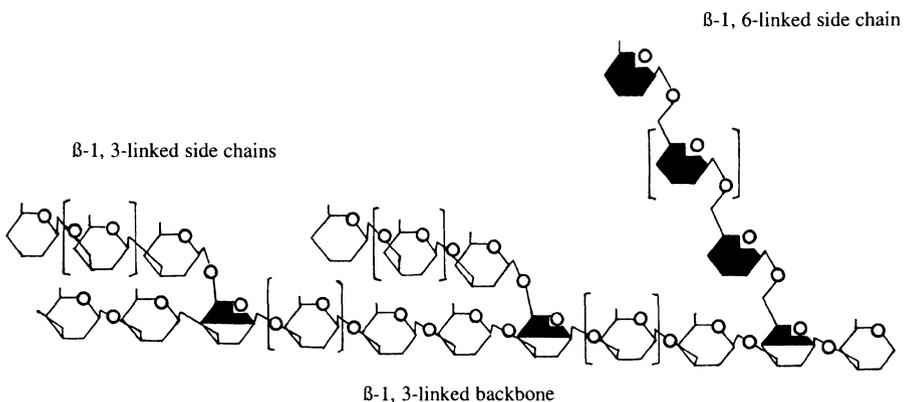


Figure 22-01. Structural formula of β -1,3,6-glucan (simplified).

Mode of Action

β -glucans activate phagocytic leukocytes of aquatic animals by binding them to specific receptors. The ability to activate phagocytic cells depends on the molecular structure of the β -glucan^(8, 12).

22.4 Application Response

Immersion Treatment

Glucan preparation from barley administered by immersion to juvenile rainbow trout (*Oncorhynchus mykiss*) increased non-specific disease resistance mechanism⁽⁷⁾. Immersed yeast β -1,3-1,6-glucan improved growth and reduced mortality of tiger prawns (*Penaeus monodon*)⁽¹⁶⁾.

Oral Administration

Yeast β -glucans dispensed in the feed at stress situations or outbreak of diseases reduced markedly mortality of Atlantic salmon (*Salmo salar*) smolt and yellowtail (*Seriola quinqueradiata*)^(10, 13, 14). Coho salmon (*Oncorhynchus kisutch*) and chinook salmon (*Oncorhynchus tshawytscha*) became disease resistant after being fed with yeast β -glucans⁽⁹⁾. A more efficient antibody production was observed in channel catfish (*Ictalurus punctatus*) when a diet containing yeast glucans was fed⁽¹⁾.

22.5 Doses of Administration and Legal Aspects

Due to a number of uncertainties related to the dosage, time and duration of administration and formulation in the feed⁽¹²⁾, a general recommendation cannot be given.

The approval of immunostimulants in the feed for cultured aquatic animals is to be considered by the competent authorities of respective countries.

22.6 References

1. Ainsworth, A.J.; Mao, C.P.; Boyle, C.R. (1994): Immune response enhancement in channel catfish, *Ictalurus punctatus*, using β -glucan from *Schizophyllum commune*. In: Stolen, J.S.; Fletcher, T.C. (eds.): Modulators of fish immune responses, models for environmental toxicology/biomarkers, immunostimulators, Vol. 1, 67-81. SoS Publications, Fair Haven, NJ/USA
2. Ballou, C.E. (1982): Yeast cell wall and cell surface. In: Strathern, J.N.; Jones, E.W.; Broach, J.R.: Molecular biology of the yeast *Saccharomyces*: Metabolism and gene expression, 335-360. Cold Spring Harbor Lab., New York/USA.
3. Bhatti, R.S. (1986): Physicochemical and functional breadmaking properties of hull-less barley fractions. *Cereal Chemistry*, 1., 31.
4. Ganßman, W. (1994): Private communication.
5. Handreck, B.; Pötschke, L.; Senge, C. (1997): Gewinnung β -glucanreicher Mahlfraktionen aus Gerste. *Die Mühle + Mischfuttertechnik*, 134., (13), 396-399.
6. Henry, R.J. (1987): Pentosan and 1,3; 1,4 β -glucan concentrations in endosperm and wholegrain of wheat, barley, oats and rye. *J. Cereal Sci.*, 6., 253.
7. Jeney, G.; Andersen, D.P. (1993): Glucan injection or bath exposure given alone or in combination with bacteria enhance the non-specific defence mechanism in rainbow trout (*Oncorhynchus mykiss*). *Aquaculture*, 116., 315-329.
8. Newman, K. (1995): The immun system: Nature's defence mechanism - manipulating it through nutrition.

Proc. Alltech's Annu. Seminar, May.

9. Nikl, L.; Albright, L.J.; Evelyn, T.P.T. (1992): Immunostimulants hold promise in furunculosis prevention. Bull. Aquacult. Ass. Canada, 92., 49-52.
10. Onarheim, A.M. (1992): Now a yeast extract to fortify fish. Fish Farmer, 15., (4), 45.
11. Qureshi, A.A. (1992): Immuno-modulation: Poultry International, 31., (4), 56-62.
12. Raa, J. (1996): The use of immunostimulatory substances in fish and shellfish farming. Rev. Fish. Sci., 4. (3), 1-60.
13. Raa, J.; Rørstad, G.; Engstad, R.; Robertsen, B. (1992): The use of immunostimulants to increase resistance of aquatic organisms to microbial infections. In: Shariff, I.M.; Subasinghe, R.P.; Arthur, J.R. (eds.): Diseases in Asian aquaculture. Asian Fish. Soc., 39-50.
14. Seto, A. (1994): Immunostimulatory effect of yeast β -1,3-glucan (MacroGard) for marine and fresh water fish in Japan. Proc. 3rd Int. Marine Biotechn. Conf., Tromsø/Norway
15. Söderhäll, K.; Cerenius, L. (1992): Crustacean immunity. Annu. Rev. Fish Diseases, 2., 2-23.
16. Sung, H.H.; Yang, Y.L.; Song, Y.L. (1996): Enhancement of microbicidal activity in the tiger shrimp *Penaeus monodon* via immunstimulation. J. Crustacean Biology, 16., 278-284.
17. West, G.P. (1992): Black's veterinary dictionary. A & C Black, London, 17th Edition.

23. KRILL MEAL

23.1 Rationale

Krill meal is a protein rich feedstuff from aquatic organisms. The word krill is derived from the Norwegian “krill” which stands for young fish fry and zooplankton. In the colloquial languages it means a small, shrimp-like, phosphorescent crustacea, especially of the genus *Euphausia* (order: *Euphausiacea*). Major species are^(16, 17, 28):

- *Euphausia superba*,
- *Euphausia pacifica*.

The so called “Antarctic Krill” is composed of 85 species of which about 30 belong to the family *Euphausiidae*. Most prominent among the latter is *Euphausia superba* (Figure 23-01) which is a stenotherme coldwater species and can be found in vast quantities in the Antarctic, particularly south of the 50th degree of latitude between the southern tip of South America and Africa^(13, 28).

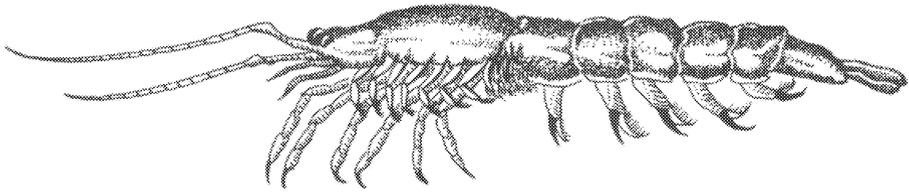


Figure 23-01. Atlantic krill (*Euphausia superba*).

The length of *Euphausia superba* varies from 1.5 to 6.0 cm, and mature animals have a liveweight of around 1.0 to 1.5 g. Their living space is in a water depth of approximately 50 m. Krill is the food of particular mammals like baleen whales and seals. Baleen whales ingest daily between 800 and 1,500 kg of krill⁽²³⁾. It is estimated that world-wide roughly the same quantity of krill meal could be produced as fish meal without endangering krill species⁽⁶⁾.

23.2 Manufacture and Processing

Krill autolysis very rapidly. The fresh krill, therefore, has to be processed on board. Fresh catch can be stored on deck for a maximum of four hours at a temperature of 2°C to 4°C. Krill meal is generally steam-dried on board⁽²⁾. Prior to deep-freezing, fresh krill is short-term heated at 100°C⁽²³⁾. But krill is also hydrolysed and spray-dried into a red, hygroscopic powder⁽¹⁰⁾.

23.3 Chemical, Physiological and other Properties

Chemical Properties

The chemical composition of krill meal (Table 23-01) is affected by the season, availability of food, the area where krill is caught, the age and sex of the animals. The nitrogen content of the chitin cannot be utilised by aquatic animals, thus has to be deducted from the total nitrogen content as crude protein⁽²⁰⁾. The amino acid profile of the krill protein (Table 23-02) is similar to that of fish meal. The essential amino acids of the krill *Meganctiphanes norvegica* is well balanced and e.g. meets well the requirements of the coalfish (*Pollachius virgens*)⁽⁸⁾.

Table 23-01: Chemical composition of krill meal (as fed)^(2,4, 23, 26)

		Mean	Variation	
Dry matter	%	92.0	90.8 -	94.0
Crude protein ¹	%	58.8	52.2 -	67.3
Crude fat	%	9.2	4.2 -	15.9
Crude ash	%	13.6	9.7 -	15.9
N-free extract	%	3.7	0.5 -	9.8
Chitin (crude fibre)	%	6.4	5.3 -	8.4
Carotenoids ²	mg/kg	225	130 -	330
Fluoride (F ⁻)	mg/kg	2,247	2,000 -	2,700

¹ N-content of chitin deducted

² Mainly astaxanthin

Table 23-02: Essential amino acid profile of krill meal
(g/16 g N)⁽²³⁾

	Mean	Variation	
Arginine	5.9	4.9 -	7.0
Histidine	2.1	1.3 -	2.6
Isoleucine	4.8	4.5 -	5.4
Leucine	7.5	6.5 -	8.5
Lysine	7.1	5.9 -	8.4
Methionine	3.0	2.2 -	3.4
Phenylalanine	4.3	3.8 -	5.0
Threonine	4.3	3.6 -	4.7
Tryptophan	0.9	0.5 -	1.2
Valine	4.8	4.5 -	5.6

The krill fat content varies widely (Table 23-01). The fat has a high level of unsaturated fatty acids, particularly the omega-3 fatty acids:

- Saturated fatty acids: 35.2 to 49.5%
- Mono-unsaturated fatty acids: 20.2 to 41.9%
- Poly-unsaturated fatty acids: 18.4 to 38.6%.

The phospholipid content of krill fat amounts to 16.1 to 29.2% and the triglyceride content varies between 26.0 and 51.6%^(19, 21, 28).

Fat and water soluble vitamins occur at relatively high levels⁽⁷⁾. Carotenoids are present in the form of cryptoxanthin and astaxanthin^(24, 28, 31).

Physiological Properties

Due to the high fat content, krill meal is also an energy source. The digestible energy is highly affected by the fat content and is estimated to be 3,647 kcal/kg (15.2 MJ/kg) but may vary widely.

Krill meal is a good pigmenting agent. The strength of pigmentation is influenced by the feeding period and the level of krill meal in the diet, and the age of the fed animals. The higher the feeding level or the feeding period of krill meal the more carotenoids, mainly in the form of astaxanthin, are accumulated and deposited in the muscle^(3, 11, 25). The astaxanthin and phospholipid fractions of krill meal improve the egg quality as demonstrated in the red seabream (*Pagrus major*)⁽³¹⁾.

Other Properties

Krill meal may contain high levels of fluoride (compound of fluorine and one or more elements or radicals) because of its deposition in the exoskeleton, a chitinous shell. After krill is caught the fluoride moves from the shell into the meat^(5, 23, 26). Feeding krill meal to fish insignificantly increases the fluoride content of fish muscle because fluoride is deposited in the skin and the skeleton while the fillet is actually free of the compound (Table 23-03)^(26, 29). Since most of the fluoride content is deposited in the skeleton of fish, there is no harm to the consumer, who eats fish fed with krill meal^(4, 5, 22, 29).

Pesticide residues and some heavy metals have also been found in krill meal⁽¹²⁾, they are:

- | | | |
|------------|----|------------|
| • Chromium | Cr | 0.44 ppm |
| • Cadmium | Cd | 0.82 ppm |
| • Mercury | Hg | <0.005 ppm |
| • Lead | Pb | 0.32 ppm |
| • Arsenic | As | 0.70 ppm |

Table 23-03: Fluoride content of feed containing krill meal and fluoride content of rainbow trout (*Salmo gairdneri*) fed with that feed (mg F/kg)⁽²⁶⁾

	Without krill meal	With krill meal	Difference %
Feed	-	1,590	
Fingerlings ¹	6.4	62.5	+923.3
Market size fish	6.7	8.5	+26.9
Fillet of market size fish	2.2	2.4	+9.1

¹ Without head and offal; ² Control = 100%

23.4 Feeding Value

Fishes

Rainbow trout (*Salmo gairdneri*) grew faster by improved feed conversion when 50% of the animal protein of the diet was replaced by krill meal (Table 23-04)⁽²⁵⁾. No adverse effect was observed when all fish meal (35%) was replaced by the same amount of krill meal in diets for rainbow trout⁽³⁾. Even the total replacement of animal protein by krill meal had no negative effect in the development of the fish (Table 23-05 and 23-06)^(26, 30). Significantly improved feed intake and less feed waste were observed when the chemo-attractant capacity of krill hydrolysate and acid-preserved krill were tested in rainbow trout⁽¹⁸⁾.

Table 23-04: Replacing 50% of animal protein by krill meal in the diet for rainbow trout (*Salmo gairdneri*) (trial period: 101 days)⁽²⁵⁾

Krill meal	%	-	26.0
Crude protein	%	48.3	38.3
Crude fat	%	5.3	5.3
Digestible energy	kcal/kg	2,703	2,697
	MJ/kg	11.31	11.28

Initial fish weight	g	2.0	2.0
Weight gain	g	18.1	20.8
	%	100.0	114.5
Feed conversion	1:	1.16	1.01
	%	100.0	87.1
Losses	%	0.38	0.38

Table 23-05: Total replacement of animal protein by krill meal in diets for rainbow trout (*Salmo gairdneri*) (140 feeding days; initial liveweight 39 g)⁽²³⁾

Krill meal	%	-	79.7
Fish meal	%	34.5	-
Feather meal	%	13.5	-
Poultry offal meal	%	17.9	-
Crude protein	%	43.7	44.3
Crude fat	%	12.6	11.8

Weight gain	g	104.5	103.4
	%	100.0	98.9
Feed conversion	1:	1.195	1.185
	%	100.0	99.2

Table 23-06: Replacement of 50% and 100% of animal protein by krill meal in the diet for rainbow trout (*Salmo gairdneri*)⁽²⁶⁾

Krill meal	%	-	29.5	59.0
Crude protein	%	49.0	48.0	46.9
Crude fat	%	6.6	6.1	5.5

<u>Experiment 1:</u>				
Trial period	days	173	173	173
Initial fish weight	g	1.8	1.8	1.8
Weight gain	g	39.0	39.8	39.7
Feed conversion	1:	1.48	1.45	1.41
<u>Experiment 2:</u>				
Trial period	days	112	112	112
Initial fish weight	g	≈2.0	≈2.0	≈2.0
Weight gain	g	23.2	25.2	25.0
Feed conversion	1:	1.31	1.18	1.19

Juvenile chinook salmon (*Oncorhynchus tshawytscha*) accepted 25% air-dried krill meal well. They grew fast and the survival rate was high⁽¹⁾.

In diets for juvenile (initial weight: 0.65 g) and older (180 g) carp (*Cyprinus carpio*) fish meal could be easily replaced by krill meal (Table 23-07)^(12, 27), but substitution of all animal protein also can be less successful⁽¹²⁾.

Table 23-07: Replacement of all animal protein by krill meal in the diet for carp (*Cyprinus carpio*) (trial period: 28 days)⁽²⁷⁾

Krill meal	%	-	59.0
Crude protein	%	46.7	46.9
Crude fat	%	5.0	5.5

Initial fish weight	g	185	181
Weight gain	g	13.3	15.5
Feed conversion	1:	1.34	1.15

<u>Results of blood test (n = 5)</u>			
Hematocrit	%	37.7	37.6
Hemoglobin	g/100 m	19.4	11.0
Erythrocyte	mill./mm ³	1.66	1.34

Depressed performances were observed in juvenile channel catfish (*Ictalurus punctatus*) when fish meal was totally replaced by krill meal (Table 23-08)⁽⁹⁾. Weight gain, PER and

productive protein value also decreased with increasing dietary krill (*Meganyctiphanes norvegica*) level in the coalfish (*Pollachius virens*)⁽⁸⁾.

The chemical composition of carcasses of salmonids and carp fed diet with and without krill meal were not significantly different^(3, 25, 26, 27). However, there is a tendency for developing fatty liver syndrome, if krill meal diets contain high fat levels^(7, 25).

Table 23-08: Krill meal as the only protein source in replacement for fish meal in diets for channel catfish (*Ictalurus punctatus*) (trial period 4 months)⁽⁹⁾

		Fish meal	Krill meal
Crude protein	%	42.8	41.8
Crude fat	%	11.8	13.0
Ash	%	16.2	11.3
Metabolisable Energy	kcal/kg	3,390	3,480
	MJ/kg	14.2	14.6

Mean weight gain	g	87.3	61.4
	%	100.0	70.3
Feed conversion	1:	1.87	2.33
	%	100.0	124.6
PER		1.26	1.03

Crustaceans

Not much is known on krill meal feeding to crustaceans. In practical diets for the juvenile tiger prawn (*Penaeus monodon*) 1/3 of the diet's shrimp meal has been replaced by krill meal. The results are not significant but they indicate that krill meal may partially substitute shrimp meal (Table 23-09)⁽¹⁵⁾.

Table 23-09: The effect of partial replacement of shrimp meal by krill meal in diets for juvenile tiger prawn (*Penaeus monodon*) (trial period: 8 weeks)⁽¹⁵⁾

Krill meal	%	-	10.0
Shrimp meal	%	15.0	10.0
Crude protein	%	36.4	35.6
Crude fat	%	12.5	12.9
Ash	%	11.5	11.6

Initial weight	g	0.62	0.63
Weight gain	%	127	131
Feed conversion		12.0	7.8
Survival	%	50.0	50.0

23.5 Recommended Inclusion Rates

Experiments have demonstrated that krill meal may replace all animal protein in diets for fish. For practical diets it is advisable to use krill meal at the following rates:

- Fishes 40 to 60% of diet's animal protein,
- Crustaceans: 10 to 20% of diet's animal protein.

23.6 Legal Aspects

In the legal sense krill meal has to be considered as shrimp meal (see chapter 38). However, there might be limitations concerning the fluoride content of krill meal. According to German feedstuff legislation the fluorine content may not exceed the following levels⁽³²⁾.

- Single feedstuff of animal origin: 500 ppm
- Compound feed: 150 ppm

The toxic levels of fluorine for man are as follows⁽¹⁴⁾:

- Toxic level: 10.0 to 20.0 mg/day
- Fatal level: >20.0 mg/day.

23.7 References

1. Anderson, J.S.; Richardson, N.L.; Higgs, D.A.; Dosanjh, B.S. (1997): The evaluation of air-dried whole krill meal as a dietary protein supplement for juvenile chinook salmon (*Oncorhynchus tshawytscha*). Can. Tech. Rep. Fish. Aquat. Sci., (2148), 1-12.
2. Anonymous (1993i): Animal feed is our concern (Product specification). Tesgo Services B.V., The Netherlands.
3. Beck, H.; Koops, H.; Tiews, K; Gropp, J. (1977): Weitere Möglichkeiten des Fischmehl-Ersatzes im Futter für Regenbogenforellen: Ersatz von Fischmehl durch Alkanhefe und Krillmehl. Archiv Fisch. Wissenschaft, 28. (1), 1-17.
4. Christians, O.; Leinemann, M. (1980): Untersuchungen über Fluor im Krill (*Euphausia superba* Dana). Inform. Fischwirtschaft, 28., 254-260.
5. Christians, O.; Leinemann, M.; Manthey, M. (1981): Neue Erkenntnisse über den Fluoridgehalt im Krill (*Euphausia superba*). Inform. Fischwirtschaft, 28., 70-72.
6. Frisecke, H. (1984): Handbuch der praktischen Fütterung. BLV Verlagsgesellschaft, München.
7. Goryczko; Gliszczynski (1979): Quoted from: Steffens, W. (1980).
8. Gulbrandsen, K.E. (1979): Experiments with red feed (*Calanus finmarchicus*) and krill (*Meganyctiphanes norvegica*) as protein sources in feeds to coalfish (*Pollachius virens*). Proc. World Symp. on Finfish Nutrition and Fishfeed Techn., Hamburg, 20-23 June, 1978, Vol. II, 157-166.
9. Hilge, V (1979): Preliminary results with krill meal and fish meal in diets for channel catfish (*Ictalurus punctatus*). Proc. World Symp. on Finfish Nutrition and Fishfeed Techn., Hamburg, 20-23 June, 1978, Vol. II, 167-171.
10. House, C. (1997): Krill entering the mainstream aquaculture market. Feedstuffs, 7, 24 March.
11. Kotik et al. (1979): Quoted from: Steffens, W. (1980).
12. Lukowicz, M. von (1979): Experiences with krill (*Euphausia superba* Dana) in the diet for young carp

- (*Cyprinus carpio*). Proc. World Symp. on Finfish Nutrition and Fishfeed Techn., Hamburg, 20-23 June, 1978, Vol. II, 293-302.
13. Marr (1962): Quoted from: Steffens, W. (1980).
 14. Miller Jones, J. (1992): Food safety. Eagon Press, St. Paul, Minnesota.
 15. Murai, T.; Sumalangcay, A.; Piedad-Pascual, F. (1983): Supplement of various attractants to practical diets for juvenile *Penaeus monodon* Fabricius. Fish. Res. J. Philipp., 8., (2), 61-67.
 16. New, M.B. (1987): Feed and feeding of fish and shrimp. Aquaculture Dev. and Coord. Programme Publication ADCP/REP/87/26.
 17. OECD (1984): Multilingual dictionary of fish and fish products. Fishing News Books, Farnham, Surrey, England.
 18. Oikawa, C.K.; March, B.E. (1996): A method for assessment of the effectiveness of feeding stimulants for salmonid fish. Bull. Aquacult. Assoc. Canada, (3), 29-31.
 19. Rogoshin et al. (1979): Quoted from: Steffens, W. (1980).
 20. Roschke; Schreiber (1977): Quoted from: Steffens, W. (1980).
 21. Rshavskaja et al. (1979): Quoted from: Steffens, W. (1980).
 22. Søvik, T.; Brækkan, O.R. (1970): Fluoride in antarctic krill (*Euphausia superba*). Fish. Res. Board Canada, 36., (11), 1414-1416.
 23. Steffens, W. (1980): Krillmehl als Eiweißquelle im Fischfutter. 1. Mitt. Biologie and Nährstoffzusammensetzung des Krills. Z. Binnenfischerei DDR, 27., (6), 182-186.
 24. Steffens, W. (1982): Neue Wege der Fütterung von Karpfen (*Cyprinus carpio*) und Regenbogenforellen (*Salmo gairdneri*). Fortschritte Fischereiwissenschaft, 1., 43-47.
 25. Steffens, W.; Albrecht, M.-L. (1980): Krillmehl als Eiweißquelle im Fischfutter. 2. Mitt. Einsatz von Krillmehl im Forellenfutter. Z. Binnenfischerei DDR, 27., 305-308.
 26. Steffens, W.; Albrecht, M.-L. (1981): Krillmehl als Eiweißquelle im Fischfutter. 3. Mitt. Vollständiger Ersatz von tierischem Protein durch Krillmehl im Forellenfutter. Z. Binnenfischerei DDR, 28., 178-184.
 27. Steffens, W.; Albrecht, M.-L. (1982): Krillmehl als Eiweißquelle im Fischfutter. 4. Mitt. Krillmehl als alleinige tierische Eiweißquelle bei der Karpfenaufzucht. Z. Binnenfischerei, 29., 79-83.
 28. Storebakken, T. (1988): Krill as a potential feed source for salmonids. Aquaculture, 70., 193-205.
 29. Tiews, K.; Manthey, M.; Koops, H. (1981): Über die Fluoridaufnahme von Forellen bei Fütterung von Krillmehlpellets. Inform. Fischwirtschaft, 28., 135-136.
 30. Tiews, K.; Koops, H.; Beck, H.; Schwalb-Bühling, A.; Gropp, J. (1981): Entwicklung von Ersatzfuttern für die Regenbogenforelle. Veröffentlichungen des Inst. für Küsten- und Binnenfischerei, Bundesforschungsanstalt für Fischerei, Hamburg, No. 75/1981.
 31. Watanabe, T.; Fujima, T.; Lee, M.-J.; Fukusho, K.; Satoh, S.; Takeushi, T. (1991): Effects of polar and non-polar lipids from krill on quality of egg of red sea bream *Pagrus major*. Nippon Suishu Gakkaishi, 57., 695-698.
 32. Weinreich, O.; Koch, V.; Knippel, J. (1994): Futtermittelrechtliche Vorschriften. Buchedition Agrimedia, Hamburg/Germany.

24. LEATHER MEAL (HYDROLYSED)

24.1 Rationale

Leather meal is a by-product of tanning animal hides into leather. Tanning yields two different by-products⁽⁴⁾:

- Leather scrap (fleshings),
- Leather waste (trimmings).

Leather scrap results from the preparation of the hides prior to tanning. It is comprised of connective tissues of the hypodermis as well as of meat and fat scraped off from the hides. Leather waste are the trimmings of the tanned hides. In the tanning of leather various chemicals such as tannic acid, alum, sodium chloride and chromium salts are used.

24.2 Manufacture and Processing

Leather scraps and leather wastes are commonly hydrolysed with steam for not less than 33 minutes and at a pressure of not less than 9.0 kg per cm²⁽³⁾. During hydrolysis the protein molecules absorb one or more water molecules and this assists in breaking down the complex protein molecules to their degradation products such as polypeptides and in some cases amino acids⁽³⁾. After completion, the hydrolysate is dried, ground and screened⁽³⁾.

Leather waste meal from chromium tanning contains high levels of chromium (Cr). Its removal is technically possible but not economical^(4, 10). Due to the tanning the leather collagen changes its properties and cannot be utilised by animals. Hydrolysis of leather waste improves the digestibility.

24.3 Properties

Leather meal is a rather heterogeneous product (Table 24-01). The protein is fibrous collagen and can be hardly utilised by animals. The amino acid profile is in Table 24-02. The fat content ranges between 0.7 and 55.8%^(4, 10), due to the fat reservoir of the hypodermis⁽⁶⁾.

The chromium content of leather meal from chromium tanned material may be as high as 4.0%. At this level leather meal is toxic. Chromium containing feed may also negatively affect flavour and taste of animal produce although there is general acceptance that chromium is an essential trace element for man and animals⁽⁷⁾. However, the added level to the feed is just 200 ppb⁽¹⁾ and in most feedstuffs chromium is present at levels of less than 1.0 ppm⁽²⁾.

Table 24-01: Chemical composition (% in dry matter) of leather scrap meal and leather waste meal

	Leather scrap meal ^(8, 10)	Leather waste meal ⁽¹⁰⁾
Moisture	7.1 - 15.5	-
Crude protein	36.9 - 82.0	72.0 - 86.0
Crude fat	0.7 - 56.7	1.3 - 4.0
Ash	2.2 - 25.4	13.5 - 16.5
N-free extract	-	1.5 - 8.0

Table 24-02: Essential amino acid profile of leather meal (g/16 g N)⁽¹⁰⁾

	Collagen	Leather scrap meal	
Arginine	8.9	7.6	8.2
Histidine	0.8	1.2	1.0
Isoleucine	1.8	}5.1	1.5
Leucine	3.7	}	3.1
Lysine	4.2	4.1	3.7
Methionine	0.9	1.0	0.6
Phenylalanine	2.4	2.3	1.7
Threonine	2.3	2.0	1.6
Tryptophan	-	0.2	-
Valine	2.7	2.5	1.9

EAA-Index	30.0	38.0	29.8

24.4 Feeding Value

Digestibility of leather scrap meal in land animals can be high but also poor. This is due to the heterogeneous material used for making leather meal. Similar results were obtained with hydrolysed leather waste meal. A maximum of 10% leather scrap meal and leather waste meal, respectively, of the total protein content of the ration might be suitable for terrestrial farm animals⁽¹⁰⁾

Leather meal has to be considered as a hardly suitable feedstuff in diets for aquatic animals. There are no reports of feeding trials. Its high protein content and its use in small quantities make it a potential addition in aquatic feed for less demanding species.

24.5 Legal Aspects

FDA⁽³⁾ allows the use of hydrolysed leather meal as a source of protein but only in finished pig feed at a maximum level of 1.0% and if the following quality criteria are met:

- Moisture: max. 10.0%
- Crude protein: min. 60.0%
- Crude fat: min. 5.0%
- Crude fibre: max. 6.0%
- Chromium: max. 2.75%.

According to German feedstuff legislation hides, leather and leather by-products are prohibited feedstuffs⁽⁹⁾.

24.6 References

1. *Blum, R.A.* (1995): Chromium(II)nicotinate. Lonza Product Information, Basle/Switzerland (Mimeograph).
2. *Dressler, D.* (1971): Mineralische Elemente in der Tierernährung. Verlag Eugen Ulmer, Stuttgart/Germany.
3. *FDA* (1994): Food additives permitted in feed and drinking water of animals. Food and Drug Admin., 21 CFR Ch.I (4-1-94 ed.), 514.
4. *Günther, C.* (1988): Abfälle der Lederindustrie für die Tierernährung. (Mimeograph).
5. *Gutcho, M.H.* (1973): Feeds for livestock, poultry and pets. Noyes Data Corp., London/England.
6. *Kolb, E.* (1989): Lehrbuch der Physiologie der Haustiere (I). VEB Gustav Fischer Verlag, Jena/Germany.
7. *Mertz, W.; Schwarz, K.* (1955): Quoted from: *Blum, R.A.* (1995).
8. *Stählin, A.* (1957): Methodenbuch, Beurteilung der Futtermittel, Vol. XII. Die Beurteilung der Futtermittel. Neumann Verlag, Radebeul and Berlin/Germany.
9. *Weinreich, O.; Koch, V.; Knippel, J.* (1994): Futtermittelrechtliche Vorschriften. Buchedition Agrimedia, Hamburg/Germany.
10. *Wöhlbier, W.* (1977): Futtermittel aus Landtieren. In: *Kling, M.; Wöhlbier, W.*: Handelsfuttermittel. Verlag Eugen Ulmer, Stuttgart/Germany.

25. LEUCAENA LEAF MEAL

25.1 Rationale

The genus *Leucaena* is a fast growing tropical legume and a member of the family *Leguminosae* and of the sub-family *Mimosoideae*. *Leucaena* is native to Central America. Spaniards took them from Mexico to the Philippines. From there it spread to entire Southeast Asia, Papua New Guinea, and later to Hawaii, Australia, India and even to Africa⁽¹⁰⁾.

The genus *Leucaena* is comprised of 51 species and more than 100 varieties. It has a wide range of application: soil preservation, hardwood timber, charcoal production and the leaves for feedstuff^(15, 17). *Leucaena leucocephala* is most commonly used and is named for short "*Leucaena*". In the Philippines it is called "Ipil-Ipil", in Indonesia "Lamtoro", in Malaysia "Accacia" and in Hawaii "Koa-haole"⁽¹⁷⁾.

Leucaena leucocephala is broadly classified into three varieties⁽¹⁾:

- Hawaiian, a local bushy variety up to five meters high;
- Salvador or Hawaiian Giant, a branchless trunk up to 20 m;
- Peruvian, 15 m tall with extensive branching

25.2 Manufacture and Processing

Processing of leucaena as feedstuff has two objectives: To remove the moisture from the fresh leaves and to eliminate the toxic glycoside "mimosine". This can be done at backyard level or as a commercial operation.

The mimosine content of leaves can be reduced and removed, respectively by soaking in water^(14, 25, 36), sun-drying⁽¹⁰⁾ and heat treatment (70°C)⁽²²⁾ (Table 25-01).

Table 25-01: Mimosine content of leucaena leaf meals processed by various methods^(25, 35, 36)

	Mean mimosine content %	Range %
Unsoaked	4.47	0.63 - 3.33
Soaked, 24 hrs	3.34	2.49 - 4.35
Sun-dried, 2 days	3.00	
Commercial leaf meal	1.80	

Supplementing leucaena with metal ions such as ferrous sulphate ($\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$) and aluminum sulphate ($\text{Al}_2(\text{SO}_4)_3$), which chelate with mimosine and prevent its absorption in the gastrointestinal tract is another means to eliminate toxicity⁽³⁷⁾.

Detoxifying bacteria from the rumen, cultured in vitro and infused into animals, degrades mimosine into its less toxic metabolite dihydroxypyridone (DHP)^(3, 19).

25.3 Chemical, Physiological and Other Properties

Chemical Properties

The chemical composition of leucaena leaf meal vary widely, depending on the variety, the area/country where it grows, the age at the time of harvesting the leaves and the amount of branches and twigs.

Good leucaena leaf meal may have a crude protein content of about 29% while the mean crude protein content is 24.5% (Table 25-02). The essential amino acid profile is in Table 25-03. The amino acid index when compared to that of tiger prawn (*Penaeus monodon*) is quite low (0.54)⁽²⁴⁾.

Table 25-02: Chemical composition of Leucaena leaf meal (% in dry matter)^(2, 5, 6, 9, 12, 16, 20, 21, 22, 24, 29, 31, 32)

	Mean	Range
Dry matter	90.5	92.7 - 88.5
Crude protein	24.5	12.6 - 31.1
Crude fat	5.4	1.6 - 10.1
Ash	8.4	2.2 - 13.5
Crude fibre	10.6	7.5 - 19.6
N-free extract	51.1	39.5 - 78.2

Table 25-03: Essential amino acid profile of Leucaena leaves (g/16 g N)^(8, 24)

	Mean	Range
Arginine	2.20	1.02 - 5.25
Histidine	0.72	0.40 - 1.44
Isoleucine	2.44	1.24 - 6.65
Leucine	3.02	1.60 - 6.65
Lysine	2.37	1.28 - 6.07
Methionine	0.58	0.23 - 1.19
Phenylalanine	1.89	1.07 - 3.92
Threonine	1.94	0.87 - 5.07
Tryptophan	0.31	0.24 - 0.38
Valine	2.31	1.01 - 6.29

The calcium and phosphorus ratio is 1:5 and is rather wide. Iron is quite high and the sodium content is remarkably low (Table 25-04).

Leucaena leaf meal also contains β -carotene, a precursor of Vitamin A and other carotenoids.

Table 25-04: Macro and micro mineral content of Leucaena leaves^(5, 6, 7, 16, 22, 29, 31)

		Mean	Range
Calcium	%	1.76	0.37 - 2.52
Phosphorus	%	0.35	0.07 - 1.47
Sodium	%	0.02	0.00 - 0.04
Potassium	%	1.80	0.80 - 1.99
Magnesium	%	0.49	0.42 - 0.56
Manganese	mg/kg	9.3	7.0 - 10.6
Iron	mg/kg	255.0	181.0 - 407.0
Zinc	mg/kg	22.6	21.0 - 29.9
Copper	mg/kg	49.3	42.1 - 60.0

Physiological Properties

Digestibility of leucaena leaf meal is not very high. The protein digestibility for unsoaked leaf meal is lower (62.7%)^(14, 35) than for soaked ones (64.3%)^(14, 19, 35). Rabbits, e.g. digest protein at 75.9%⁽⁶⁾. The fat digestibility of soaked leaf meal is 69.2%⁽¹⁹⁾.

With increasing levels of leucaena leaf meal in the diet, both soaked and unsoaked, digestibility of protein and fat declines in Indian major carps (*Catla catla* *Labeo rohita*) and Nile tilapia (*Oreochromis niloticus*)^(14,20,36).

Other Properties

Leucaena leaf meal is a source of pigments. As much as 762.4 mg total xanthophylls and 227 mg β -carotenoid were found in 1.0 kg fresh and dried leaves, respectively^(7, 11). Field samples of leucaena showed a wide variation in the xanthophyll and β -carotene content (Table 25-05)⁽¹⁷⁾.

Table 25-05: Pigment content of leucaena meal from various countries (in dry matter)⁽¹⁷⁾

Country of sample's origin	Crude Protein %	Xanthophylls ppm	β -carotene ppm	Lutein ppm	Zeaxanthin ppm
Indonesia	20.7	252	87	214	27
P.R. China	19.8	183	36	-	-
Philippines	26.2	313	96	-	-
Thailand	12.3	141	33	-	-

There are two reasons for the variation of xanthophylls in leucaena leaf meal, xanthophylls are unstable and deteriorate rather fast when stored under tropical and subtropical conditions and adulteration of the leaf meal with a high percentage of stems and twigs. After three months of storage, the mean xanthophyll and β -carotenoid content can decline by 11.1 and 13.6%, respectively⁽¹⁷⁾.

Indications of an adulterated leucaena leaf meal is a low crude protein and high crude fibre content⁽¹⁷⁾.

Undesirable substances of leucaena leaf meal is the toxic glycoside “mimosine” which is a heterocyclic amino acid (α -amino- β (N-(3-hydroxy-4-pyridon)(-propionic acid)⁽³³⁾. Mature leaves contain less mimosine than immature leaves^(24, 25) and the mimosine content may vary according to species.

Mimosine poisoning in land animals are hair loss, low weight gain, loss of appetite and reproductive failure^(4, 6, 10). In the rumen and by plant enzymes, mimosine is converted to a less toxic metabolite, dihydroxypyridone (DHP)^(3, 19).

Cataracts were observed in Nile tilapia after four weeks of feeding with 50% sun-dried leucaena in the diet⁽³⁶⁾. Likewise, R-cells of the hepatopancreas of tiger prawns were reported to be damaged after 20 days of feeding a diet containing 20% unsoaked leucaena leaves⁽³⁵⁾. An intake of 0.20g mimosine/kg fish per day was harmful for carp⁽³⁴⁾.

Other undesirable substances in leucaena leaf meal which reduce the animal's performances, if not removed, are⁽¹⁰⁾: Tannins, saponins, procyanidins, protease inhibitors, glactomannan gums.

25.4 Feeding Value

Fishes

Feeding increasing levels of leucaena leaf meal (soaked and unsoaked) to Nile tilapia in replacement, e.g. for fish meal depressed performances of the fish as the leaf meal level in the diet increased. Fish responded significantly better on soaked than on unsoaked or sun-dried leucaena leaf meal (Table 25-06)^(18, 36). The use of leucaena leaf meal as the sole source of protein is completely inadequate⁽²⁷⁾.

However, leucaena leaf meal was performance enhancing when it replaced rice bran in tilapia diets because with the exchange of rice bran the protein content increased⁽²³⁾.

Nile tilapia broodstock performed best (fry production, weight gain) when the diet contained not more than 20% leucaena leaf meal. With increasing levels of leaf meal the performance decreased significantly and at an inclusion rate of 80% the female fish even lost weight⁽²⁸⁾.

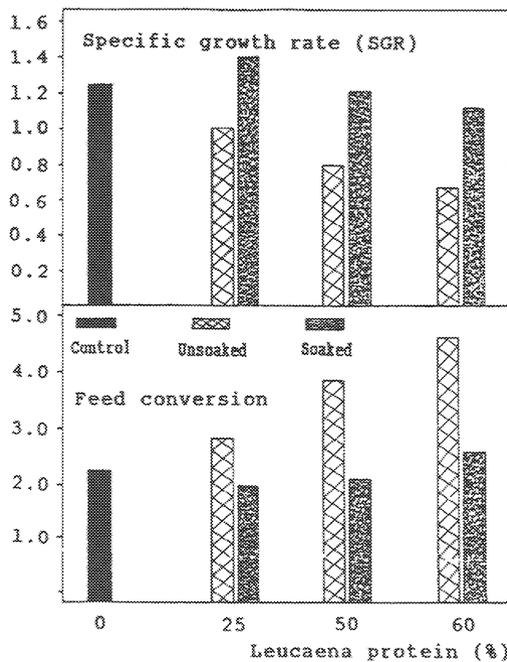
Also in diets for fry and fingerlings of the Indian rohu carp at levels of 20 to 60% leucaena leaf meal protein (of the total) fish responded negatively compared to the iso-nitrogenous control (Figure 25-01)^(13, 14). Soaking the leaves did not significantly improve the performances of the fry⁽¹³⁾ while fingerlings yielded better on soaked leaf meal⁽¹⁴⁾. Histopathological lesions such as congestion of blood vessels and fatty changes in the hepatocytes were found after feeding of unsoaked leaf meal. Lesions were milder or not evident at all when soaked leaf meal was fed⁽¹⁴⁾.

Table 25-06: Growth responses and feed utilisation efficiencies of Nile tilapia (*Oreochromis niloticus*) fingerlings fed various levels of *Leucaena* leaf meal for 70 days⁽³⁶⁾

		Soaked				Unsoaked ¹		
Leucaena protein								
of total protein	%	0	25	50	100	25	50	100
Mimosine content	%	0	0	0	0	0.71	1.34	1.61

Weight gain	%	737	563	367	62	305	115	46
SGR	%/day	3.0	2.7	2.2	0.7	2.0	1.1	0.5
FCR	1:	1.3	1.5	1.9	6.3	2.1	4.1	8.1
PER	2.5	2.3	1.8	0.7	1.6	0.8	0.6	
ANPU	%	40.7	36.6	26.6	11.3	22.9	8.6	5.9
Total								
Digestibility	%	50.6	51.1	46.4	44.3	50.5	45.8	43.0

¹Mimosine content is 0.71 to 1.61% in commercial leaf meal



Figures 25-01. The effect on growth and feed conversion of increasing levels of leucaena protein in feeds for the Indian rohu, carp (*Labeo rohita*)⁽¹⁴⁾.

Leucaena leaf meal fed at reasonable levels to milkfish (*Chanos chanos*) is equivalent to fish meal/soybean meal diets (Table 25-07). Of the total protein content of 40%, 15% was replaced by soaked leucaena leaf meal⁽²⁾.

Table 25-07: Responses of milkfish (*Chanos chanos*) fed Leucaena leaves⁽²⁾

Leucaena leaf	%	-	20.0
Fish meal	%	53.1	43.8
Soybean meal	%	14.6	14.6
Crude protein	%	41.2	41.1
Fat	%	10.2	10.5

Weight gain	%	751.5	764.4
SGR	%/day	3.06	3.07
Survival rate	%	67	77
Feed conversion	1:	1.6	1.6
PER	%	1.58	1.60

Crustaceans

Juvenile tiger prawns responded negatively when fish meal was replaced by leucaena leaf meal at a 10% level⁽²⁶⁾. However, the protein content of the two diets were not isonitrogenous (Table 25-08). The rating of the leaf meal effect, therefore, is uncertain. Significant differences were observed in mass weight and survival between Peruvian and Hawaiian varieties of leucaena leaves, soaked or unsoaked, when used as one third of the protein source, aside from fish and shrimp head meals, in tiger prawn diets fed for eight weeks under laboratory conditions⁽²⁵⁾.

Table 25-08: Leucaena leaf meal as a protein source in diets¹ for tiger prawns (*Penaeus monodon*)⁽²⁶⁾

Fish meal	%	30.0	20.0
Soybean meal	%	15.0	15.0
Leucaena leaf meal		-	10.0
Crude protein	%	48.2	43.0
Fat	%	13.0	13.4

Initial weight	g	0.37	0.38
Final weight	g	1.28	1.07
SGR	%/day	2.2	1.9
Feed conversion	1:	2.6	3.2
Survival	%	71	58

¹Mimosine content of the diet = 0.6%

Soaked leucaena leaves in diets fed to tiger prawns post-larvae are better than unsoaked leaves⁽³⁵⁾. Histological changes were observed in the hepatopancreas even at a mimosine level of 0.25% in the feed.

25.5 Recommended Inclusion Rate

Leucaena leaf meal is a protein feedstuff. Due to the relatively high crude fibre content, it is merely for herbivorous and omnivorous aquatic animals. In fish and shrimp diets 5.0 to 10.0% leucaena leaf meal are advisable⁽²²⁾.

25.6 Legal Aspects

No specific regulations exist for leucaena leaf meal. In general users of leucaena leaf meal, particularly commercial feedmills, should consider the principle of the Thai feedstuff law of 1982, which states that "Feed ingredients liable to have high levels of certain anti-nutrients need to be tested prior to use"⁽³⁰⁾. Leucaena leaf meal falls under this quality control requirement.

25.7 References

1. *Anonymous* (1977): Philippine Council for Agriculture and Resources Research (PCARR) and the United States National Academy of Sciences (NAS): Leucaena, promising forage and tree crop for the tropics. Nat. Acad. Sci., Washington D.C./USA. 115.
2. *Borlongan, I.G.; Coloso, R.M.* (1994): Leaf meal as protein sources in diets for milkfish, *Chanos chanos* (Forsskal). Proc. Fifth Asian Fish Nutrition Workshop. Asian Fish. Soc. Spec. Publ. 9. Manila/Philippines. 63-68.
3. *Cadioux-Ledoux, H.* (1980): Leucaena update. IDRC (mimeograph).
4. *Castillo, L.S.; Gerpacio, A.L.; Javier, T.R.; Gloria, L.A.; Gerpacio, C.P.* (1963): Quantitative changes in nutrient composition of ipil-ipil leaf during storage. Philipp. Agric., 46., 681-700.
5. *Castillo, L.S.; Gerpacio, A.L.* (1976): Nutrient composition of some Philippine feeds. Tech. Bull. No. 21. College of Agric., Univ. Phil., 114.
6. *Cheeke, P.R.* (1987): Rabbit feeding and nutrition. Academic Press, Inc., Orlando, Florida/USA.
7. *D'Mello, J.P.F.; Thomas, D.* (1978): The nutritive value of dried leucaena leaf meal from Malawi: Studies with young chicks. Trop. Agric. (Trinidad), 55., 45-50.
8. *D'Mello, J.P.F.; Fraser, K.W.* (1981): The composition of leafmeal from *Leucaena leucocephala*. Trop. Science, 23., 75-58.
9. *Devendra, C.* (1983): The utilization of tree leaves by goats in the humid tropics. Proc. V. World Anim. Prod. Conf., 14 to 19 August, (2), 543-544.
10. *Ekpenyong, T.C.* (1990): Leucaena leaf meal. In: *Thacker, P.A.; Kirkwood, R.N.* (eds.): Nontraditional feed sources for use in swine nutrition. Butterworths Publishers, Stoneham, MA/USA.
11. *Ellis* (1982): Quoted from: *J.H.* (1983).

12. *Feed Development Section* (1994): Feeds and feeding of milkfish, Nile tilapia, Asian sea bass, and tiger shrimp. SEAFDEC Aquaculture Department, Tigbauan, Iloilo, Philippines.
13. *Hasan, M.R.; Moniruzzaman, M.; Omar Farooque, A.M.* (1990): Evaluation of leucaena and water hyacinth leaf meal as dietary protein sources of the Indian major carp (*Labeo rohita*) (Hamilton). In: *Hirano, R.; Hanyu, I.* (eds.): The Asian Fisheries Forum. Asian Fish. Soc. Manila/Philippines. 275-278.
14. *Hasan, M.R.; Roy, P.K.; Akand, A.M.* (1994): Evaluation of leucaena leaf meal as a dietary protein source for Indian major carp, *Labeo rohita* fingerlings. Proc. Fifth Asian Fish Nutrition Workshop. Asian Fish. Soc. Spec. Publ. 9. Manila/Philippines. 69-76.
15. *Hertrampf, J.H.* (1994): Füttermittel von tropischen und subtropischen Standorten. Paper presented at Colloquium Inst. für angewandte Botanik, Univ. of Hamburg/Germany. 29 Aug.
16. *Ija, P.A.; Okonkwo, A.C.* (1991): Potential protein sources for layers? Feed International, 12., 29-32.
17. *J.H.* (1983): Leucaena leafmeal - a source of carotenoids. Animal Nutrition News, 12/83 (July), BASF AG, Ludwigshafen/Germany.
18. *Jackson, A.J.; Caffer, B.S.; Matty, A.J.* (1982): Evaluation of some plant proteins in complete diets for the tilapia *Sarotherodon mossambicus*. Aquaculture, 27., 97-109.
19. *Lowry, J.B.; Tangendjaja, M.; Tangendjaja, B.* (1983): Optimising autolysis of mimosine to 3-hydroxy-4(1H)-pyridone in green tissues of *Leucaena leucocephala*. J. Sci. Food Agric., 34., 529-533.
20. *Nandeesh, M.C.; Srukanth, G.K.; Keshavanath, P.; Das, S.K.* (1991): Protein and digestibility of five feed ingredients by an Indian major carp *Catla catla* (Ham.). Proc. Fourth Asian Fish Nutrition Workshop. Asian Fish. Soc. Spec. Publ. 5. Manila/Philippines. 75-81.
21. *NRC* (1983): Nutrient requirements of warmwater fishes and shellfishes. National Academy Press, Washington, D.C./USA.
22. *New, M.B.* (1987): Feed and feeding of fish and shrimp. ADCP/REP/87/26 UNDP/FAO, Rome/Italy.
23. *Pantastico, J.B.; Baldia, J.P.* (1980): Ipil-ipil leaf meal as supplemental feeds for *Tilapia nilotica* in cages. Fish. Res. J. Phil., 5., 63-68.
24. *Peñaflorida, V.D.* (1989): An evaluation of indigenous protein sources as potential component in the diet formulation for tiger prawn, *Penaeus monodon*, using essential amino acid index (EAAI). Aquaculture, 83., 319-330.
25. *Peñaflorida, V.D.; Pascual, F.P.; Tabbu, N.S.* (1992): A practical method of extracting mimosine from ipil-ipil, *Leucaena leucocephala*, leaves and its effect on survival and growth of *Penaeus monodon* juveniles. Bamidgeh 44., (1), 24-31.
26. *Piedad-Pascual, F.; Catacutan, M.* (1990): Defatted soybean meal and leucaena leaf meal as protein sources in diets for *Penaeus monodon* juveniles. In: *Hirano, R.; Hanyu, I.* (eds.): The Second Asian Fisheries Forum, Asian Fisheries Society, Manila Philippines. 345-348.
27. *Santiago, C.B.; Reyes, O.S.; Aldaba, M.B.; Laron, M.A.* (1986): An evaluation of formulated diets for Nile tilapia fingerlings. Fish. Res. J. Philipp., 11., 5-12.
28. *Santiago, C.B.; Aldaba, M.B.; Laron, M.A.; Reyes, O.S.* (1988): Reproductive performance and growth of Nile tilapia (*Oreochromis niloticus*) broodstock fed diets containing *Leucaena leucocephala* leaf meal. Aquaculture, 70., 53-61.
29. *Sison, J.A.* (1985): Handbook on crisis management on feedmilling and technology for the Philippines. Feedindex (Phils.), Quezon City/The Philippines.
30. *Sitasit, P.* (1993): Feed ingredients and quality control. Proc. FAO/AADCP Regional expert consultation on farm-made aquafeeds, 14 to 18 December 1992, Bangkok/Thailand, 343 (FAO-RAPA/AADCP, Bangkok, Thailand). 75-86.
31. *Somsueb, P.* (1993): Aquafeeds and feeding strategies in Thailand. Proc. FAO/AADCP Regional expert

- consultation on farm-made aquafeeds. 14 to 18 December 1992, Bangkok, Thailand FAO-RAPA/AADCP. Bangkok/Thailand. 365-385.
32. Tacon, A.G.J. (1993): Feed ingredients for warmwater: Fish meal and other processed feedstuffs. FAO Fisheries Circular No. 856, FAO, Rome Italy.
 33. Täufel, A.; Ternes, W.; Tunger, L.; Zobel, M. (1993): Lebensmittel-Lexicon. Behr's Verlag, Hamburg/Germany.
 34. Ter Meulen, U.; El Harith, E.A. (1983): Effects of oral administration of 4-N(3-hydroxy-4 pyridone)- α amino propionic acid mimosine in carps (*Cyprinus carpio* L.). In: Z. Tropenlandwirt, 84., 29-37.
 35. Vogt, G.; Quinitio, E.T.; Pascual, F.P. (1986): *Leucaena leucocephala* leaves in formulated feed for *Panaeus monodon*: A concrete example of the application of histology in nutrition research. Aquaculture, 59., 209-234.
 36. Wee, K.L.; Wang, S.S. (1987): Nutritive value of leucaena leaf meal in pelleted feed for Nile tilapia. Aquaculture, 62., 97-108.
 37. Yoshida, R.K. (1945): Chemical and physiological study of nature and proportion of *Leucaena glauca* (*Koa haole*). Proc. Hawaii Acad. Sci., 19., 5.

26. LIVE FOODS

26.1 Rationale

Live food is the essential link between endogenous nutrition and exogenous feeding of aquatic animals commercially cultured. It is necessary for rearing of larval fish and crustaceans as well as molluscs or until the animals can ingest formulated feed. Filter feeding organisms such as bivalve molluscs may be fed in the post-larval stage also with live food.

Live food has to be of microscopical size. For instance, abalone (*Haliotis* sp.) spat require food particles that are smaller than 0.01 mm and probably as small as 0.001 mm⁽⁶⁾.

Live food is preferred by the larviculture industry although progress has been achieved in formulated larval food. However, the physiology and the culture of feed organisms producing live food have received less attention than they deserve⁽¹⁷⁾. Live food has an advantage over artificial feed in that when not completely consumed by the fish, the tank water is not polluted⁽²²⁾. Furthermore, live food meets the habits of larvae for catching its prey. The physical movement of this habit is subdivided in several phases (Figure 26-01)⁽¹⁾.

26.2 Feed Organisms

Feed organisms used for larval rearing are of low floral and faunal order and are classified into:

- Phytoplanktons
- Zooplanktons
- Micro-crustaceans
- Other feed organisms

26.2.1 Phytoplanktons

Micro-algae are the most important phytoplankton used as live larval food. They are single-celled or form small colonies of similar cells⁽¹⁷⁾. The smallest micro-algae have a size of less than 0.002 mm, not much bigger than some bacteria and the largest can be a thousand times as large (2.0 mm)⁽⁶⁾.

Micro-algae have been selected on the basis of mass-culture potential, cell size, digestibility and overall food value. Algae like *Chlorella* sp. are easily cultured as feed for *Brachionus*.

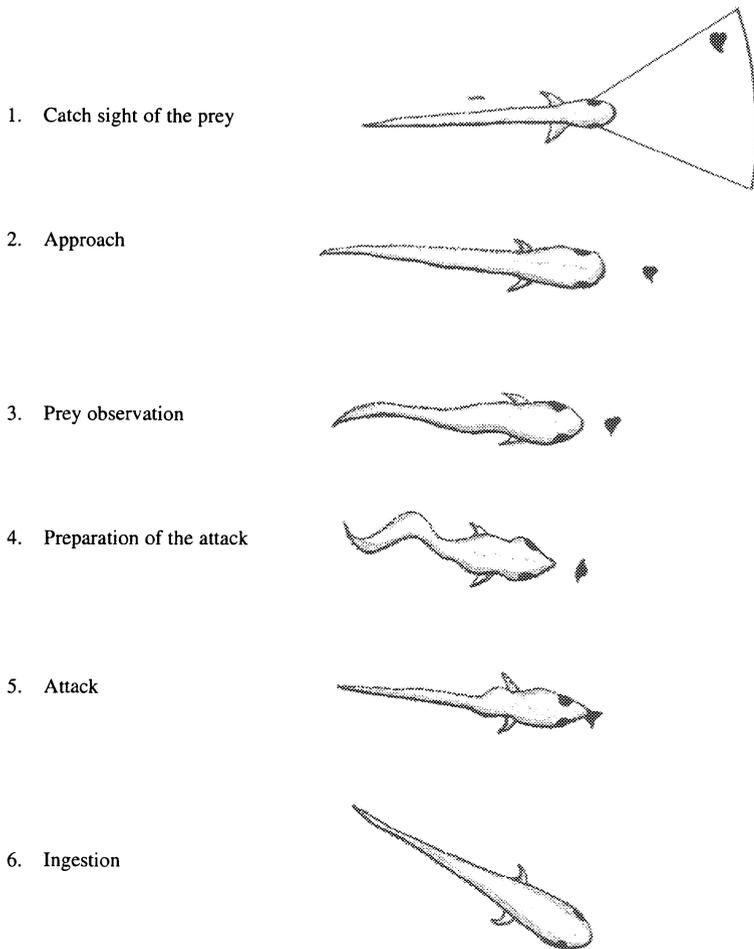


Figure 26-01. Physical movements of a larva for catching the prey *Brachionus plicatilis* (redesigned from: 1).

Blue-green Algae

The blue green micro-algae belongs to the phylum *Cyanobacteria* which means that they may be more closely related to bacteria than other algae. *Spirulina* also is a part of this phylum which is cultured not only as feed but also as food for man^(6, 17).

Red Algae

Rhodophyta are unicellular micro-algae. Related forms also grow into macro-algae (seaweeds). In the wild they are the preferred food for abalone (*Haliotis* sp.) spat⁽⁶⁾.

Dinoflagellates

Dinoflagellates of the phylum *Dinophyta* are quite large micro-algae and are usually single but may form chains⁽⁶⁾. They have two flagella and one eyespot⁽¹⁷⁾. In coastal areas certain species of this micro-algae cause “red tides”. These species contain a toxin which kill most other life in the respective area^(6, 17).

Haptophyta

The phylum *Haptophyta* is a small group of micro-algae. They are predominantly used as food for gastropods. The important genera for aquaculture are *Isochrysis*, *Monochrysis* and *Pavlova*^(5, 14, 17).

Chlorophyta

The green micro-algae of the phylum *Chlorophyta* is an important food for gastropods and food for the mass-culture of rotifer. It is also supplied to tanks to naturalise the water. The phylum varies greatly with regard to reproduction, structure and ecology. Three of the commonly reared genera are: *Chlorella*, *Dunaliella* and *Tetraselmis*⁽¹⁴⁾.

Diatoms

The phylum *Bacillariophyta* are commonly named diatoms. Diatoms range in size from 0.002 to 0.2 mm. Their most outstanding feature is the external shell. They are divided into: *Centric diatoms* and *Pennate diatoms*.

Pennate diatoms are mainly used as live food and are the important diet for abalone (*Haliotis* sp.)⁽⁶⁾ and for bivalve molluscs^(5, 19).

26.2.2 Zooplanktons

There are thousands of zooplankton species which could serve as larval food in aquaculture but only few have high reproductive capacity⁽²³⁾. The most important zooplankton for live food production are rotifers of the phylum *Ratatoria*. It is a microscopic invertebrate animal, primarily found in freshwater. Due to its rotating movement it is also named “wheel animal”⁽¹⁷⁾.

Brachionus plicatilis

This is probably the most commonly grown rotifer. The strains of this rotifer vary widely⁽²³⁾. They are subdivided in accordance to their size (larger than 150 microns and smaller than 150 microns). The larger strain should not contain more than 1.0 to 2.0% rotifers of the smaller strain and vice versa: the smaller strain should have at least 80% animals smaller than 150 microns. Rotifers as feed organism are not only produced by mass-culture but also collected from the sea^(14, 17, 23).

26.2.3 Micro-crustaceans

Micro-crustaceans are also considered to be zooplanktons because of their microscopical size⁽²³⁾. But the feed organisms used as larval food have an organised anatomical structure (Figure 26-02) in contrast to the very simple zooplanktons hence are considered separately.

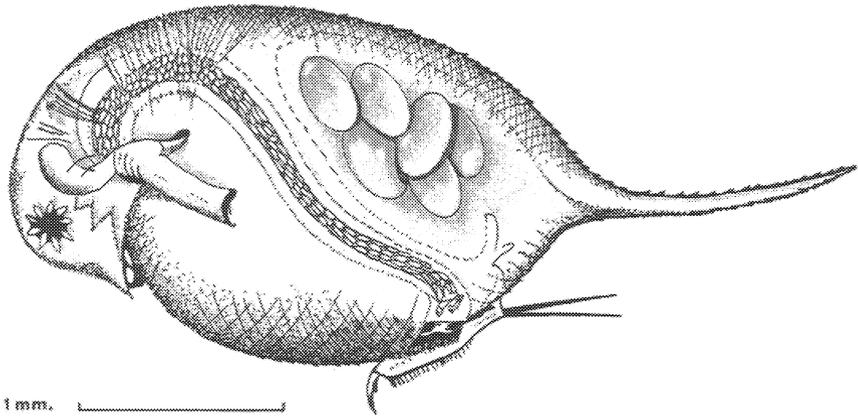


Figure 26-02. The micro-crustacea *Daphnia pulex* (redesigned from: 27).

Daphnia

Daphnia also named as “water flea” live in freshwater. It belongs to the group of crustaceans which is known as *Cladocerans*. *Daphnia* is a rather large feed organism with a size of up to 2.5 mm. *Moina* is similar to *Daphnia* and belongs also to *Cladocerans*⁽¹⁷⁾.

Copepods

Copepods are a diverse group of micro-crustaceans. These marine species are benthic as well as pelagic⁽¹⁷⁾. Common genera mass-cultured are:

- *Acartia*
- *Centropages*
- *Calanus*
- *Labidocera*
- *Rhinalcanus* (can be also a predator).

Brine Shrimp

The brine shrimp (*Artemia*) is a crustacean, closely related to shrimp and belonging to the phylum *Arthropoda*. *Artemia* is the most common feed organism for feeding larval fish and crustaceans⁽²⁶⁾. More than 85% of the marine animals cultured are raised with *Artemia*⁽¹⁴⁾. Artificial feeds have been formulated but none have equalled that of *Artemia*. The unique nature and role of *Artemia* has revolutionized the aquaculture industry particularly the shrimp industry⁽³⁾. There are several strains of *Artemia*-bisexual, parthenogenetic, diploid, or polyploid - and they differ not only in nutritional requirement but also in their value as food for various predators, fish and shrimp larvae⁽¹⁷⁾. Mostly used *Artemia* strains come from Canada, San Francisco Bay and South America. The brine shrimp can live in high salinity water. Only the cysts, also called winter eggs, are of interest as live food⁽¹⁷⁾.

26.2.4 Other Feed Organisms

Other feed organisms are *Protozoa*, *Oligochaete* worms (genus *Tubifex*), round worms (Nematodes), amphipods, frog tadpoles (*Rana sp.*) and larvae and fish eggs. Certain species such as Protozoa and Nematodes are also parasites^(6, 19).

26.3 Mass-Culture of Food Organisms

Feed Organisms should be easy to culture, have a high reproduction rate and economical to mass produce. The species cultured should be of pure strains. High production output, can only be obtained, if the culture facilities are free of predators.

Micro-algae

They are very diverse and can live in almost any kind of habitat. Since they are plants, they need light for photosynthesis to convert inorganic matter into organic substances. Nutrients for micro-algae are nitrogen, phosphates and trace minerals. Some need also vitamins. For best performances the culture temperature is important and should be for⁽⁶⁾:

- Tropical species: 25° to 31°C
- Subtropical species: 15° to 27°C
- Temperate species: 10° to 12°C
- Polar species: 0° to 12°C

Micro-algae such as the *Chlorophyta*, and *Dunaliella salina* produce significant amounts of β -carotene⁽¹⁷⁾.

Rotifers

They are cultured by batch, continuous or semi-continuous method. The batch culture procedure is the method of choice⁽²⁰⁾. Rotifers can be harvested after about five days when the density has reached around 600 animals/ml. The nutritional quality of rotifers can be improved by feeding them with essential fatty acids, Vitamin C and other nutrients⁽⁴⁾.

Artemia

The brine shrimp is either mass-cultured in salt ponds or under controlled conditions. Dormant cysts (embryos) are immersed in seawater to activate the larvae (nauplii) of about 0.4 mm length within 24 hours. After hatching and prior to feeding the crustacean or fish larvae, *Artemia nauplii* should be separated from the cyst shells and other matters⁽⁴⁾.

Daphnia

Vitamins, trace minerals as well as polyunsaturated fatty acids in the culture medium are needed for normal growth of *Daphnia*. Micronised, de-oiled rice bran was found to support the reproductive population of *Daphnia*. It increased population in six weeks from 100 animals/l to 12,000 animals/l. Feed conversion was 1:1⁽¹⁷⁾.

Nematodes

The Nematodes *Panagrellus revivus* and *Caenorhabditis elegans* are cultured on a medium of breakfast cereals, soy peptone, yeast extract and liver extract mixed with sterile water.⁽⁴⁾

26.4 Chemical, Physiological and Other Properties

Chemical Properties

The chemical composition of live food differs from species to species, culture to culture, type of food given and the source of the cysts as in the brine shrimp (*Artemia salina*) (Table 26-01)⁽²⁷⁾. Some live foods like *Artemia salina* and the round worm, nematodes, can bio-encapsulate nutrients hence, their chemical composition can be manipulated⁽⁴⁾.

Table 26-01: Chemical composition of live food (% in dry matter)⁽²⁷⁾

	Moisture	Crude protein	Crude lipid	Crude ash
<i>Brachionus plicatilis</i>				
Baker's Yeast ¹	90.7	67.0	19.4	7.5
Baker's Yeast + Chlorella ¹	88.7	67.2	21.5	4.9
Chlorella ¹	86.9	60.3	29.8	5.3
<i>Moina sp.</i>				
Yeast ¹	87.2	68.8	22.6	-
Yeast & poultry Manure ¹	89.0	78.2	11.8	-
Poultry manure ¹	87.9	67.8	27.3	-
<i>Artemia salina</i>				
Eggs :				
San Francisco ²	-	54.4	6.4	6.3
South America ²	-	51.5	10.5	13.0
Canada ²	-	47.5	4.8	15.3
Larva :				
San Francisco ²	-	59.2	19.4	11.7
South America ²	-	71.4	17.6	11.0
Canada ²	-	57.6	17.8	12.7

¹Culture media; ²Country of origin

Except for the brine shrimp the amino acid profile of some commonly used live foods are not very variable (Table 26-02).

The content of essential fatty acids in live foods is the principal factor in their dietary value⁽²⁸⁾. The fatty acid content of the brine shrimp differs among strains and sources and culture media affects the fatty acid composition of rotifer *Brachionus plicatilis*⁽²⁷⁾. Generally, rotifers have fatty acid profiles like their algal food (Table 26-03)⁽³⁰⁾.

Table 26-02: Essential amino acid profile of selected live food (g/16 g N)

	<i>Artemia</i>	Copepods		Zooplanktons	
	<i>Salina</i>	<i>Acartia clausi</i> ⁽²⁸⁾	<i>Tigriopus japonicus</i> ⁽²⁸⁾	<i>Moina</i> sp. ⁽²⁸⁾	<i>Brachionus plicatilis</i> ⁽²⁸⁾
	larva ⁽⁹⁾ 22, 28)				
Arginine	7.7	4.3	5.2	5.1	4.6
Histidine	2.7	1.9	1.6	1.6	1.5
Isoleucine	4.5	3.5	2.5	2.5	3.5
Leucine	7.7	5.5	5.0	6.0	5.9
Lysine	8.5	5.4	5.7	6.8	5.9
Methionine	1.9	1.5	1.1	1.0	0.8
Phenylalanine	4.3	3.7	3.5	3.6	3.9
Threonine	3.8	4.2	3.8	3.8	3.4
Tryptophan	1.0	1.1	1.1	1.2	1.2
Valine	4.6	4.5	3.3	3.2	3.9

Table 26-03: Fatty acid profile of live food (% of total fatty acids)

Fatty acids	Brine shrimp (<i>Artemia</i> spp.) from... ⁽²¹⁾			Rotifer (<i>Brachionus plicatilis</i>) cultured with... ⁽²⁹⁾		
	Australia	Brazil	California	Yeast	Yeast + Chlorella chlorella	Chlorella
	Saturated	18.2	20.5	15.7	11.6	14.4
Mono-saturated	45.0	48.7	46.6	61.7	50.3	36.1
Poly-saturated	36.5	30.7	37.1	11.3	24.5	37.2

The mineral contents of live food can differ greatly (Tables 26-04). Little is known of the vitamin content of the brine shrimp. When vitamin content is compared to the minimum daily requirement of salmonid fry the brine shrimp contains more than the requirement (Table 26-05).

Physiological Properties

The gross energy of live food ranges from 4,100 to 6,100 kcal/kg (17.2 to 25.5 MJ/kg) (Table 26-06). Newly hatched brine shrimp nauplii have a high energy content, but 48 hours after hatching a large portion of their lipids have been used and their energy content has declined⁽¹⁷⁾.

Table 26-04: Macro and trace mineral contents of live food

		<i>Acartia</i> (27)	<i>Daphnia</i> sp (27)	<i>Moina</i> sp. (27)	Rotifer	Brine shrimp ^(18, 27)	
						Egg	Larvae
Calcium	%	0.5	0.02	0.02	0.02	0.25	0.03
Phosphorus	%	0.15	0.15	0.16	0.13	0.74	0.13
Magnesium	%	0.09	0.01	0.01	0.02	0.36	0.04
Sodium	%	0.64	0.07	0.10	1.0	0.22	10.7
Potassium	%	0.27	0.07	0.10	0.04	0.61	0.35
Iron	mg/kg	36.6	72.2	86.7	25.5	1,011.0	0.11
Zinc	mg/kg	89.2	12.8	12.2	7.9	92.8	64.9
Manganese	mg/kg	0.7	13.2	1.6	0.9	54.7	2.8
Copper	mg/kg	7.9	1.1	4.1	0.9	13.9	5.4
Lead	mg/kg	-	-	-	-	7.9	4.3
Cadmium	mg/kg	-	-	-	-	0.2	0.1
Chromium	mg/kg	-	-	-	-	3.0	0.9
Cobalt	mg/kg	-	-	-	-	0.9	0.3
Selenium	mg/kg	-	-	-	-	1.5	1.3

Table 26-05: Vitamin content (per 1,000 g) of the brine shrimp (*Artemia*) as compared to minimum dietary requirement (MDR) of salmonids

Vitamin		<i>Artemia</i> ^(9,23)	Salmonid MDR ^(12, 23)
Vitamin A	I.U.	14,000	2,500
Vitamin B ₁	mg	27.0	1.0
Vitamin B ₂	mg	17.0	5.0
Vitamin B ₆	mg	8.0	5.0
Vitamin B ₁₂	mg	3.0	-
Vitamin C	mg	9.0	50.0
Biotin	mg	1.0	0.05
Folic acid	mg	1.0	1.0
Nicotinic acid	mg	1.3	1.0
Pantothenic acid	mg	9.0	10.0
Choline	g	6.1	0.05
Inositol	g	1.2	0.25

Table 26-06: Gross energy content of live food (dry sample)⁽²⁷⁾

	Kcal/kg	MJ/kg
<i>Brachionus plicatilis</i>		
Fed on: - Yeast	5,200	21.7
- Yeast + chlorella	5,400	22.6
- Chlorella	6,100	25.5
<i>Artemia salina</i>	5,200	21.8
<i>Arcatia clausi</i>	4,100	17.2
<i>Trigriopus japonicus</i>	5,300	22.2

The protein digestibility of live foods is high in carp (*Cyprinus carpio*) and rainbow trout (*Salmo gairdneri*). The protein efficiency ratio (PER) as well as the net protein utilisation (NPU) do not differ significantly between both fish species (Table 26-07).

Table 26-07: Apparent protein digestibility (APD), protein efficiency ratio (PER) and net protein utilization (NPU) (%) of live foods⁽²⁷⁾

	Rainbow trout (<i>Salmo gairdneri</i>)			Carp (<i>Cyprinus carpio</i>)		
	APD	PER	NPU ¹	APD	PER	NPU ¹
<i>Rotifer (Brachionus plicatilis)</i>						
fed on: - Yeast	93.8	2.9	68 ¹	90.3	2.8	78 ¹
- Yeast + Chlorella	94.1	3.2	72	92.1	3.8	76
- Chlorella	89.1	3.1	76	89.1	2.6	73
<i>Trigriopus japonicus</i>	-	3.6	-	-	-	-
<i>Daphnia</i> sp.	-	3.9	-	-	-	-
<i>Moina</i> sp.	-	2.6	-	-	-	-
<i>Artemia salina</i>	89.3	-	-	82.9	2.5	66

¹relative to casein = 100%

Other properties

Micro-algae might have unique antibacterial and/or immunostimulatory properties. Extracts of the micro-algae *Tetraselmis suecica* inhibit bacterial activity within 15 minutes, soon after addition to fish tanks and up to four hours. Supplementation of spray-dried *Tetraselmis* to the diet of Atlantic salmon (*Salmo salar*) prevents the outbreak of infections due to bacteria *Vibrio anguillarum*, *Vibrio salmonicida* and *Serratia liquefaciens*⁽⁴⁾.

Micro-algae may also stimulate enzymatic synthesis and onset of feeding in young larvae. Furthermore, they act as a water conditioner by stripping off nitrogenous substances or by changing the properties of the incoming light by creating more shaded conditions⁽⁴⁾.

Artemia improves the quality and purity of the salt (NaCl) by feeding on impurities in the saltwater like calcium carbonate, calcium sulphate and micro-algae⁽³⁾.

26.5 Feeding Value

Live food has to be carefully selected. The wrong choice may result in poor productivity of aquatic animals cultured and may cause high losses. The culture conditions of the food organism will determine its feeding value to the primary crop organism⁽¹⁷⁾. The dietary value of live foods for larval cultured aquatic animals in terms of protein quality, vitamins, minerals, lipid profiles and their bio-availability is fully dependent on their nutritional status⁽²⁷⁾.

Live food is used only in primary phase rearing of commercially produced larvae⁽¹⁶⁾. Rotifers are given as the first exogenous diet followed by marine copepods (*Trigriopus*, *Acartia*, *Oithona* and *Paracalanus*) or of freshwater origin (*Moina* and *Daphnia*) together with rotifer. When there are no copepods available, *Artemia salina* is the live food of choice in Japanese hatcheries⁽²⁷⁾.

Fishes

There are some species of live food that may not be suitable for certain fish larvae but have been found to produce good growth responses in other fish species. For example, freshwater catfish (*Clarias macrocephalus*) fry grew better on brine shrimp than on *Moina macrocopa*⁽⁸⁾. But *Moina macrocopa* fed to bighead carp (*Aristichthys nobilis*) larvae, promoted highest growth⁽⁷⁾.

Grass carp (*Ctenopharyngodon idellus*) grew poorly on *Spyrogira* while bigmouth buffalo (*Ictiobus cyprinellus*) and blue tilapia (*Oreochromis aureus*) responded well to *Spirulina platensis*⁽²⁴⁾.

Milkfish (*Chanos chanos*) fry fed live water flea (*Moina macrocopa*) grew and survived significantly better than when fed *Brachionus* or the frozen *Moina*⁽²⁵⁾.

Nile tilapia (*Oreochromis niloticus*) fry fed with uni-algal culture of zooplankton, *Naviculla* or *Chroococcus*, resulted in high weight gains and survival rates whereas the phytoplankton, *Chlorella* gave poor survival and growth⁽²⁰⁾.

Growth responses of fish to brine shrimp will not only depend on the species but also on the geographical strains of *Artemia* (Table 26-08).

Crustaceans

Like fish, crustaceans do not respond similarly to various *Artemia* strains as shown in Table 26-08.

Larvae of the giant freshwater prawn (*Macrobrachium rosenbergii*) and (*Palaemon elegans*) fed exclusively live *Artemia salina* developed into first postlarval state within 12 days and 24 days, respectively⁽¹⁵⁾. Survival and growth of both species on live *Artemia* alone was significantly better than when no feed was given or when compared to an artificial diet.

Table 26-08: Biological response of some cultured aquatic animals to different geographical strains of *Artemia*⁽²³⁾

	Brazil	Australia	Utah ¹	SPB ¹	Italy
1. <u>Fishes</u>					
Atlantic silverside (<i>Menidia menidia</i>)	++	++	++	±±	++
Winter flounder (<i>Pseudopleuronectes americanus</i>)	++	++	—	—	++
2. <u>Crustaceans</u>					
Rock crab (<i>Cancer irroratus</i>)	++	++	—	—	—
Mudcrab (<i>Rhithropanopeus harrisee</i>)	++	++	—	—	++
Mysid (<i>Mysidopsis bahia</i>)	++	++	++	±±	++

++ = good survival; — = poor survival; ±± = good survival, but poor growth

¹California, USA; ²San Pablo Bay

Molluscs

Although phytoplankton are the principal food source for bivalve larvae such as American oyster (*Crassostrea virginica*), blue mussel (*Mytilus edulis*) and window pane oyster (*Placuna placenta*) not all are suitable dietary components because of their cell size, thick walls or presence of toxic metabolites⁽³⁰⁾.

Synergistic effects in growth resulted when two algal species were mixed in diets for the American oyster. *Platymonas suecica* alone gave negative growth but when fed in combination with *Isochrysis galbana* or *Thalassiosera pseudonana* a much better response was observed. Mixing *Isochrysis galbana* and *Thalassiosera pseudonana* gave the best growth in soft tissue and shell organic material compared to feeding these singly or in combination with *Platymonas suecica* (Table 26-09)⁽⁶⁾.

Table 26-09: Growth response of juvenile blue print oysters (*Crassostrea virginica*) to various algal species⁽⁵⁾

Algae species	Soft tissue ¹ mg	Shell organic matter ¹ mg	Growth g	Growth efficiency (%)
<i>Platymonas suecica</i> (1)	55.0	56.1	negative	negative
<i>Isochrysis galbana</i> (2)	97.8	70.0	1.09	39.1
<i>Thalassiosera pseudonana</i> (3)	100.8	66.6	1.08	38.7
Combination of:				
- (1) + (2)	85.1	68.4	0.75	41.9
- (1) + (3)	93.9	68.1	0.92	36.5
- (2) + (3)	123.7	79.5	1.74	54.7

¹Dry weight

Sexually immature window-pane oyster (70 mm shell height) were fed *Isochrysis galbana*, *Tetraselmis tetrahele* or a 1:1-combination at 100,000 cells per ml divided into two rations per day. Oysters fed the combination of *Isochrysis* and *Tetraselmis* attained sexual maturity in the third month of rearing, a month ahead of those fed single algal species⁽¹⁰⁾.

26.6 Feeding Recommendations and Precautions

Feeding Recommendations

The amount of live food fed to the cultured larvae will vary according to species of fish or crustacean, density, stocking rate as well as developmental stage of larvae hence, there is no standard formula. For instance the daily consumption of rotifers by red sea bream (*Pagrus major*) larvae increased in 25 days by 86 times in pieces and 93 times by weight of rotifers (Table 26-10)⁽¹⁴⁾. However, a close monitoring of the larvae in the tank is important for^(2, 16):

- Feeding behaviour
- Pattern of food selection
- Swimming and searching action
- Growth rate
- Schooling.

A rule of thumb is that the live food supplied daily should be equal to 80 to 100% of the larval fish weight⁽¹⁷⁾.

Table 26-10: Estimated daily consumption of rotifers (*Brachionus plicatilis*) by red sea bream (*Pagrus major*) larvae during the first month of culture⁽¹⁴⁾

Days from Hatching	Consumption per larvae/day		Length mm	Body weight mg
	Number	Weight mg		
4	22	0.07	3.0	-
9	58	0.17	3.9	0.32
13	156	0.47	5.1	1.0
18	285	0.86	6.0	2.1
21	427	1.30	6.9	3.6
24	747	2.20	7.8	5.5
27	1,213	3.60	8.9	8.9
28	1,665	5.00	9.7	12.1
29	2,151	6.50	10.4	13.7

Precautions

Some harmful organisms may be found in the water when live food is obtained from the wild. They may contaminate the rearing medium.

26.7 References

1. *Barnabe, G.* (1980): Rotifers; biology and rearing technology. In: *Barnabe, G.* (ed.): Aquaculture, Vol. 1, Ellis Horwood Publication, London/England.
2. *Bautista, M.N.; Parado-Esteva, F.; Millamena, O.M.; Borlongan, E.L.* (1991): Large-scale hatchery production of *Penaeus monodon* using natural food and artificial diets. *Bamidgeh*, 43., 137-144.
3. *Bhat, B.V.* (1995): *Artemia*. In: Live feed Handbook on Aquafarming. The Marine Products Export Development Authority (Ministry of Commerce, Government of India), Kochi/India.
4. *Dhert, P.; Sorgeloos, P.* (1995): Live feeds in aquaculture. *Infofish International*, (2), 31-39.
5. *Epifanio, C.E.* (1982): Phytoplankton and yeast as foods for juvenile bivalves. A review of research at the University of Delaware. Proc. 2nd Conf. on Aquaculture Nutrition: Biochem. and Physiol. Approaches to Shellfish Nutrition, Rohoboth Beach, Delaware/U.S.A., October, 180-201.
6. *Fallu, R.* (1991): Abalone Farming. Fishing News Books, Oxford/England.
7. *Fermin, A.C.; Recometa, R.D.* (1989): Larval rearing of bighead carp *Aristichthys nobilis* Richardson, using different types of feed and their combinations. *Aquaculture and Fish. Mgt.*, 19., 283-290.
8. *Fermin, A.C.; Bolivar, E.C.* (1991): Larval rearing of the Philippine freshwater catfish, *Clarias macrocephalus* (Gunther), fed live zooplankton and artificial diet: a preliminary study. *Bamidgeh*, 43., 87-94.
9. *Gallagher, M.; Brown, W.D.* (1975): Composition of San Francisco Bay brine shrimp (*Artemia salina*). *Agriculture and Food Chemistry*, 23., 630-632.
10. *Gallardo, W.G.; De Castro, M.T.R.; Buensuceso, R.T.; Espigadera, C.C.; Baylon, C.C.* (1992): Gonad development of *Placuna placenta* Linnaeus fed *Isochrysis galbana* Par, *Tetraselmis tetrahele* (G.S. West) Butch, or their combination. *Aquaculture*, 102., 367-371.
11. *Hernandorena, A.* (1982): *Artemia* Nutrition. Proc. 2nd Conf. on Aquaculture Nutrition: Biochem. and Physiol. Approaches to Shellfish Nutrition, Rohoboth Beach, Delaware/U.S.A., October, 166-177.
12. *Ketola, H.G.* (1976): Quantitative nutritional requirements of fishes for vitamins and minerals. *Feedstuffs*, 48., (7).
13. *Kinne, O.* (1977): Marine ecology. Vol. 3, Cultivation, Part 2. John Wiley and Sons, New York/U.S.A.
14. *Komis, A.* (1991/92): Improved production and utilization of the rotifer *Brachionus plicatilis* Müller, in European sea bream (*Sparus aurata* Linnaeus) and sea bass (*Dicentrarchus labrax* L.) larviculture. Dr. thesis, University Ghent/Belgium.
15. *Kumlu, M.; Jones, D.A.* (1995): Feeding and digestion in the Caribbean shrimp larva of *Palaemon elegans* (Rathke) and *Macrobrachium rosenbergii* (De Man) (Crustacea:Palaemonidae) on live and artificial diets. *Aquaculture Nutrition*, 1., 3-12.
16. *Kuronuma, K.; Fukusho, Y.* (1984): Rearing of marine fish larvae in Japan. IDRC-TS 47. 25-30.
17. *Landau, M.* (1992): Introduction to aquaculture. John Wiley & sons, Inc., New York/U.S.A.
18. *Olney, C.E.; Schauer, P.S.; McLean, S.; You-Lu; Simpson, K.L.* (1980): International study on *Artemia*. VIII. Comparison of the chlorinated hydrocarbons and heavy metals in five different strains of newly hatched *Artemia* and a laboratory-reared marine fish. In: The Brine Shrimp *Artemia*. Vol. 3, Universal Press, Wetteren/Belgium. 343-352.
19. *Quayle, D.B.; Newkirk, G.F.* (1989): Farming bivalve molluscs. Methods for study and development. The World Aquaculture Soc., Baton Rouge, LA/U.S.A.
20. *Santiago, C.B.; Reyes, O.S.* (1989): Effect of feeding regimes on growth and survival of bighead carp (*Aristichthys nobilis* Richardson) fry. Proc. Third Asian Fish Nutrition Network Meeting, 6 to 10 June 1988, Bangkok/Thailand, Asian Fish. Soc. Spec. Publ. 4; Manila/ Philippines. 130-136.
21. *Schauer, P.S.; Johns, D.M.; Olney, C.E.; Simpson, K.L.* (1980): International study on *Artemia*. IX. Lipid

- level, energy content and fatty acid composition of the cysts and newly-hatched nauplii from five geographical strains of *Artemia*. In: *The Brine Shrimp Artemia*. Vol. 3. Universal Press, Wetteren/Belgium. 365-372.
22. Seidel, C.R.; Kryznowek, J.; Simpson, R.L. (1980): International study on *Artemia*. XI. Amino acid composition and electrophoretic protein patterns of *Artemia* from five geographical locations. In: *The Brine shrimp Artemia*. Vol. 3, Universal Press, Wetteren, Belgium. 375
 23. Simpson, K.L.; Klein-McPhee, G.; Beck, A.D. (1982): Zooplankton as a food source. Proc. 2nd Conf. on Aquaculture Nutrition: Biochem. and Physiol. Approaches to Shellfish Nutrition, Rehoboth Beach, Delaware/U.S.A., October, 180-201.
 24. Stanley, J.G.; Jones, J.B. (1976): Feeding algae to fish. *Aquaculture*, 7., 219-223.
 25. Villegas, C.T.; Lumasag, G.L. (1991): Biological evaluation of frozen zooplankton as food for milkfish (*Chanos chanos*) fry. *J. Appl. Ichthyol.*, 7., 65-71.
 26. Ward and Whipple (1918): Quoted from: Landau, M. (1992).
 27. Watanabe, T. (1988): Fish nutrition and mariculture. In: Watanabe, T. (ed.): *Live feeds*. JICA Textbook, The General Aquaculture Course. Kanagawa International Fisheries Training Centre, Japan Int'l. Cooperation Agency.
 28. Watanabe, T.; Arakawa, T.; Kitajima, C.; Fujita, S. (1978): Nutritional evaluation of proteins of living feeds used in seed production of fish. *Bull. Jap. Soc. Sci. Fish.*, 44., 985-988.
 29. Watanabe, T.; Kitajima, C.; Fukusho, K.; Fujita, S. (1978): Nutritional quality of rotifer, *Brachionus plicatili*, as a living feed from the viewpoint of essential fatty acids for fish. *Bull. Jap. Soc. Sci. Fish.*, 44., 1109-1114.
 30. Webb, K.L.; Chu, F.L.E. (1982): Phytoplankton and yeast as foods for juvenile bivalve larvae. Proc. Second Intern. Conf. on Aquaculture Nutrition: Biochemical and Physiological Approaches to Shellfish Nutrition. Spl. Pub. No. 2, Louisiana State Univ. Div. Continuing Education. 272-291.

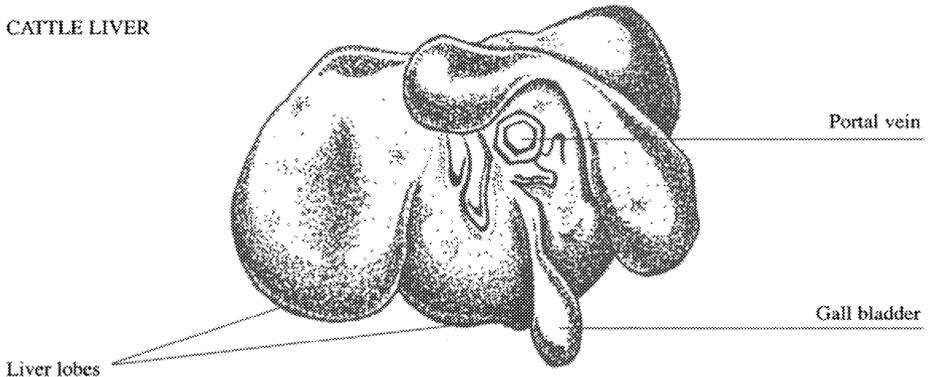
27. LIVER FROM WARM-BLOODED ANIMALS

27.1 Rationale

The liver is the “Central Laboratory” of warm-blooded animals. It is the most essential glandular organ of the body (Figure 27-01). The animal will die shortly after the removal of the liver⁽¹⁴⁾. In the liver nutrients are versatile and intensively synthesised, reduced, and converted⁽¹⁰⁾. The amount of nutrients stored in the liver, particularly vitamins, is related directly to the dietary level of the nutrients⁽⁹⁾.

Liver as a feedstuff is a by-product of the slaughtering of animals. Since liver is food for man, mainly discarded livers not fit for human consumption are used as a feedstuff. However, livers are not always available, because they are usually incorporated in meat meal⁽⁸⁾.

CATTLE LIVER



PIG LIVER

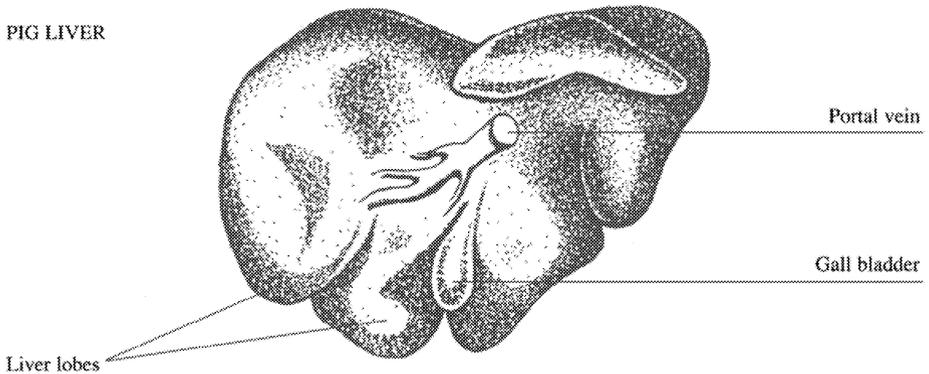


Figure 27-01. The liver of the pig and cattle.

27.2 Processing

Fresh Liver

Fresh or frozen liver is used as the first exogenous food for fish larvae. Only healthy livers should be used for larval feeding. The fresh livers are minced in a meat-chopper by using the smallest die. Mincing the material several times may be an advantage. Minced raw liver should be stored in a refrigerator but only for a short period.

Discarded livers are cooked before using them as feed for older fish. The cooked livers are minced together with other feed ingredients.

Liver Meal

Whole livers are dried at low temperature and then ground into a meal⁽⁶⁾. Whale livers and residues from the manufacture of liver extract are also processed into liver meal.

Liver meal has a limited storage time. It is prone to rancidity because of its relatively high fat content. Its moisture content should not exceed 10.0%. Storage should be in a dry and cool place^(9, 26). Liver meal may also contain other abattoir by-products such as lungs and hearts. The nutritional value of these meals is lower than of true liver meal⁽⁹⁾.

A liver-drying process suitable for small-scale and laboratory use is described as follows⁽⁷⁾: Fresh liver is sliced, deep-frozen in liquid nitrogen (b.p.-196°C) and ground in a kitchen-mixer with enough liquid nitrogen to avoid thawing. The ground slurry with liquid nitrogen, is poured into aluminum foil capsules and stored in a freezer at -20°C.

27.3 Chemical, Physiological and Other Properties

Chemical Properties

Liver meal is a protein feedstuff having a mean protein content of about 67%. The protein content of fresh liver does not differ significantly among species (Table 27-01). It is a good source of essential amino acids (Table 27-02).

Table 27-01: Chemical composition of liver meal and livers of various animals (% as fed)^(3, 8, 17, 19, 20, 22, 24, 26)

	Liver meal	Fresh liver			
		Beef	Pork	Chicken	Turkey
Dry matter	93.6	27.4	27.9	27.5	29.6
Crude protein	67.1	21.8	19.7	18.9	19.3
Crude fat	16.5	3.5	3.8	3.8	4.0
Ash	5.9	1.4	1.5	1.4	1.3
Crude fibre	0.8	0.1	0.1	2.9	2.9
N-free extract	3.3	0.6	2.8	0.5	2.1

Table 27-02: Essential amino acid profile of mammal liver
(g/16 g N)^(8, 20, 22, 26)

	Mean	Variation
Arginine	4.90	4.04 - 6.10
Histidine	1.67	1.48 - 2.20
Isoleucine	3.62	3.10 - 4.60
Leucine	5.86	5.31 - 7.30
Lysine	5.81	4.81 - 6.80
Methionine	1.28	1.22 - 1.30
Phenylalanine	3.31	2.91 - 4.30
Threonine	2.75	2.49 - 3.30
Tryptophan	0.65	0.60 - 0.70
Valine	4.52	4.15 - 5.50

The fat content of liver meal varies widely, and is affected by the fat content of the animal feed. However, the fat content of fresh liver from different species are similar (Table 27-01). The linoleic acid of liver meal amounts to 1.7%⁽¹⁷⁾.

Fresh liver is rich in Vitamin A (20,000 to 50,000 I.U./kg) but not in liver meal. The drying process destroys vitamins. However, liver meal is a good source of B-vitamins, particularly Vitamin B₁₂ (Table 27-03) but liver meal made of residues from liver extraction is more or less free of Vitamin B₁₂⁽²⁶⁾.

The mineral content of liver meal is low and its contribution in aquaculture feeds is insignificant (Table 27-03).

Table 27-03: Mineral and vitamin contents of liver meal (as fed)

Minerals ^(3, 8, 17, 20, 22, 24, 26)			Vitamins (per 1,000 g) ^(3, 8, 20, 24)		
Calcium	%	0.28	Vitamin B ₁	mg	0.2
Phosphorus	%	0.81	Vitamin B ₂	mg	47.3
Sodium	%	0.32	Vitamin B ₁₂	mg	502.6
Potassium	%	0.62	Vitamin C	mg	-
Magnesium	%	0.07	Biotin	mg	0.4
Manganese	mg/kg	9.87	Folic acid	mg	5.6
Iron	mg/kg	664.3	Nicotinic acid	mg	204.5
Zinc	mg/kg	128.3	Pantothenic acid	mg	37.2
Copper	mg/kg	95.6	Choline	g	11.4

Physiological Properties

Information on the energy content and the digestibility of liver meal is only available for land animals. A digestible energy of 5,019 kcal/kg liver meal (21.0 MJ/kg) and a protein

digestibility of 59.0% has been reported for dogs⁽¹⁷⁾. The digestibility of liver meal in chicken is for⁽²⁶⁾:

- Crude protein: 65.0%
- Crude fat: 91.0%
- N-free extract: 45.0%

Other Properties

Liver meal may also contain the unidentified growth factor (UGF) which is known as the “whey factor”^(9, 26) (see Chapter 44).

27.4 Feeding Value

Fishes

Fresh or frozen beef liver is used to grow trout larvae to stocking size⁽¹²⁾. As early as 1927, trout were grown on purified rations but only those rations containing liver supported growth⁽¹⁵⁾. However, due to the cost, instead of using 100% liver, mixtures of fish meal, vegetable oil meals, salmon eggs, were substituted for part of the liver^(2, 23). A ration containing 47.5% fresh liver, 47.5% canned carp and 5% dried brewer’s yeast fed at the rate of 6% fish body weight gave results equal to the use of an all fresh liver diet⁽¹⁶⁾. The cost of feeding fresh beef liver was also reduced by using dry mixtures containing dried skim milk, white fish meal, cottonseed meal and wheat middlings and adding fresh or thawed frozen spleen and/or liver to the dry mixture⁽¹²⁾. Since the use of dry feed mixtures is more feasible, the use of liver and other meat by-products in the fresh state is minimized.

Liver meal has been found to be good for larvae of cyprinids. Common carp (*Cyprinus carpio*) larvae were fed two diets based on freeze-dried liver and yeast (Table 27-04)⁽⁵⁾. The larvae fed the diet with freeze-dried beef liver grew better than those fed the pork liver. Larval growth or weight of common carp also was superior with beef liver diet (800 mg mean final weight) compared to fish fed the casein containing diet (235 mg)⁽²¹⁾. This shows that common carp larvae can be reared solely on dry diets as early as first feeding stages.

Table 27-04: Survival and growth of common carp (*Cyprinus carpio*) larvae fed freeze-dried pork or beef liver⁽⁵⁾

Beef liver	%	40	-
Pork liver	%	-	40
Yeast powder (<i>Pichia pastoris</i>)	%	45	45

Survival after 4 weeks	%	93	91
Weight	mg	266	242
Length	mm	26.4	23.9

After two weeks of feeding powdered pork liver to a hybrid larvae bighead carp (*Aristichthys nobilis* females) and silver carp (*Hypophthalmichthys molitrix* males) the fish performed significantly better than those fed with fresh zooplankton and a commercial feed (Table 27-05)⁽⁷⁾.

Table 27-05: Growth of a hybrid bighead carp (*Aristichthys nobilis*) x silver carp (*Hypophthalmichthys molitrix*) larvae fed for two weeks pork liver, zooplankton and crumbled feed (initial weight: 1.5 to 2.5 mg, initial length: 7.0 to 9.0 mm)⁽⁷⁾

		Pork liver (powdered)	Zooplankton	Commercial crumbled feed ¹
Body length	mm	14.4	14.2	9.7
Liveweight	mg	21.2	13.7	3.8
Body dry matter	%	15.4	12.1	11.5
Survival rate	%	>90	>90	15

¹composition not specified

Crustaceans

Beef liver may benefit prawns because it is a good source of B-vitamins and cholesterol. Water-soluble vitamins also may leach out more rapidly from the formulated feed than from the frozen liver⁽¹¹⁾.

Good growth and survival can be economically obtained by feeding post-larvae freshwater prawns (*Macrobrachium rosenbergii*) with 15 to 20% fresh frozen beef liver as supplement to high quality trout or shrimp feeds (Table 27-06)^(11, 18). Tiger prawn (*Penaeus monodon*) grew better on formulated diets than on the fresh beef liver diet⁽¹³⁾.

Table 27-06: Growth responses of juvenile freshwater prawn (*Macrobrachium rosenbergii*) to various supplemental levels of frozen beef liver⁽¹²⁾

Beef liver ¹	% ¹	5	10	15	20	25
Final weight	g	0.71	0.84	0.92	0.96	1.01
Yield ²	g/m ³	675	799	897	903	972
Food conversion ³	1:	0.51	0.51	0.48	0.53	0.53
Survival	%	95.2	95.2	96.8	94.2	96.3

¹ % dry weight of total daily ration; ²Yield = total weight in g/m³

$$^3 \text{FCR} = \frac{\text{dry weight of food given;}}{\text{weight gain}}$$

Juvenile American lobsters (*Homarus americanus*) and hybrids of *Homarus americanus* and *Homarus gammarus* fed liver either as a daily supplement or every 4th day with a purified diet containing casein, wheat gluten and spray-dried egg white as protein sources produced heavier animals (567 mg) and higher survival rate (100%) than when given only the purified diet (448 mg and 17%)⁽¹⁶⁾.

Juvenile freshwater crayfish (*Pacifastacus leniusculus*) fed pork liver for 50 days had higher survival (32%) and carapace length 6.0 mm compared to those fed phytoplankton alone (10.7% and 5.1 mm)⁽⁴⁾.

27.5 Recommended Inclusion Rates

There is no limit in the use of fresh liver and liver meal except for economic reasons. However, high inclusion rates of liver meal may affect pellet stability due to the structure of the product and the high fat content. Recommended inclusion rates of liver meal are:

- Carnivorous fish: 10.0 - 15.0
- Omnivorous fish: 5.0 - 10.0
- Herbivorous fish: 5.0 - 10.0
- Crustaceans: 5.0 - 10.0

27.6 Legal Aspects

Animal liver is a feedstuff listed as No. 9.7 in the AAFCO-list of feedstuff definitions. It has to be from slaughtered mammals and the product has to correspond with the description. Another listed product is “fish liver and glandular meal” (No. 51.34). It contains the entire viscera, but 50% of the dry weight has to be from fish liver and it must contain at least 40 mg Vitamin B₂/kg⁽¹⁾.

The EU-Directive does not have an assignment for liver meal. It is included under “meat meal tankage” (No. 9.02) which requires a minimum protein content of 50% in the dry matter.

The German feedstuff legislation describes “animal liver meal” as a product obtained from fresh livers of warm-blooded, terrestrial animals. It must contain at least 65% crude protein and the moisture content should not exceed 11%⁽²⁵⁾.

27.7 References

1. AAFCO (1995): Official publication 1995. Ass. of American Feed Control Officials (publisher). Sacramento, CA/USA.
2. Agersborg (1934): Quoted from: *Hastings, W.H.; Dickie, L.M.* (1972).
3. *Anonymous* (1968): Food and Nutrition Research Institute, Nat. Sci. Dev. Bd., Manila/Philippines.
4. *Celada, J.D.; Carral, J.M.; Gaudioso, V.R.; Temiño, C.; Fernandez, R.* (1989): Response of juvenile freshwater crayfish (*Pacifastacus leniusculus* Dana) to several fresh and artificially compounded diets.

- Aquaculture, 76., 67-78.
5. *Charlon, N.; Bergot, P.* (1984): Rearing system for feeding fish larvae on dry diets trial with carp (*Cyprinus carpio* L.) larvae. Aquaculture, 41., 1-9.
 6. *Conklin, D.E.; D'Abramo, L.R.; Bordner, C.E.; Baum, N.A.* (1980): A successful purified diet for the culture of juvenile lobsters: The effect of lecithin. Aquaculture, 21., 243-249.
 7. *Csengeri, I.; Petitjean, M.* (1987): Fresh liver powder: A new starter diet for the larvae of a cyprinid fish. Aquaculture, 65., 189-192.
 8. *Evans, M.* (1985): Nutrient composition of feedstuffs for pigs and poultry. Queensland Dept. Primary Ind., Brisbane. Australia (Series Q 185001).
 9. *Feltwell, R.; Fox, S.* (1978): Practical poultry feeding. Faber and Faber, London and Boston.
 10. *Friesecke, H.* (1984): Handbuch der praktischen Fütterung von Rind, Schaf, Pferd, Schwein, Geflügel and Süßwasserfischen. BLV Verlagsges. München/Germany.
 11. *Garces, C.L.; Heinen, J.M.* (1993) Evaluation of beef liver, fruits and vegetables as dietary supplements for indoor nursery culture of freshwater prawns (*Macrobrachium rosenbergii*), J. World Aqua. Soc., 24., 58-65.
 12. *Hastings, W.H.; Dickie, L.M.* (1972): Feed formulation and evaluation. In: *Halver, J.E.* (ed.). Fish Nutrition. Academic Press. 327-370.
 13. *Kibria, G.* (1993): Studies on molting, molting frequency and growth of shrimp (*Penaeus monodon*) fed on natural and compounded diets. Asian Fish. Science, 6., 203-211.
 14. *Kolb, E.* (1989): Lehrbuch der Physiologie der Haustiere (I and II) VEB Gustav Fischer Verlag, Jena/Germany.
 15. *McCay, C.M.; Dilley, W.E.* (1927): Quoted from: *Hastings, W.H.; Dickie, L.M.* (1972).
 16. *McLaren, B.A.; Herman, E.S.; Elvehjem, C.A.* (1946): Quoted from: *Hastings, W.H.; Dickie, L.M.* (1972).
 17. *Meyer, H.; Heckötter, E.* (1986): Futterwerttabelle für Hunde und Katzen. Schlütersche Verlagsanstalt. Hannover/Germany.
 18. *Molina-Vozzo, R.E.; Heinen, J.M.; D'Abramo, L.R.* (1995): Supplementation of commercial feeds with beef liver for indoor nursery culture of freshwater prawns *Macrobrachium rosenbergii*, J. World Aqua. Soc., 26., 103-106.
 19. *Nandeesh, M.C.* (1993): Aquafeeds and feeding strategies in India. Proc. FAO/AADCP Regional Expert Consultation on Farm-Made Aquafeeds, 14 to 18 December 1992. Bangkok/Thailand. 434 (FAO-RAPA-AADCP, Bangkok/Thailand). 213-254.
 20. *NRC* (1977): Nutrient requirements of warmwater fishes. Nutrient requirement of domestic animals. Nat. Acad. Press., Wash. D.C./USA.
 21. *Szlaminska, M.; Escaffre, A.M.; Alami-Durante, H.; Charlon, N.; Bergot, P.* (1990): Casein in the place of beef liver in artificial diets for common carp (*Cyprinus carpio* L.) larvae. Aquat. Living Resour., 3., 229-234.
 22. *Tacon, A.G.J.* (1993): Feed ingredients for warmwater fish: Fish meal and other processed feedstuffs. FAO Fisheries Circular No. 856, FAO, ROME/Italy. 64p.
 23. *Titcomb et al.* (1928): Quoted from: *Hastings, W.H.; Dickie, L.M.* (1972).
 24. *Watt, B.K.; Merrill, A.L.* (1963): Composition of Foods. Agri. Handbook No. 8. U.S. Dept. of Agriculture, Washington D.C./USA.
 25. *Weinreich, O.; Koch, V.; Knippel, J.* (1994): Füttermittelrechtliche Vorschriften. Buchedition Agrimedia, Hamburg/Germany.
 26. *Wöhlbier, W.; Tran Thu, D.* (1977): Blutmehl. In: *Kling, M.; Wöhlbier, W.* (eds.): Handelsfuttermittel Verlag Eugen Ulmer, Stuttgart/Germany.

28. MAIZE PRODUCTS

28.1 Rationale

Maize (*Zea mays*) is a cereal, belonging to the family *Poaceae* and has its origin in Central America. Now maize is grown world-wide whenever the climate permits cultivation.

Maize is a staple food for the natives in the Americas and Africa and maize porridge (Polenta) is a common dish in the southern and south-eastern part of Europe.

World production of maize is more than 500 million MT a year. U.S.A. is the largest maize producer (44.0%), followed by P.R. China (14.0%), Brazil (4.5%) and Argentina (2.6%). Of the total world production about 30% are consumed by man and the remaining 70% are used as feedstuffs. In many civilisations the most important cereal among the grains is called “corn”. Since maize is the most important cereal in U.S.A. it is named “corn”⁽⁷⁵⁾. In Sweden and Norway barley is named “corn”, in eastern parts of Germany, in Poland and Russia rye is named “corn”.

According to the kernel characteristics, maize is grouped into eight classes the grouping of which is important for international trading of maize.

Dent maize, *Zea mays* var. *dentiformis* or var. *indendata* and flint maize, var. *vulgaris* or var. *indurata* are the most important types for feedstuffs. Both are comprised mainly of hard starch and their kernels are very hard⁽¹⁶⁾.

Today cultivation of hybrids is prevalent. In 1963 an old strain of maize known as “opaque-2” was found to have twice as high lysine and tryptophan as ordinary maize⁽⁴⁶⁾ but the yield of high lysine hybrids is less than that of ordinary dent hybrids⁽¹⁶⁾.

28.2 Manufacture and Processing

Maize is processed either by dry milling or wet milling. Bran and germ meal are obtained from dry milling such as grits and “hominy,” a product of dry milling. The products from dry and wet milling are compiled in Table 28-01^(16, 75). The starch can be further processed and split into maize syrup (maize sugar) and dextrin, also called starch gum.

Most maize for human consumption and technical application is processed into maize starch by wet milling (Figure 28-01).

The starch or the entire kernel can be gelatinised by thermal or hydro-thermal processing to improve utilisation by animals.

Table 28-01: Products from dry milling and wet milling of maize (%) ⁽¹⁶⁾

	Dry milling	Wet milling
Flour	60.0	-
Starch	-	69.0
Bran	21.0	-
Gluten feed	-	20.3
Grits	9.0	-
Gluten meal	-	4.5
Germ meal	8.5	3.2
Maize oil	1.5	3.0
Total	100.0	100.0

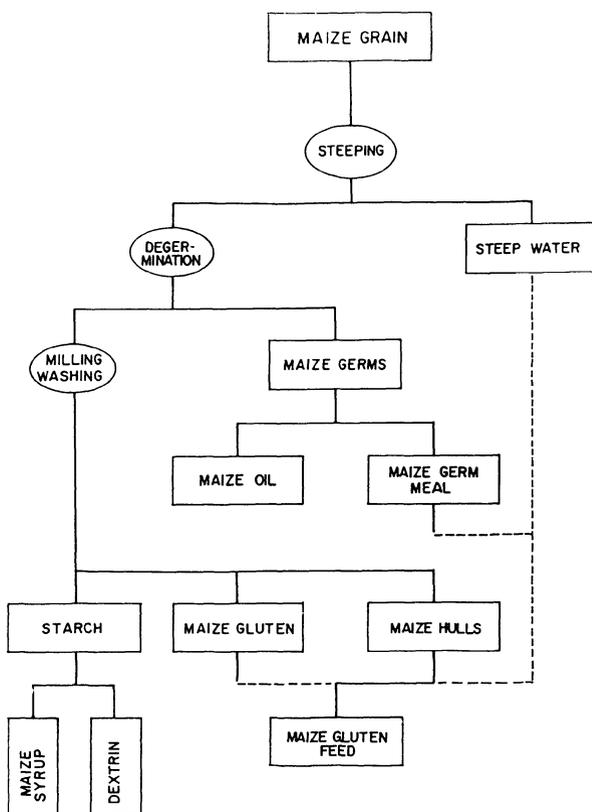


Figure 28-01. Production diagram of wet milling of maize.

28.3 Maize Meal

28.3.1 Description

Ground maize or maize meal is an excellent energy source but low in protein. It is a major feed ingredient for terrestrial farm animals and is considered the most palatable of the cereals used in animal feeding. Its utilisation by animals can be improved by thermal or hydro-thermal treatment.

28.3.2 Chemical, Physiological and Other Properties

Chemical Properties

Maize meal, aside from its low crude protein is also low in crude fibre (Table 28-02). It is a poor source of the amino acids lysine, methionine and tryptophan (Table 28-03) except for the high-lysine type of maize (Opaque-2 maize). The macro and trace mineral contents is insignificant (Table 28-04).

Table 28-02: Chemical composition of maize products (% in dry matter)

	Maize meal	Maize starch		Maize gluten		Hominy feed	Maize bran
	(10, 11, 14, 22, 25, 27 47, 49, 51, 52, 53, 71)	Raw (47, 51, 52, 75)	Cooked (52)	Meal (13, 14, 22, 24, 25, 28, 36, 51, 53, 61, 71)	Feed (13, 28, 36, 47, 53, 71)	(22, 51, 71, 75)	(11, 25, 47)
Dry matter	87.8	90.2	88.0	91.3	90.1	90.1	87.5
Crude protein	10.2	0.4	0.2	59.9	24.7	8.9	15.0
Crude fat	4.8	0.4	-	3.6	3.5	5.4	5.7
Ash	1.6	0.1	0.1	2.5	7.0	2.4	5.7
Crude fibre	2.8	0.1	0.1	2.4	9.4	4.5	9.9
N-free extract	80.6	99.0	99.6	31.6	55.4	78.8	63.7

Table 28-03: Essential amino acid profile of maize products (g/16 g N)

	Maize meal	Maize gluten		Hominy feed	Maize bran
	(5, 10, 22, 25, 50, 52, 53)	Meal (5, 13, 30, 52, 61)	Feed (5, 25, 36, 50)	(50, 52)	(5)
Arginine	0.5	1.6	1.4	0.5	-
Histidine	0.3	1.1	-	0.2	-
Isoleucine	0.4	2.4	-	0.4	-
Leucine	1.4	8.0	-	0.9	-
Lysine	0.4	1.0	0.6	0.4	1.4
Methionine	0.2	1.4	1.4	0.2	-
Phenylalanine	0.5	3.1	-	0.4	3.2
Threonine	0.7	2.2	-	0.4	3.1
Tryptophan	1.0	0.3	0.3	0.1	0.7
Valine	0.4	2.4	1.5	0.6	-

Table 28-04: Macro and trace mineral contents of maize products (in dry matter)

		Maize meal (22, 25, 50, 51)	Maize gluten		Hominy feed (22, 51, 52, 71)
			Meal (13, 22, 25, 36, 50, 51, 52, 61, 71)	Feed (13, 36, 47, 53)	
Calcium	%	0.1	0.2	0.2	0.1
Phosphorous	%	0.3	0.4	0.8	0.6
Sodium	%	0.2	0.1	0.3	0.1
Potassium	%	0.3	0.1	1.6	0.6
Magnesium	%	0.1	0.1	0.5	0.3
Chlorine	%	0.1	0.0	-	0.1
Sulfur	%	0.1	0.6	-	-
Manganese	mg/kg	6.7	6.7	31.1	16.0
Iron	mg/kg	32.5	34.7	0.1	73.6
Zinc	mg/kg	21.1	86.3	72.2	3.0
Copper	mg/kg	6.5	29.2	21.1	15.4
Selenium	mg/kg	0.3	0.6	-	0.1

Meal from yellow maize is considerably high in Vitamin A because it contains the pigments “cryptoxanthin” and carotene which are precursors for Vitamin A (Table 28-05). Part of the yellow colour of maize is due to “xanthophyll” which does not have any Vitamin A value⁽¹⁶⁾.

Table 28-05: The vitamins of maize products (as fed) (1,000 g)

		Maize meal (5, 22, 25, 50, 51, 52, 70)	Maize gluten		Hominy feed (22, 51, 52)
			Meal (22, 25, 50, 51, 52)	Feed (5)	
Vitamin A	I.U.	6,155.3	207	-	400
Vitamin E	mg	16.6	25.0	15.0	-
Vitamin K	mg	13.3	11.7	-	-
Vitamin B ₁	mg	0.3	0.2	2.0	5.7
Vitamin B ₂	mg	3.6	1.6	2.5	2.1
Vitamin B ₆	mg	5.4	6.4	15.0	11.0
Biotin	mcg	62.0	187.5	150.0	130.0
Folic acid	mg	0.2	0.2	0.3	0.3
Nicotinic acid	mg	21.7	56.6	70.0	46.0
Pantothenic acid	mg	5.5	8.2	17.0	7.7
Choline	mg	509.1	342	1,500	1,030

Physiological Properties

The digestible energy of maize meal for rainbow trout (*Oncorhynchus mykiss*) is low. Gelatinised maize meal has an almost 40% better digestible energy content than native

(raw) maize meal for channel catfish (*Ictalurus punctatus*). The metabolisable energy of maize meal is high for carp (*Cyprinus carpio*) (Table 28-06).

Table 28-06: Energy values of maize products per kg

Species	Gross Energy		Metabolisable energy		Digestible energy		Reference
	kcal	MJ	kcal	MJ	kcal	MJ	
Maize meal							
	4,110	17.1	-	-	-	-	(43, 47)
Rainbow trout	-	-	-	-	1,195	5.0	(43)
Carp	-	-	3,460	14.5	-	-	(78)
Channel catfish	-	-	-	-	2,200	9.2 ¹	(52)
-	-	-	-	3,840	16.1 ²	(43, 51)	
Fish ³	-	-	-	-	3,240	13.6	(50)
Maize starch							
	3,700	15.5	-	-	-	-	(47, 75)
Rainbow trout	-	-	2,150	9.0	2,533	10.6 ²	(68)
			717	3.0	1,147	4.8 ¹	(68)
Channel catfish	-	-	-	-	2,700	11.3	(52)
Maize gluten meal							
	5,067	21.2	-	-	-	-	(47)
Rainbow trout	-	-	3,859	16.1	4,240	17.7	(13, 51)
Maize gluten feed							
	4,087	17.1	-	-	-	-	(47)
Rainbow trout	-	-	-	-	1,290	5.4	(13)
Maize bran							
	4,015	16.8	-	-	-	-	(47)
Dogs	-	-	-	-	2,677	11.2	(47)
Hominy feed							
Chicken	-	-	2,880	12.1	3,595	15.0	(22)
Dextrin							
Rainbow trout	-	-	3,035	12.7	3,824	16.0	(68)
Channel catfish	-	-	-	-	2,420	10.2 ³	(51)

¹Native; ²Gelatinised; ³Species not specified

The apparent digestibility of nutrients of maize meal varies widely among species. Gelatinizing maize meal, however, improves the digestibility remarkably (Table 28-07) (4, 18, 34, 39).

Since the nicotinic acid of maize is not very available, deficiencies may cause “black tongue” in dogs^(5, 70, 81).

Table 28-07: Apparent digestibility (%) of maize meal (raw and gelatinised)^(4, 34, 39)

	Dry Matter	Crude protein	Crude fat	Carbo- hydrates	Crude fibre	Energy
Atlantic salmon (<i>Salmo salar</i>)	-	89.7 ¹	95.6 ¹	64.0 ¹	-	-
Common carp (<i>Cyprinus carpio</i>)	-	88.0	79.0	84.3	38.0	-
Grass carp (<i>Ctenopharyngodon idellus</i>)	64.8	50.6	19.5	87.9	-	21.5
Channel catfish (<i>Ictalurus punctatus</i>)	-	66.1	76.1	-	-	26.0
European eel (<i>Anguilla anguilla</i>)	-	78.0 ¹	96.0 ¹	-	-	58.2 ¹
Tiger prawn (<i>Penaeus monodon</i>)	-	-	-	94.0 ¹	-	-
	-	-	-	99.3 ¹	-	-

¹Gelatinised (pre-cooked)

Minerals of the maize meal are generally well utilised by aquatic animals particularly magnesium and phosphorus. They are effectively utilised by grass carp (*Ctenopharyngodon idellus*) while iron and calcium could be scarcely absorbed⁽³⁷⁾. There is a tendency for the Chinese shrimp (*Penaeus chinensis*) to utilise manganese and zinc of maize meal very well so that the requirement of both trace elements may be met^(41, 42).

Other Properties

Maize meal has a high pelletising ability but the resistance for abrasiveness is low^(32, 35). Ground maize is not only used as feed ingredient in aquaculture diets but also significantly reduces pH levels in aquaculture ponds⁽⁶⁰⁾.

28.3.3 Feeding Value

Feeding rainbow trout fingerlings with increasing levels of maize meal improved nutrient digestibility and growth. The higher the maize meal level, the better the performances (Table 28-08)⁽⁷⁷⁾.

Extruded (gelatinised) maize meal is the better energy source for optimum protein utilisation⁽²⁶⁾. Extrusion of the maize meal in diets for rainbow trouts (*Salmo gairdneri*) improved the feed conversion compared to the native unextruded maize by 17%. The reduced protein level of the control did not affect the feed conversion.

Under simple production conditions the common guppy (*Lebistes reticulatus*) responded better to diets made from maize meal (opaque-2) and leaf meal of the plant, *Bohemeria nivea* and soybeans (50:50) than on a mixture with another plant (*Pereskia aculeata*) meal. The mixture not only improved the weight gain of the adults but also their progeny born during the trial period grew better⁽⁶²⁾.

Table 28-08: Effect of maize meal on protein and carbohydrate digestibility by rainbow trout (*Oncorhynchus mykiss*) (trial period: 10 weeks)⁽⁷⁷⁾

Maize meal	%	0	10	20	30
Crude protein	%	43.0	43.9	43.6	44.4
Digestible carbohydrates	%	1.6	8.9	17.4	26.6

Initial fish weight	g	46.1	47.2	46.3	44.9
Weight gain	%	20.3	51.1	65.1	93.1
Protein digestibility	%	86.9	87.6	90.1	90.2
Carbohydrate digestibility	%	6.0	42.5	43.4	54.0

28.4 Maize Starch

28.4.1 Description:

Maize starch or amyllum is a polysaccharide and almost free of any crude fibre, protein and other substances. The major components of starch are amylopectin, amylose and moisture.

Starch can be modified whereby the properties of starch are completely changed by chemical, enzymatical and physical processes. There are a number of modified starches⁽⁷⁵⁾. Maize starch has a wide range of applications in the food and technical industry.

28.4.2 Chemical, Physiological and Other Properties

Chemical Properties

The crude protein, fat, crude fibre and ash are insignificant and are merely considered impurities because maize starch is a pure carbohydrate (Table 28-02).

Physiological Properties

Aside from fats and oils, starch is the purest form of energy in animal nutrition. The past master of animal nutrition, *Oskar Kellner* (1851-1911) used starch to express the energy value of feedstuffs. He developed the "Starch Equivalent" (SE), a net energy system of feed evaluation in 1905. One kg of starch is equivalent to 2,356 kcal (9.86 MJ) net energy for fattening and this is one SE^(28, 59). This system was widely used in Germany and throughout Europe in ruminant feeding.

The energy values of maize starch is in Table 28-06. The higher the starch level, the lower the digestibility by rainbow trout. Native starch digestibility increased from 38% at the 1.0% feed intake to 55% at the 0.5% intake level. The digestibility of gelatinized starch was much higher than that of the native starch^(7, 70).

Raw starch heated for 10 minutes at 112°C, could not be digested, by rainbow trout⁽¹²⁾. Apparently the carp digests starch better than salmonids since 95% of gelatinised maize starch can be digested by the former^(63, 64). In the white leg shrimp (*Penaeus vannamei*)

apparent digestibility of maize starch is 68.3% for dry matter and 81.1% for protein⁽²⁾ and for tiger prawn (*Penaeus monodon*) 72.1% for protein⁽²⁴⁾.

Other Properties

Maize starch has good pelletising properties. The combination of 5% maize starch and 10% wheat flour provides a good water durability of the pellets⁽⁵⁵⁾.

28.4.3 Feeding Value

Maize starch in aquaculture diets serves as an energy source and spares the protein for energy in the production of aquatic animals.

Fishes

Rainbow trout fingerlings responded substantially better to gelatinised than to native maize starch (Table 28-09) particularly at higher gelatinized starch levels^(40, 74, 76). On the other hand, in rainbow trout 30% glucose improved the protein utilisation of the diet better than the same amount of raw maize starch. Weight gain, feed conversion and protein efficiency of glucose fed fish were superior to fish fed native maize starch by 8.5%, 17.9% and 14.2%, respectively⁽⁶⁾. However, gelatinised maize starch was better utilised at the same level as saccharose (28%) by the rainbow trout⁽⁴⁴⁾. Higher levels of gelatinised maize starch have a higher degree of utilisation than saccharose as determined by the glucose activity in the liver of which was 50% lower after feeding of saccharose. Increasing the levels of gelatinised maize starch in the diet improved protein utilisation by the rainbow trout but weight gain decreased⁽⁵⁷⁾.

Gelatinized maize starch fed to rainbow trouts tend to deposit higher levels of fat in the body⁽⁵⁸⁾.

Table 28-09: The effect of native (raw) and gelatinised (cooked) maize starch on growth and feed conversion of rainbow trout (*Salmo gairdneri*)⁽⁷⁶⁾

Maize starch		Crude protein %	Weight gain g	Feed conversion 1:
Native %	Gelatinised %			
15	-	42	80	1.74
-	15	42	92	1.55
13	-	42	107	1.73
-	13	42	121	1.62
13	-	42	67	2.34
-	13	42	115	1.64
29	-	32	66	2.30
-	29	32	112	1.67

Maize starch were better utilised by carp when gelatinised by extrusion. Growth, feed efficiency and protein efficiency were greater when fish were fed the extruded diets than diets that were not extruded and contained raw ingredients⁽⁷⁴⁾.

Juvenile white sturgeon (*Acipenser transmontanus*) fed diets containing 27.2% of raw maize starch for eight weeks were not able to utilise it sufficiently⁽³⁸⁾.

Maize starch in isonitrogenous diets for European eels (*Anguilla anguilla*) at levels of 30% and an initial weight of 4.6 g had a daily weight gains of 2.28 g but fish fed wheat and bread meal diets performed better⁽¹⁹⁾. The performance of eel elvers was significantly superior on 20 and 30% glucose diets than on maize starch, regardless of the water temperature (25° and 27°C). However, at higher water temperature and the higher level of maize starch or glucose accumulated more lipids in the body than the control groups⁽¹⁷⁾.

Similar effects were found of up to 25% maize starch or 15% fat as energy sources in diets for channel catfish (*Ictalurus punctatus*)⁽⁵⁴⁾.

Crustaceans

Maize starch at the 40% level in a semi-purified diet for tiger prawn (*Penaeus monodon*) gave a better survival rate (32%) than sago or cassava starch (0%) after six weeks of feeding⁽⁵⁶⁾.

The white shrimp (*Penaeus setiferus*) had higher growth rates with 30% maize starch, than glucose fed animals⁽³⁾. Similarly best growth and survival was obtained in pink shrimp (*Penaeus duorarum*) with 40% maize starch in the diet⁽⁶⁶⁾.

Molluscs

In studies on gastropod nutrition, starch was used as the major carbohydrate source at levels of 5.0 to 15.0%⁽⁹⁾. In diets for commercial feeding of the marine snail abalone (*Heliantis* spp.) starch is used as an energy source at levels of 5.0 to 30.0%⁽²³⁾.

28.5 Maize Gluten Meal and Maize Gluten Feed

28.5.1 Description

Maize gluten is the protein portion of the maize kernel and is a by-product of wet milling in the processing of starch. Dried gluten is practically free of any other components while maize gluten feed is not. Besides gluten it contains hulls, evaporated steepwater and germ. The germ may be extracted. About 25% of the whole maize kernel are maize gluten (5.0%) and maize gluten feed (20%) (Table 28-01). Maize gluten feed is more common in animal feeding than maize gluten meal.

28.5.2 Chemical and Physiological Properties

Chemical Properties

Maize gluten meal has a protein content of around 60%. The crude protein content of maize gluten feed is about 25% and much lower (Table 28-02). As in maize meal, the amino acids lysine, methionine and tryptophan are limiting factors (Table 28-03).

The rather high crude fibre content of maize gluten feed may limit its use in aquaculture feeds.

Maize gluten meal is a source of β -carotene and xanthophyll⁽²⁵⁾. In general, the vitamin and the mineral content is higher than in maize meal (Tables 28-04 and 28-05).

Physiological Properties

The digestible energy of maize gluten meal is much higher than for maize gluten feed, as found in rainbow trout (Table 28-06)⁽¹³⁾. There are also substantial differences in the dry matter and energy digestibility between maize gluten meal and maize gluten feed in rainbow trout but protein and fat digestibility differs only slightly (Table 27-10). The biological values of maize gluten meal are 36 and 55 while net protein utilization is 35⁽³⁴⁾.

The true digestibility of maize gluten meal in channel catfish and carp is 80% and 91%, respectively⁽⁷⁹⁾.

In terrestrial animals, the phosphorus availability for maize gluten meal (29%) is lower than for maize gluten feed (59%)^(22, 36).

Table 28-10: Digestibility of maize gluten meal and maize gluten feed in rainbow trout (*Salmo gairdneri*)

	Maize gluten Meal ^(12, 13, 52)	Maize gluten feed ^(13, 52)
Dry matter	80.0	23.0
Crude protein	89.6	92.0
Carbohydrates	62.0	-
Fat	92.5	89.7
Energy	80.7	29.0

28.5.3 Feeding Value

Maize gluten meal is a protein source. The feeding value of maize gluten feed is lower than maize gluten meal but its carbohydrate content is higher.

Rainbow trout fed with protein-equivalent diets grew faster on wheat gluten than on maize gluten. Also feed conversion was better for wheat gluten-fed than maize gluten-fed fish (Table 28-11)⁽⁷⁶⁾.

Growth rate and feed conversion was better when fish meal protein was partially replaced by maize gluten protein in diets fed to rainbow trout for 91 days⁽³³⁾.

Performance response of milkfish (*Chanos chanos*) fry fed various levels of maize gluten meal decreased as levels were increased in the diet (Table 28-12)⁽⁶⁵⁾.

Maize gluten is used as a component in experimental and practical diets for various species, at levels between 2.0 and 10.0%^(40, 79, 83):

Table 28-11: Maize gluten versus wheat gluten as protein source in diets for rainbow trout (*Salmo gairdneri*) (Feeding period: 149 days)⁽⁷⁶⁾

Maize gluten	%	12.50	-	12.50	-
Wheat gluten	%	-	9.05	-	9.05
Whey powder, acid	%	-	-	10.70	10.70
Whey powder, neutral	%	10.70	10.70	-	-
Crude protein	%	45.00	45.00	45.00	45.00
Fat	%	9.63	7.86	9.63	7.86

Growth	g	149.30	163.00	159.50	167.30
	%	100.00	109.20	100.00	104.50
Feed conversion	1:	1.54	1.38	1.50	1.39
	%	100.00	89.60	100.00	92.70

Table 28-12: Performance response of milkfish (*Chanos chanos*) fry fed maize gluten meal at various levels⁽⁶⁵⁾

Maize gluten meal	%	38.1	45.4	52.8
Weight gain	%	1,275.0	862.0	312.0
Survival	%	63.0	56.0	14.2
Feed conversion	1:	1.5	1.8	4.9

28.6 Maize Bran

28.6.1 Description

Maize bran is the by-product of dry milling of maize kernels into maize flour and maize grits. It contains the hulls and other parts of the kernel which have not been separated from the starch. About 21% of the maize kernel is maize bran (Table 28-01).

Hominy is a by-product which belongs to this category of maize products. It is comprised of bran, germ and part of the starch.

28.6.2 Properties

Maize bran has a higher crude protein content than hominy but the latter is much lower in crude fibre than maize bran. The high content of N-free extract implies that hominy contains more carbohydrates (starch) than maize bran (Table 28-02).

The amino acid profile of hominy feed is similar to maize meal (Table 28-03). Mineral and vitamin contents of hominy feed in general do not differ much from maize gluten feed (Tables 28-04, 28-05).

The gross energy of maize bran is 4,015 kcal/kg (16.8 MJ/kg) and digestible energy in dogs is 2,677 kcal/kg (11.2 MJ/kg) (Table 28-06)⁽⁴⁷⁾. The digestibility is 66.7%. The digestible energy of hominy in chicken is 3,595 kcal/kg (15.0 MJ/kg)⁽²²⁾.

28.6.3 Feeding Value

Mudfish (*Clarias anguillaris*) fingerlings (two to four months old) were fed for ten weeks with a practical diet containing 60% maize bran and other local available feedstuffs. On the diets with maize bran, fish meal, blood meal, and groundnut cake fish responded with best growth and feed utilization⁽⁴⁵⁾. But feeding maize bran (11.1% crude protein) alone gave poor results.

28.7 Maize Germ Meal

Maize germs contain around 50% oil. The valuable oil is used for human consumption and is obtained by solvent extraction and screw-pressing, respectively. The by-product is maize germ meal or maize germ cake. Fresh maize germs are prone to rancidity due to its high content of unsaturated fatty acids⁽²⁵⁾.

Maize germ meal may also be available as a by-product from the brewery and distillation industry. This type of product usually contains only 10% crude protein⁽²⁵⁾

Maize germ meal has a high protein content (Table 28-13). Data on amino acids are in Table 28-03. Crude fibre content increases with extraction of the oil, thus, reducing the digestibility of the organic matter. Maize germ meal is a good source of Vitamin E⁽²⁵⁾.

Table 28-13: Chemical composition of maize germs and maize germ meal
(% in dry matter)⁽²⁸⁾

	Maize germs	Maize germ meal (solvent extracted)	Maize germ cake (screw pressed)
Crude protein	13.9	24.6	22.5
Crude fat	49.2	2.2	7.4
Crude fibre	5.7	9.4	10.5
Ash	4.8	5.0	3.5
N-free extract	26.4	58.8	56.1
Digestibility of organic matter (pigs)	86.0	65.0	64.0

28.8. Dextrin

28.8.1 Description

Dextrin is used in dietetics, in the food industry as fat-replacer, and in the technical industry as adhesives and sizes⁽⁷⁵⁾. In animal nutrition dextrin serves as a pure carbohydrate in purified diets and is used for standardising nutrient levels in experimental diets⁽⁶⁹⁾.

28.8.2 Chemical and Physiological Properties

Chemical Properties

Dextrin is a white or yellowish powder, soluble in water, gummy, and a dextrorotatory polysaccharide. Dextrin gives a turbid, viscose liquid when dissolved in water. It is obtained from the breakdown of starch. The breakdown can be achieved by enzymes (amylase), acids and high temperature (150°C).

Physiological Properties

The digestible energy is higher for rainbow trout than for channel catfish (Table 28-06). The dextrin digestibility for rainbow trout is between 77 and 85%^(34, 68). However, dextrin digestibility declines as its level in the diet increases (Table 28-14)^(15, 67).

Table 28-14: Relationship between the dextrin level of the diet and the dextrin digestibility

Dextrin in the Diet	Digestibility (%)	
	Rainbow trout ⁽⁶⁷⁾ (<i>Salmo gairdneri</i>)	Plaice ⁽¹⁵⁾ (<i>Pleuronectis platessa</i>)
%		
10	-	84.0
20	77.2	80.0
30	74.8	79.0
40	60.0	60.0
50	50.1	38.0
60	45.5	35.0

Absorption within two hours of dextrin is slower (65%) than glucose (95%) as found in red sea bream (*Chrysophrys major*)⁽²⁹⁾. But a retarded absorption-time is better for the utilisation of carbohydrates because the digestive enzymes can act more effectively. Addition of carboxymethylcellulose to dextrin containing diets may retard absorption further⁽⁴⁸⁾.

28.8.3 Feeding Value

Juvenile chinook salmon (*Oncorhynchus tshawytscha*) of about 1.0 g liveweight were fed with 20% dextrin and 20% glucose, respectively. Growth rate of the dextrin fed group was inferior to the glucose fed fish (Figure 28-02)⁽⁸⁾.

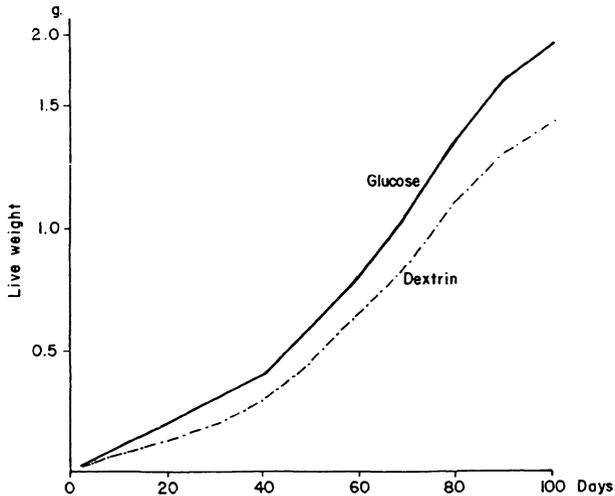


Figure 28-02. Weight development of chinook salmon (*Oncorhynchus tshawytscha*) fed diets containing 20% glucose or dextrin^(Data from: 8)

Growth retardation and low feed efficiency were observed in common carp fed diets with over 40% dextrin, red sea bream fed diets with more than 30% dextrin and yellowtail (*Seriola quinqueradiata*) when fed diets containing over 20% dextrin. Thus, carp utilises dextrin better than the latter two fish species⁽³⁰⁾.

Nutrients were best utilised in channel catfish when the diets contained 14 to 25% dextrin in the dry matter⁽²¹⁾. But compared to isonitrogenous, isocaloric and semipurified diets free of dextrin growth rates of channel catfish fingerlings were reduced when diets contained added dextrin⁽³¹⁾. The species is apparently unable to efficiently utilize dietary mona and disaccharides as energy sources. Best response was achieved when dextrin is mixed with maize starch glucose, maltose, fructose and sucrose, respectively⁽⁸²⁾.

Kuruma prawn (*Penaeus japonicus*) utilise dextrin better than glucose⁽²⁰⁾.

Alligators (*Alligator mississippiensis*) reared on purified diets efficiently digested maize dextrin and isolated soybean protein. High-solubility maize dextrin was slightly but significantly more digestible than low-solubility maize dextrin⁽⁶⁹⁾.

28.9 Recommended Inclusion Rates

As high as 50% maize has been incorporated in diets for herbivores and omnivores. But maximum of 35% has been suggested for these fishes⁽⁷²⁾. Recommended practical inclusion rates are listed in Table 28-15.

Table 28-15: Recommended inclusion rates (%) for maize products in aquaculture feeds^(72, 73)

Maize product ¹	Fishes		Crustaceans	
	Carnivores	Omnivores/ Herbivores	Marine shrimp	Freshwater prawn
	max.	max.	max.	max.
Maize grain meal	20	35	25	35 ¹
Maize starch	15	35	15	15
Maize gluten meal	15	20	15	15
Maize gluten feed	10	20	-	15
Maize bran	5	20	-	15
Dextrin	-	15	-	-

¹Should be free from mycotoxin contamination

28.10 Legal Aspects

Maize products are used everywhere as a feedstuff. Nevertheless, there may exist quality regulations which can differ from country to country. The EU-Directive 92/87/EEC of 26 October 1992, contains definition for eight maize products used in animal feeding. A list of not less than 28 maize products as feed is under Chapter 48 of the Feed Ingredients Definitions of AAFCO (USA)⁽¹⁾. The German feedstuff legislation not only defines the individual maize products but also has quality requirements (Table 28-16).

Table 28-16: Quality requirements (%) for maize products by the German feedstuff law⁽⁸⁰⁾

Product	Moisture max.	Starch min.	Fat max.	Crude protein min.	Crude fibre max.	Ash max.
Maize feed meal	14.0	32.0	-	-	7.0	-
Maize bran	14.0	-	-	-	-	-
Maize germ cake	13.0	35.0	4.0	-	-	-
Maize germ meal	13.0	-	-	19.0	-	-
Maize gluten feed	13.0	-	-	20.0	10.0	6.0
Maize gluten meal	13.0	-	-	60.0	4.5	3.0
Maize starch	14.0	84.0	-	-	-	0.5
Maize starch, extruded	12.0	88.0	-	-	-	0.5

28.11 References

1. *AAFCO* (1995): Official publication 1995. Ass. Of Amrican Feed Control Officials (Publisher). Sacramento, Ca/USA.
2. *Akiyama, D.M.; Coelho, S.T.; Lawrence, A.L.* (1988): Apparent digestibility of feedstuffs by the marine shrimp *Penaeus vannamei* Boone. Bull. Japan Soc. Sci. Fish. 55., 91.
3. *Andrews, J.W.; Sick, L.V.; Baptist, G.J.* (1972): The influence of dietary protein and energy levels on growth and survival of penaeid shrimp. Aquaculture, 1., 341-347.
4. *Anonymous* (w/o year): Digestibility trials on suprex and precooked corn. Humberside Intern. Fish. Insistute, University of Hull/England (Mimeograph).
5. *Behm, G.; Dressler, D.; Kohler, W.; Küther, K.; Lindner, H.; Schwarz, G.* (1992): Vitamins in animal nutrition. Arbeitsgemeinschaft für Wirkstoffe in der Tierernährung, Bonn/Germany (Publisher).
6. *Bergot, F.* (1979): Carbohydrate in rainbow trout diets: Effects of the level and source of carbohydrate and the number of meals on growth and body composition. Aquaculture, 18., 157-167.
7. *Bergot, F.; Breque, J.* (1983): Digestibility of starch by rainbow trout: effects of the physical state of starch and of the intake level. Aquaculture, 34., 203-212.
8. *Buhler, D.R.; Halver, J.E.* (1967): Nutrition of salmonid fishes. IX. Carbohydrate requirements of *chinook salmon*. J. Nutrition, 74., 307-318.
9. *Carefoot, T.H.* (1982): Gastropod nutrition. Proc. 2nd Conf. on Aquaculture Nutrition: Biochem. and Physiol. Approaches to Shellfish Nutrition, Rohoboth beach, Delaware/U.S.A., October. 321-337.
10. *Cheeke, P.R.* (1987): Rabbit feeding and nutrition, Academic Press, Inc., Orlando, Florida/U.S.A.
11. *Chen, K.Z.; Co, W.G.* (1988): Prawn culture. Cuisson Printing Press, Pangasinan/The Philippines.
12. *Cho, C.Y.; Slinger, S.J.* (1979): Apparent digestibility measurement in feedstuffs for rainbow trout. Proc. World Symp. on Finfish Nutr. and Fishfeed Techn., Hamburg/Germany, Vol. II, 20-23 June 1978.
13. *Cho, C.Y.; Cowey, C.; Watanabe, T.* (1985): Finfish nutrition in Asia: Methodological approaches to research and development. IDRC, 233e. Ottawa/Canada.
14. *Chou, R.* (1993): Aquafeeds and feeding strategies in Singapore. Proc. FAO/AADCP Regional Expert Consultation on Farm-made aquafeeds. 14 to 18 December 1992, Bangkok/Thailand. FAO-RAPA/AADCP, Bangkok, Thailand. 354-364.
15. *Cowey, C.; Sargent, J.R.* (1972): Fish nutrition. Advanced Marine Biol., 10., 382-492.
16. *De Boer, F.; Bickel, H.* (1988): Livestock feed resources and feed evaluation in Europe. Elsevier Sciences Publishers, Amsterdam/The Netherlands.
17. *Degani, G.; Levanon, D.* (1987): Effects of dietary carbohydrates and temperatures on slow growing juvenile eels *Anguilla anguilla*. Environ. Biol. Fish., 18., 149-154.
18. *Degani, G.; Revach, A.* (1991): Digestive capabilities of three commensal fish species: carp, *Cyprinus carpio* L.; tilapia, *Oreochromis aureus* x *O. niloticus*; and African catfish, *Clarias gariepinus* (Burchell, 1822). Aquacult. Fish. Manage., 22., 397-403.
19. *Degani, G.; Viola, S.; Levanon, D.* (1986): Effects of dietary carbohydrates source on growth and body composition of the European eel (*Anguilla anguilla* L.). Aquaculture, 52., (2), 97-104.
20. *Deshimaru, O.; Yone, Y.* (1978): Optimum level of dietary protein for prawn. Bull. Jap. Soc. Sci. Fisheries, 44., 1395-1397.
21. *Dupree, H.K.; Sneed, K.E.* (1966): Response of channel catfish fingerlings to different levels of major nutrients in purified diets. Techn. Papers, U.S. Bureau of Sport Fish and Wildlife, 9., 1-21.
22. *Evans, M.* (1985): Nutrient composition of feedstuffs for pigs and poultry. Queensland Dept. of Primary Industries Information Series Q185001, Brisbane.

23. *Fallu, R.* (1991): Abalone Farming. Fishing News Books, Oxford/England.
24. *Feed Dev. Section* (1994): Feeds and feeding of milkfish, Nile tilapia, Asian sea bass, and tiger shrimp. SEAFDEC Aquaculture Department, Tigbauan, Iloilo/Philippines.
25. *Feltwell, R.; Fox, S.* (1978): Practical poultry feeding. Faber and Faber, London and Boston.
26. *Forneris, G.; Boccignons, M.; Damasio, L.* (1986): Mais estruso rell' alimentazione della trota iridea (*Salmo gairdneri*). Rio. Ital. Piscic. Ittiopatol., 21., (2), 59-62.
27. *Friedrich, W.; Jansen, H.D.; Abel, H.; Becker, K.* (1982): Die Warmbehandlung von Getreide, eine richtungsweisende Technologie für die Herstellung von protein-reduziertem Fischfutter. Kraftfutter, 65., 52-58.
28. *Friescke, H.* (1984): Handbuch der praktischen Fütterung von Rind, Schaf, Pferd, Schwein, Geflügel und Süßwasserfischen. BLV Verlagsges., München/Germany.
29. *Furuichi, M.; Yone, Y.* (1980): Effect of dietary dextrin levels on the growth and feed efficiency, the chemical composition of liver and dorsal muscle and the absorption of dietary protein and dextrin in fishes. Bull. Jap. Soc. Sci. Fisheries, 46., 225-229.
30. *Furuichi, M.; Yone, Y.* (1981): Change of blood sugar and plasma insulin levels of fishes in glucose tolerance test. Bull. Jap. Soc. Sci. Fisheries, 47., 761-764.
31. *Garling, D.L.; Wilson, R.P.* (1977): Effects of dietary carbohydrate-to-lipid ratios on growth and body composition of fingerling channel catfish. Progr. Fish-Culturist, 39., 3-47.
32. *Gill, E.* (1993): Chemistry for high quality pellets. Feed International, 14., (3), 10-11.
33. *Gropp, J.; Koops, H.; Tiews, K.; Beck, H.* (1976): Ersatz von Fishmehl in Forellenfutter. Arb. Deutscher Fischerei-Verb., (19), 85-102.
34. *Hepher, B.* (1988): Nutrition of pond fishes. Cambridge University Press, Cambridge/U.K.
35. *Hertrampf, J.W.* (1992): On the water durability of aquaculture feed pellets - A review. Advances in Feed Techn., (7), 18-38.
36. *Holden, P.J.* (1990): Corn gluten feed. In: *Thacker, P.A.; Kirkwood, R.N.*: Non-traditional feed sources for use in swine production. Butterworth Publishers, Boston/U.S.A.
37. *Huang, Y.; Liu, Y.* (1990): Availabilities of Ca and P in nutritive salts and Ca, P, Mg in feeds for grass carp (*Ctenopharyngodon idellus*). Acta Hydrobiol. Sing. Shiuhsen Shengwy Xuebo. 14., 145-152.
38. *Hung, S.S.O.; Fynn-Aikins, K.* (1991): Carbohydrates utilization and its impact on some metabolic and histological parameters in white sturgeon. In: *Kaushik, S.J.; Luquet, P.* (eds.) (1993): Fish Nutrition in France. France Institut National de la Recherche Agronomique, 61., 127-136.
39. *Josefsen, K.; Olivera, M.A.; Rosenlund, G.* (1988): Low temperature extrusion of fish feed. SINTEF-Rapport STF21 F88099, Trondheim/ Norway.
40. *Kaushik, S.J.; Medale, F.; Fauconneau, B.; Blanco, D.* (1989): Effect of digestible carbohydrates on protein/energy utilization and on glucose metabolism in rainbow trout (*Salmo gairdneri* R.) Aquaculture, 79., 63-74.
41. *Li, H.; Hao, B.; Liu, F.; Wang, H.; Sun, F.; Liang, D.* (1993): Effects of dietary manganese supplementation on the prawn, *Penaeus chinensis*. Mar. Sci. Haiyang Kexue, 4., 48-52.
42. *Liang, D.; Liu, F.; Sun, F.; Lan, X.* (1989): Effects of dietary zinc on the prawn, *Penaeus orientalis*. Mar. Sci., Haiyan Kexue, 5., 49-52.
43. *Lovell, R.T.* (1979): Formulating diets for aquaculture species. Feedstuffs, 51., (28), 28-32.
44. *Luquet, P.; Leger, C.; Bergot, F.* (1975): Effects de la suppression des glucides dans l'alimentation de la truite arcenciel la temperature de 10°C. I. Croissance en fonction du niveau d'ingestion proteique. Ann. Hydrobiol., 6., 61-70.
45. *Madu, C.T.; Ajibola, R.F.* (1989): Dietary protein requirements of mudfish (*Clarias anguillaris*) fingerlings. Annu. Rept. Natl. Inst. Freshwat. Fish. Res., Nigeria, 1988. 110-116.

46. Mertz, E.T. (1992): Discovery of high lysine, high tryptophan cereals. In: Mertz, E.T. (ed.): Quality protein maize. The American Ass. of Cereal Chemists, St. Paul, Min./U.S.A.
47. Meyer, H.; Heckötter, E. (1986): Futterwertabelle für Hunde und Katzen. Schlütersche Verlagsanstalt, Hannover/Germany.
48. Morita, K.; Fukuichi, M.; Yone, Y. (1982): Effect of carboxymethylcellulose supplemented to dextrin-containing diets on the growth and feed efficacy of red sea bream. Bull. Jap. Soc. Sci. Fisheries, 48., 1-28.
49. Nandessha, M.C. (1993): Aquafeeds and feeding strategies in India. Proc. FAO/AADCP Regional Expert Consultation on Farm-made Aquafeeds. 14 to 18 Dec. 1992, Bangkok, Thailand. FAO-RAPA/AADCP, Bangkok/Thailand. 213-254.
50. NRC (1977): Nutrient requirements of warmwater fishes. National Academy Press, Washington D.C./USA.
51. NRC (1983): Nutrient requirements of fishes and shellfishes. National Academy Press, Washington D.C./USA.
52. NRC (1993): Nutrient requirements of fish. National Academy Press, Washington D.C./USA.
53. New, M.B. (1987): Feeds and feeding of fish and shrimp - A manual on the preparation and presentation of compound feeds for shrimp and fish in aquaculture. ADCP/Rep/87/26 UNDP. FAO, Rome.
54. Page, J.W.; Andrews, J.W. (1973): Interactions of dietary levels of protein and energy on channel catfish (*Ictalurus punctatus*). J. Nutr., 103., 1339.
55. Piedad-Pascual, F.; Bandonil, L.; Destajo, W.M. (1978): The effect of different binders on the water stability of feeds for prawn. Quarterly Res. Reports. 1st. Qrt., 11., (1), 31-35.
56. Piedad-Pascual, F.; Coloso, R.M.; Tamse, C.T. (1983): Survival and some histological changes in *Penaeus monodon* Fabricius juveniles fed various carbohydrates. Aquaculture, 31., 169-180.
57. Pieper, A. (1977): Untersuchungen über die Verwertung einiger Kohlehydrate durch Regenbogenforellen (*Salmo gairdneri* Richardson). Diss. University of Göttingen/Germany.
58. Pieper, A.; Pfeffer, E. (1980): Studies on the comparative efficacy of utilisation of gross energy from some carbohydrates, proteins and fats by rainbow trouts. Aquaculture, 20., 323-332.
59. Platt, W.P. (1988): Feed evaluation systems: Historical background. In: Oerskov, E.R. (ed.): Feed science. Elsevier Science Publishers, Amsterdam/The Netherlands.
60. Pote, C.W.; Cathcart, T.P.; Deliman, P.N. (1990): Control of high pH in aquaculture ponds. Aquacult. Eng., 9., 175-186.
61. Rossel, W. (1993): Private Communication.
62. Rodriguez de Sousa, J.; Andrade, R.D. de (1982): Nutricao de barrigudinho (*Lebistes reticulatus* Peters 1959). Poecillidae, Pisces, 1982 Seiva, 42., (90), 9-13.
63. Schwarz, F.J.; Kirchgessner, M. (1982): Zur Bestimmung der Nährstoffverdaulichkeit beim Karpfen (*Cyprinus carpio*). 1. Mitt. Aquarienaufbau und Versuchsmethodik. Bayer. Landw. Jahrbuch. 59., 79-84.
64. Schwarz, F.J.; Kirchgessner, M. (1993): Influence of different carbohydrates on digestibility, growth and carcass composition of carp (*Cyprinus carpio* L.). Proc. Fish Nutrition in France. France Institut National de la Recherche Agronomique, 61., 127-136.
65. Senereches, M.L.; Chiu, N.Y. (1988): Effect of fish meal on the growth survival and feed efficiency of milkfish (*Chanos chanos*) fry. Aquaculture, 71., 61-69.
66. Sick, L.V.; Andrews, J.W. (1973): The effect of selected dietary lipids, carbohydrates and protein on the growth, survival and body composition of *Penaeus duorarum*. Proc. 4th Ann. World Mariculture Soc., 263-276. (Louisiana State Univ.).
67. Singh, R.P.; Nose, T. (1967): Digestibility of carbohydrate in young rainbow trout. Bull. Freshw. Fisheries. Res. Lab., 17., 21-25.

68. Smith, R.R. (1971): A method for measuring digestibility and metabolizable energy of fish feeds. *Progr. Fish-Culturist*, 33., 132-134.
69. Staton, M.A.; Edwards, H.M. Jr.; Brisbin, I.L Jr.; Joanen T.; McNease, L. (1992): The influence of environmental temperature and dietary factors on utilisation of dietary energy and protein in purified diets by alligators, *Alligator mississippiensis* (Daudin). *Aquaculture*, 107., 369-381.
70. Steffens, W. (1985): Grundlagen der Fischernährung. VEB Gustav Fischer Verlag, Jena/Germany.
71. Tacon, A.G.J. (1987): The nutrition and feeding of farmed-fish and shrimp. A training manual I. The essential nutrients. Field Document 2/E, GCP/RLA/075/STA, FAO, Brazil.
72. Tacon, A.G.J. (1993): Feed ingredients for warmwater fish, fishmeal and other processed feedstuffs. FAO Fisheries Circular No. 856, FIRI/C866, FAO, Rome, April.
73. Tacon, A.G.J. (1993): Feed ingredients for crustaceans natural foods and processed feedstuffs. FAO Fisheries Circular No. 866, FIRI/C866, FAO, Rome.
74. Takeuchi, T.; Jeong, K.S.; Watanabe, T. (1990): Availability of extruded carbohydrate ingredients to rainbow trout *Oncorhynchus mykiss* and carp *Cyprinus carpio*. *Bull. Jap. Soc. Science. Fish.* 56., 1839-1845.
75. Täufel, A.; Teynes, W.; Tunger, L.; Zobel, M. (1993): Lebensmittel-Lexikon. Behr's Verlag, Hamburg/Germany.
76. Tiews, J.; Groop, J.; Koops, H.; Tiews, K. (1972): Über die Gestaltung von Mischfütterationen für Forellen in der Netzkäfighaltung. *Z. Tierphysiol., Tierernährung, Futtermittelkd.*, 29., 267-275.
77. Ufodike, E.B.C.; Matty, A.J. (1989): Effect of potato and maize meal on protein and carbohydrate digestibility by rainbow trout. *Prog. Fish. Cult.*, 51., 113-114.
78. Viola, S. (1977): Energy values of feedstuffs for carp. *Bamidgeh*, 29., 29-30.
79. Watanabe, T. (1988): Fish nutrition and mariculture. JICA Textbook, the General Aquaculture Course. Kanagawa International Fisheries training Centre (KIFTC). Japan International Cooperating Agency (JICA).
80. Weinreich, O.; Koch, V.; Knippel, J. (1994): Futtermittelrechtliche Vorschriften. Buchedition Agrimedia. Hamburg/Germany.
81. West, G.P. (1992): Black's veterinary dictionary. A & C Black, London. 17th Edition.
82. Wilson, R.P.; Poe, W.E. (1987): Apparent inability of channel catfish to utilize dietary mono- and disaccharides as energy sources. *J. Nutr.*, 117., 280-285.
83. Winfree, R.A.; Stickney, R.R. (1984): Formulation and processing of hatchery diets for channel catfish. *Aquaculture*, 41., 311-323.

29. MARINE OILS

29.1 Rationale

Marine oils are obtained from processing of marine animals and are classified as:

- Fish oils;
- Fish liver oils;
- Marine mammal oils.

The World production of fish oils amounts to more than 1.5 million MT. Almost 70% of the total production is produced by only five countries with Japan as the front-runner (26.6% of the total production), followed by Chile (13.7%), U.S.A (9.9%), Peru (9.2%) and Iceland (8.0%)⁽⁵⁾. Fish oils are used in the food industry, in feed for terrestrial and aquatic animals and in many industrial products, e.g. for fatty acid fractionation.

Fish liver oils were already used in the treatment of rickets in the Middle Ages. Its World production has declined from 76,000 MT in 1938 to less than 20,000 MT⁽⁵⁾.

The production of marine mammal oils, predominantly obtained from whales, has once accounted for as much as 75% of the total marine oil production. Now it accounts for less than 2.0% of marine oil production, due to the wild-life preservation programme⁽⁵⁾.

29.2 Manufacture and Processing

Crude fish oil is obtained from the manufacture of fish meal (see chapter 18.2.). Fish oil is processed in several steps to remove impurities such as moisture, phospholipids, trace minerals and the like that generate irreversible changes in colour and taste or may cause harmful metabolic effects^(6, 31) (Figure 29-01).

The demand for n-3 fatty acids has led to advanced processes for treating fish oils. However, they are too costly for feed grade fish oils. Feed grade fish oils should at least be refined because crude fish oil oxidises rapidly due to the high degree of unsaturation and the impurities. It is advisable to treat feed grade fish oils with an antioxidant.

29.3 Chemical, Physiological and other Properties

Chemical Properties

The major characteristic of fish oils is the high level of unsaturated fatty acids. Its composition of a single fish species varies widely (Table 29.01) which can be caused by factors such as the catching season, fishing ground, geographical location and processing. In cultured fish the fatty acid composition of the feed may be reflected in the fish oil⁽⁹⁾.

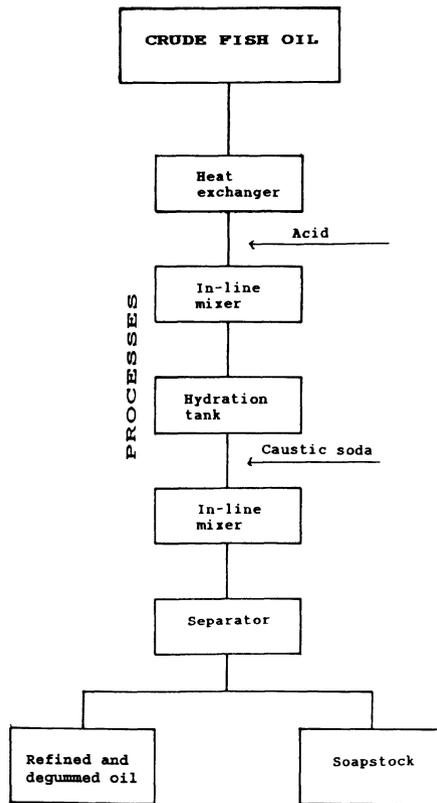


Figure 29-01. Flow diagram of the degumming and refining process of fish oil.

Table 29-01: Variation of the fatty acid composition of selected fish species (% of total oil content)⁽¹⁶⁾

Fatty acid's systematic name		Menhaden oil	American herring oil	Mullet oil
Tetradecanoic	14:0	7.2 - 12.1	4.6 - 8.4	4.6 - 11.5
Hexadecanoic	16:0	15.3 - 25.6	10.1 - 18.6	20.2 - 33.7
Hexadecenoic	16:1	9.3 - 15.8	6.2 - 12.0	13.4 - 29.3
Octadecenoic	18:1	8.3 - 13.8	9.7 - 25.2	7.1 - 13.6
Octadecadienoic	18:2	0.7 - 2.8	0.1 - 0.6	0.7 - 2.7
Octadecatrienoic	18:3	0.8 - 2.3	0 - 1.1	0.3 - 1.3
Eicosenoic	20:1	-	7.3 - 19.9	-
Eicosapentaenoic	20:5	11.1 - 16.3	3.9 - 15.2	4.6 - 8.1
Docosenoic	22:1	0.1 - 1.4	6.9 - 30.6	-
Docosahexaenoic	22:6	4.6 - 13.8	2.0 - 7.8	0.7 - 3.9

Polyunsaturated fatty acids (PUFA) in fish oils are of particular interest. According to their chemical structure they are classified as:

- n-3 fatty acids;
- n-6 fatty acids;
- n-9 fatty acids.

These are the so called “omega fatty acids”. The number expresses the position of the C-atom with the first double-bond, counting from the methyl-end, e.g. n-3 indicates that the third C-atom has the first double-bond.

Fish species rich in oil are especially abundant in n-3 fatty acids. The n-3 fatty acid content of fish oils usually exceeds the n-6 fatty acids. The linolenic acid (octadecatrienoic acid - C18:3) content of fish oil is relatively low but the content of eicosapentaenoic acid (C22:5) and docosahexaenoic acid (C22:6) is high (Table 29-02)⁽¹³⁾.

Table 29-02: n-3 fatty acid content of selected fishes (% of total fatty acids)⁽¹³⁾

Fish species		LNA ¹	EPA ²	DHA ³
English name	Scientific name			
Atlantic salmon ⁴	<i>Salmo salar</i>	0.1	0.6	1.2
Chinook salmon	<i>Oncorhynchus tscha wyttscha-</i>	0.1	0.8	0.6
Coho salmon ⁴	<i>Oncorhynchus kisutch</i>	0.1	0.4	0.8
Chum salmon	<i>Oncorhynchus keta</i>	0.1	0.4	0.6
Chub mackerel	<i>Scomber japonicus</i>	0.3	0.9	1.0
Atlantic mackerel	<i>Scomber scombrus</i>	0.1	0.9	1.6
Atlantic herring	<i>Clupea harengus harengus</i>	0.1	0.7	0.9
Atlantic sturgeon	<i>Acipenser oxyrhynchus</i> traces	1.0	0.5	
Capelin	<i>Mallotus villosus</i>	0.1	0.6	0.5

¹ Alpha-linolenic acid; ² Eicosapentaenoic acid; ³ Docosahexaenoic acid; ⁴ Farmed salmon

The vitamin content of fish liver oil is affected by the catching season, the fishing ground and other biological factors (Table 29-03)⁽²⁴⁾. The carotenoid astaxanthin is present, if the oil is red in colour⁽⁴⁾. Magnesium (5.0 mg/kg) and sodium (1.0 mg/kg) were found in cod liver oil⁽¹²⁾.

Fish oil processors differentiate between “Standard fish oil”, “Feed grade fish oil” and “Crude fish oil”. Guidelines for estimating the quality of commercial crude fish oil are compiled in Table 29-04.

Table 29-03: Mean Vitamin A and D content of selected fish liver oils⁽²⁴⁾

Oil from ...		Vitamin A mg/kg	Vitamin D mg/kg
Cod	<i>Gadus morhua</i>	300	2.5
Pollack	<i>Pollachius virens</i>	600	3.7
Halibut	<i>Hippoglossus hippoglossus</i>	15,000	37.5
Dogfish	<i>Squalidae</i>	450	0.9
Tuna	<i>Thunnidae</i>	3,000	750.0
Salmon	<i>Salmo salar/Oncorhynchus</i> spp.	3,000	25.0
Mackerel	<i>Scomber</i> spp.	3,000	20.0
Herring	<i>Clupea harengus</i>	3,000	-

Table 29-04: Guideline specifications of crude fish oil⁽³²⁾

Free fatty acids	%	2.0 - 5.0
Moisture and impurities	%	0.5 - 1.0
Peroxide value	Meq/kg	3.0 - 20.0
Anisidine	no.	4.0 - 60.0
Iodine value of oil from:		
- Capelin		95.0 - 160.0
- Herring		115.0 - 160.0
- Menhaden		150.0 - 200.0
- Sardine		160.0 - 200.0
- Anchovy		180.0 - 200.0
Colour (Gardner scale)		12.0 - 14.0
Iron	ppm	0.5 - 7.0
Copper	ppm	max. 0.3
Phosphorus	ppm	5.0 - 100.0
Sulphur	ppm	max. 30.0

Physiological Properties

Fish oil is an energy feedstuff. The gross energy content of cod liver oil is 9,395 kcal/kg (39.3 MJ/kg). The metabolisable energy of cod liver oil for dogs is 9,105 kcal/kg (38.1 MJ/kg)⁽¹²⁾ and the digestible energy of menhaden oil for the Florida pompano (*Trachinotus carolinus*) is 6,100 kcal/kg (25.5 MJ/kg)⁽²⁸⁾.

By increasing water temperature the digestibility of fish oil increases (Table 29-05). The influence of the water temperature is more pronounced in young fish than in older ones⁽¹⁷⁾. Likewise, digestibility is affected by the melting point of the fish oil. The higher the melting point of the oil, the lower the digestibility (Figure 29-02)⁽²²⁾.

Table 29-05: Apparent digestibility of fish oil by rainbow trout
(*Salmo gairdneri*) in relation to water temperature⁽⁷⁾

Water temperature °C	Digestibility %
9	89.8
12	88.2
15	89.4
18	92.6
Mean	90.0

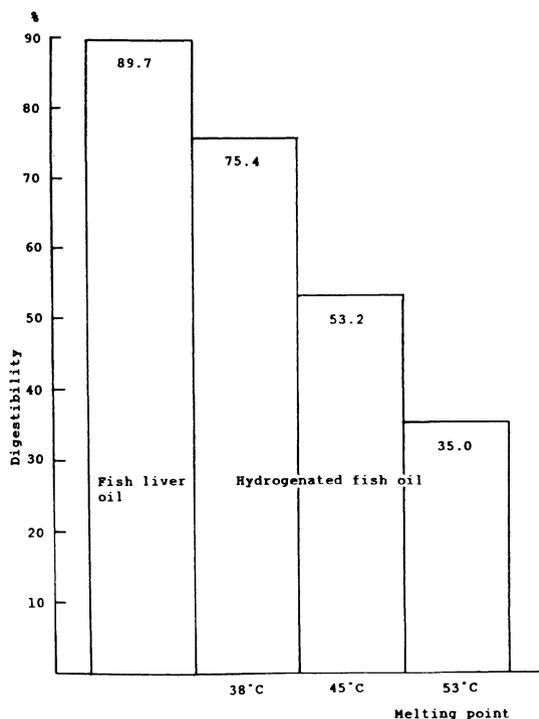


Figure 29-02. The relation between melting point of hydrogenated fish oil and its digestibility by the carp (*Cyprinus carpio*)^(data from: 22).

The apparent digestibility of fatty acids of fish oil depends on their chain-length. With increasing chain-length the digestibility of saturated fatty acids declines. Unsaturated fatty acids are better digested than saturated fatty acids. The melting point also affects the digestibility of the fatty acids⁽³⁾.

Other Properties

The high content of omega-3 fatty acids, particularly eicosapentaenoic acid (20:5n-3) and docosahexaenoic acid (22:6n-3) is of benefit to human nutrition. Consumption of fish or fish lipids reduces the incidences of cardiovascular and other diseases in man^(9, 13). Furthermore, omega-fatty acids also have a positive effect on the immunocompetence of man and animals⁽¹⁰⁾.

29.4 Feeding Value

Effect on Growth

Fish diets, particularly for salmonids have to be supplemented with essential fatty acids⁽²⁹⁾. Rainbow trouts (*Salmo gairdneri*) showed inferior growth on diets deficient in n-3 fatty acids. High levels of n-6 fatty acids could not compensate for the deficient n-3 fatty acids. Rapid fish growth was supported only by diets high in n-3 fatty acids⁽³³⁾.

In carp (*Cyprinus carpio*) fish oil failed to improve the growth rate of a diet with a poor protein quality. Compared to other fat sources fish oil showed no advantages over soybean oil (Table 29-06). Fish oil contributed energy to the same extent as other oils but did not reveal any additional benefit⁽²⁶⁾.

Table 29-06: Response of different oils on growth and carcass composition of carp (*Cyprinus carpio*)⁽²⁶⁾

Fish oil	%	- ¹	5.0	-	-	-
Poultry fat	%	-	-	5.0	-	-
Cottonseed oil	%	-	-	-	5.0	-
Soybean oil	%	-	-	-	-	5.0
<i>Fatty acids:</i>						
- Total saturated	%	-	19.0	27.0	26.0	28.0
- n-3 and n-6	%	-	11.0	2.0	1.0	4.0

Initial weight	g	310	310	310	310	310
Weight gain	g	5.7	89.3	78.0	59.2	86.7
	%	100	148	131	99	144
Daily gain	g	1.3	2.0	1.8	1.3	2.0

<i>Carcass composition by fatty acids:</i>						
- Total saturated	%	25.0	23.0	26.0	25.0	27.0
- n-3 and n-6	%	1.0	4.0	1.0	2.0	2.0

¹ Negative control

In channel catfish (*Ictalurus punctatus*) menhaden oil is superior to maize oil, although at levels of more than 15% fish oil showed a growth depressing effect⁽⁶⁾. Blue tilapia

(*Tilapia aurea*) had the best growth and feed conversion when menhaden oil was fed at a level of 10%⁽¹⁸⁾.

In red sea bream (*Chrysophrys major*) best performances were obtained with a diet containing 10% cod liver oil⁽³⁰⁾. Pollack residual oil when compared to maize oil supplemented with PUFA in diets for red sea bream gave the highest growth rate and feed efficiency although it contained only traces of linolenic acid (18:3n-3). This indicates that linolenic acid perhaps is not as important for red sea bream as it is for rainbow trout⁽²⁹⁾. However, for proper fatty acid metabolism n-3 fatty acids are essential as demonstrated in red sea bream and yellowtail (*Seriola quinqueradiata*). Fish fed beef tallow fortified with a n-3 HUFA preparation performed better than those fed pollack liver oil (Table 29-07)^(20, 21).

Table 29-07: The effect of pollack liver oil and beef tallow and n-3 HUFA on the development of red sea bream (*Pagrus major*)⁽²¹⁾

Pollack liver oil	%	10.0	9.0	10.0	-
Beef tallow	%	-	-	-	2.6
n-3 HUFA preparation	%	-	-	-	2.4
Crude protein	%	38.3	46.9	53.0	53.4
Crude lipids	%	16.1	15.3	15.9	10.7
n-3 HUFA	%	3.0	3.1	3.1	3.2

Final body weight	g	5.08	5.59	6.78	5.80
Growth rate	%	218	249	324	463
Feed conversion ¹	%	54.9	58.8	77.5	66.0
PER		1.4	1.3	1.2	

¹ $\frac{\text{g weight gain}}{\text{g feed}}$

An adverse effect on recorded parameters were observed when the diet for the Florida pompano (*Trachinotus carolinus*) contained more than 8.0% menhaden oil⁽²⁸⁾. The hybrid striped bass (*Morone chrysops x Morone saxatilis*) fed a diet containing up to 12% menhaden oil did not show any negative response in growth, liver histology and survival⁽⁹⁾.

The Japanese eel (*Anguilla japonica*) developed best on a diet containing 12% of a mixture of cod liver oil and maize oil at a ratio of 1:2⁽²⁾ and the European eel (*Anguilla anguilla*) grew most rapidly when 5.0% redfish (*Sebastes marinus*) oil was added to the diet compared to additions of vegetable oil⁽¹⁵⁾.

Effect on Carcass Quality

The n-3 fatty acid concentration in chicken muscle and chicken egg yolk can be significantly increased when hens are fed diets enriched with selected fish oils such as menhaden oil^(11, 14, 25).

The positive effect of dietary n-3 fatty acids on the fatty acid composition has been demonstrated in rainbow trout⁽¹⁹⁾ and carp. Fish carcasses had a higher content of n-3 and n-6 fatty acids when fed with fish oil than the fish carcasses fed with other lipid sources (Table 29-07)⁽²⁶⁾.

The significant increase in the deposition of n-3 fatty acids in fish muscle is related to the dietary menhaden oil concentration in the hybrid striped bass⁽⁹⁾.

29.5 Recommended Inclusion Rates

Fish oils and particularly n-3 fatty acids are effective in supporting performances of aquatic animals. Inclusion rates vary widely and there are indications of inferior performances of fish when fed diets containing fish oil. An excess supply of omega fatty acids, a too narrow ratio of n-3:n-6 fatty acids and the fish species are reasons for negative responses to the feeding of fish oil.

High levels of dietary fish oil are disadvantageous for the production of feed pellets of good quality. However, modern processing methods such as extrusion and expansion allow fat levels as high as 20%.

Considering all aspects, the recommended inclusion rate for fish oil in aquaculture feed is in the range of 3.0 to 6.0%.

29.6 Legal Aspects

Legal limits for the use of marine oils in diets for aquatic animals do not exist. *AAFCO*⁽¹⁾ has defined fish oil (No. 51.8) as the oil from rendering whole fish or canning waste. The EU-Directive accordingly only says that fish oil (No. 10.03) is oil obtained from fish. The German feedstuff decree restrict the use of marine oils for fish feed. It is the oil obtained from fish or seals and the moisture content should not exceed 0.1%⁽²⁷⁾.

29.7 References

1. *AAFCO* (1995): Official publication 1995. Ass. of American Feed Control Officials (publisher), Sacramento, CA/USA.
2. *Arai, S.; Nose, T.; Hashimoto, Y.* (1971): A purified test diet for the eel *Anguilla japonica*. Bull. Freshwa. Fish. Res. Lab., 21., 161-178.
3. *Austreng, E.; Skrede, A.; Eldegard, Å.* (1980): Digestibility of fat and fatty acids in rainbow trout and mink. Aquaculture, 19., 93-95.
4. *Bimbo, A.P.* (1990): Processing of fish oils. In: *Stansby, M.E.* (ed.): Fish oils in nutrition. Van Nostrand Reinhold, New York.
5. *Bimbo, A.P.* (1990): Production of fish oils. In: *Stansby, M.E.* (ed.): Fish oils in nutrition. Van Nostrand Reinhold, New York.
6. *Chang S.S.* (1967): Processing of fish oils. In: *Stansby, M.E.* (ed.): Fish oils, AVI Publishing Co., Westport, Conn./USA.

7. *Cho, C.Y.; Slinger, S.J.* (1979): Apparent digestibility measurement in feedstuffs for rainbow trout. Proc. World Symp. on Finfish Nutr. and Fishfeed Techn., Hamburg/Germany, Vol. II, 20-23 June, 1978.
8. *Dupree, H.K.; Gaulitz, E.J.; Hall, A.S.; Houle, C.R.* (1979): Effects of dietary lipids on the growth and acceptability (flavor) of channel catfish (*Ictalurus punctatus*). Proc. World Symp. on Finfish Nutr. and Fishfeed Techn., Hamburg/Germany, Vol. II, 20-23 June, 1978.
9. *Fair, P.H.; Williams, W.P.; Smith, T.I.J.* (1993): Effect of dietary menhaden oil on growth and muscle fatty acid composition of hybrid striped bass, *Morone chrysops* x *M. saxatilis*. *Aquaculture*, 106., 171-189.
10. *Klasing, K.C.* (1992): Nutrition and immunity. *Large Animal Veterinarian*, July/August, 16-17.
11. *Leeson, S.* (1993): Potential of modifying poultry products. *J. Appl. Poultry Res.*, 2., 380-384.
12. *Meyer, H.; Heckötter, Elke* (1986): Futterwertabelle für Hunde und Katzen. Schlütersche Verlagsanstalt, Hannover/Germany.
13. *Nettleton, J.A.* (1995): Omega-3 fatty acids and health. Chapman and Hall, New York/USA.
14. *Ratnayake, W.N.; Ackman, R.G.; Hulan, H.W.* (1989): Effect on redfish meal enriched diets on the taste and n-3 PUFA of 42-days old broiler chickens. *J. Sci. Food Agr.*, 49., 59-74.
15. *Schilling, H.U.; Greuel, E.; Hartfiel, W.* (1982): Einsatz von pflanzlichen ölen in der Produktion von Speisefischen. *Kraftfutter*, 65., 106-110.
16. *Stansby, M.E.; Schlenk, H.; Gruber, E.H.* (1990): Fatty acid composition of fish. In: *Stansby, M.E.* (ed.): Fish oils in Nutrition. Van Nostrand Reinhold, New York
17. *Steffens, W.* (1985): Grundlagen der Fischernährung. VEB Gustav Fischer Verlag, Jena/Germany.
18. *Stickney, R.P.; Wurts, W.A.* (1986): Growth response of blue tilapia to selected levels of dietary menhaden and catfish oils. *Progr. Fish Culturist*, 48., (2), 107-109.
19. *Takeuchi, T.; Watanabe, T.* (1982): Effects of various polyunsaturated fatty acids on growth of rainbow trout. *Bull. Jap. Soc. Sci. Fisheries*, 48., 1517-1519.
20. *Takeuchi, T.; Shiina, Y.; Watanabe, T.* (1992): Suitable levels of n-3 unsaturated fatty acids in diet for fingerlings of red sea bream. *Nippon, Suisan Gakkashi*, 57., (2), 293-299.
21. *Takeuchi, T.; Shiina, Y.; Watanabe, T.* (1991): Suitable protein and lipid levels in diet for fingerlings of red sea bream (*Pagrus major*). *Nippon, Suisan Gakkashi*, 58., (3), 509-514.
22. *Takeuchi, T.; Watanabe, T.; Ogino, C.* (1979): Digestibility of hydrogenated fish oils in carp and rainbow trout. *Bull. Jap. Soc. Sci. Fisheries*, 45., 1521-1525.
23. *Takeushi, T.; Shiina, Y.; Watanabe, T.; Sekiya, S.; Imaizumi, K.* (1992): Suitable protein and lipid levels in diet for fingerling of yellowtail. *Nippon Suisan Gakkaishi*, 58., (7), 1341-1346.
24. *Täufel, A.; Ternes, W.; Tunger, L.; Zobel, M.* (1993): Lebensmittel-Lexikon. Behr's Verlag, Hamburg/Germany.
25. *Van Elswyk, M.E.; Hargis, B.M.; Williams, J.D.; Hargis, P.S.* (1994): Dietary menhaden oil contributes to hepatic lipidosis in laying hens. *Poultry Sci.*, 73., 653-662.
26. *Viola, S.; Rappaport, U.* (1979): Acidulated soapstocks in intensive carp diets - their effect on growth and body composition. Proc. World Symp. on Finfish Nutr. and Fishfeed Techn., Hamburg/Germany, Vol. II, 20-23 June, 1978.
27. *Weinreich, O.; Koch, V.; Knippel, J.* (1994): Futtermittelrechtliche Vorschriften. Buchedition Agrimedia, Hamburg/Germany.
28. *Williams, S.; Lovell, R.T.; Hawke, J.P.* (1985): Value of menhaden oil in diets of Florida pompano. *Prog. Fish Culturist*, 47., (3), 159-165.
29. *Yone, Y.; Fujii, M.* (1975): Studies on nutrition of red sea bream. XI. Effect of omega-3 Fatty acid supplement in a corn oil diet on growth and feed efficiency. *Bull. Jap. Soc. Sci. Fish.*, 41., (1), 73-77.
30. *Yone, Y.; Furuichi, M.; Sakamoto, S.* (1971). Studies on nutrition of red sea bream. III Nutritive value and optimum content of lipids in diet. *Rep. Fisheries Res. Lab. Kyushu Univ.*, 1., 49-60.

31. Young, F.V.K. (1978): Processing of oils and fats. Chem. Industry, 16.9., 692-703.
32. Young, F.V.K. (1985): The refining and hydrogenating of fish oils. Fish Oil Bull. 17 (Intern. Ass Fish Meal Manufacturers).
33. Yu, T.C.; Sinnhuber, R.O. (1976): Growth response of rainbow trout (*Salmo gairdneri*) to dietary n-3 and n-6 fatty acids. Aquaculture, 8., 309-317.

30. MEAT BY-PRODUCT MEALS

30.1 Rationale

Meat by-products are offal of abattoirs, such as material confiscated and not fit for human consumption, scrap from the meat processing and canning industry, and livestock casualties processed by the rendering industry. For the control of diseases and epidemics collection of these materials is a must. In addition, they can be converted into valuable feedstuffs and by doing so will contribute to a better environment.

The utilisation of meat by-products is of economic significance. In 1993 in Germany alone 2.28 million MT of raw materials were collected, of which 0.31 million MT came from dead animals. From these by-products more than 900,000 MT animal feedstuffs were obtained⁽¹⁹⁾.

In principle meat by-products are classified into:

- Meat meal
- Meat and bone meal.

However, the international definition is not uniform. Tankage meal is a product which is processed from dead farm animals, but meat and bone meal is also described as a product derived from whole carcasses of livestock casualties less hoofs and skin⁽¹²⁾. The EU-Directive 92/87/EEC uses the terms meat meal and meat and bone meal and emphasizes that the major differences between both products is that meat and bone meal does not contain carcasses of dead animals and that the phosphorus content is substantially higher than that of meat meal⁽¹⁹⁾.

30.2 Manufacture and Processing

A wide range of different processes are used by rendering plants for the manufacture of meat by-product meals. Both batch rendering and continuous rendering are practised⁽¹⁰⁾. However, all of them are based more or less on the same principle as depicted in Figure 30-01^(19, 29).

If there is risk for spreading of epidemic diseases the health authorities (in Germany) may ban processing and usage of the dead animal⁽²⁹⁾

In general, processing of meat by-products requires a very highly hygienic standard in order to produce products which are minimally or not contaminated with bacteria (high bacteriological quality). The requirements for the hygienic standards are given in EU-Directive 90/667/EEC which includes⁽²²⁾:

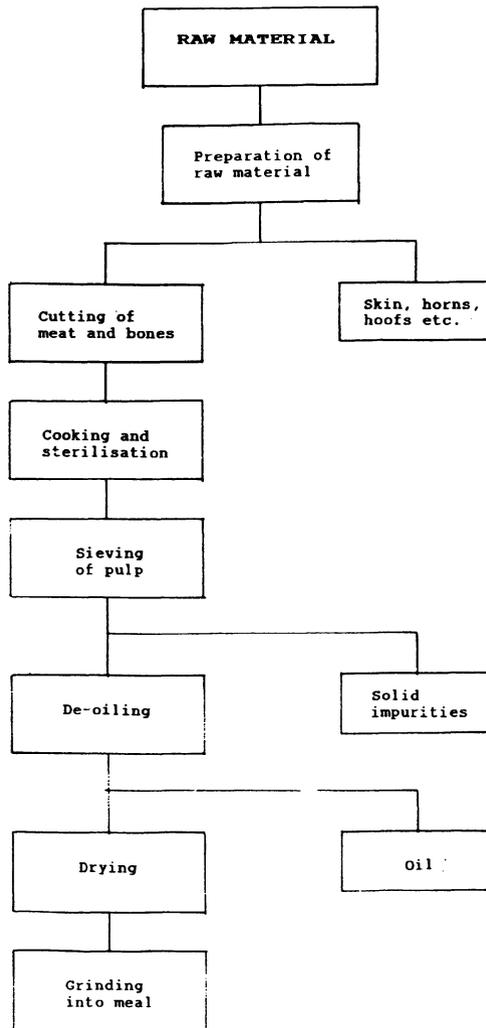


Figure 30-01. Processing diagram of meat by-product meals.

- Cleaning and disinfection: Regular cleaning and disinfection of the whole processing plant as well as the transportation fleet, and including hygienic measures for the entire staff (washing hands, disinfecting hands, wearing overalls);
- Re-contamination: Control of re-contamination by suitable treatment;
- Condensation moisture: Avoiding formation of condensation moisture which can spoil the product;
- Vermis: Control vermins (birds, mice, rats, insects) which are the cause of re-contamination.

30.3 Chemical, Physiological and other Properties

Chemical Properties

Meat meal and meat and bone meal are animal protein feedstuffs. Their chemical composition has an extreme variation (Table 30-01) which depends on the quality of the available raw materials (Table 30-02). The chemical composition of meat and bone meal within a rendering plant is rather consistent while the differences between rendering plants are more significant as indicated by the standard deviation (SD) of a respective study (Table 30-03)⁽¹⁶⁾. High portions of bones and/or fat in the raw material result in a high ash and/or fat content which reduces the protein level of the product (Table 30-04).

Table 30-01: Lowest and highest nutrient content (%) of meat by-product meals⁽²⁶⁾

	Meat meal	Meat and bone meal
No. of analysis	181	93
Crude protein	42.2 - 76.3	41.5 - 71.4
Crude fat	1.0 - 21.2	3.3 - 16.1
Crude ash	4.8 - 37.6	8.9 - 52.9

Table 30-02: Chemical composition (%) of meat by-product meals (as fed)^(4, 9, 12, 16, 17, 18, 20, 21, 24, 25,29)

	Meat meal		Meat and bone meal	
	Mean	Variation	Mean	Variation
Dry matter	94.1	92.9 - 95.0	93.3	90.2 - 95.0
Crude protein	56.9	49.5 - 64.5	50.4	45.5 - 62.4
Crude fat	5.6	1.5 - 8.1	9.8	8.3 - 12.8
Ash	21.6	15.3 - 32.0	31.3	21.8 - 37.2
Crude fibre	2.4	2.3 - 2.5	2.6	2.1 - 3.4
N-free extract	17.7		2.5	0.1 - 5.0

Table 30-03: Quality consistency of meat and bone meal within and between rendering plants in Denmark (Parameter: Standard Deviation [SD])⁽¹⁶⁾

	Within plants SD	Between plants SD
Dry matter	10.8	73.1
Protein	24.4	75.4
Ash	23.0	126.3

Table 30-04: Crude protein and crude fat content (%) of meat meal of different rendering plants (as fed)⁽²²⁾

Rendering plant	Crude protein	Crude fat
A	60.6	12.0
B	57.5	13.1
C	55.8	11.0
D	50.8	15.0
E	49.9	15.2
F	46.7	17.3

Due to the inconsistency of the chemical composition of meat meal and meat and bone meal the mean values are not very accurate, therefore, it is advisable to analyse each consignment⁽¹²⁾.

The essential amino acids of meat by-product meals have limitations. Isoleucine and methionine+cystine are particularly limiting amino acids when compared to the amino acid profile of whole egg protein⁽¹⁸⁾. In addition the amino acid profile of meat and bone meal varies from that of meat meal because the protein properties of bones and meat differ from each other as reflected in the amino acid profile (Table 30-05)⁽²⁹⁾.

Table 30-05: Essential amino acid profile of meat by-product meals (g/16 g N)^(12, 16, 17, 20, 21, 29)

	Meat meal		Meat and bone meal	
	Mean	Variation	Mean	Variation
Arginine	4.40	3.58 - 3.70	3.38	3.00 - 3.65
Histidine	1.50	0.96 - 1.80	1.03	0.96 - 1.10
Isoleucine	2.06	1.54 - 2.90	1.42	1.20 - 1.64
Leucine	4.24	3.19 - 6.10	2.86	2.65 - 3.06
Lysine	3.58	2.57 - 5.70	3.75	2.20 - 5.20
Methionine	0.88	0.66 - 1.40	1.01	0.50 - 1.40
Phenylalanine	2.37	1.81 - 3.20	1.63	1.55 - 1.70
Threonine	2.17	1.60 - 3.30	2.50	1.30 - 3.40
Tryptophan	0.52	0.34 - 0.80	0.24	0.20 - 0.30
Valine	3.08	2.52 - 4.20	2.18	1.90 - 2.45

The mineral content of meat by-product meals vary widely and is particularly pronounced in meat and bone meal (Table 30-06). With increasing ash content the macro mineral content also increases, while the trace mineral content diminishes since they are predominantly deposited in the meat (Table 30-07). The vitamin content of meat meal and meat and bone meal is rather low (Table 30-08).

Physiological Properties

Information on the physiological properties of meat by-product meals in aquatic animals are limited. Although the gross energy of meat meal is much higher than of meat and bone meal, the metabolisable and digestible values are not much different (Table 30-09).

Table 30-06: Macro and trace mineral contents of meat meal and meat and bone meal ^(4, 12, 16, 17, 20, 21)

		Meat meal		Meat and bone meal		
		Mean	Variation	Mean	Variation	
Calcium	%	6.49	3.80 - 8.85	11.03	15.20 -	8.10
Phosphorus	%	3.55	2.20 - 4.44	5.48	3.40 -	7.30
Sodium	%	0.91	0.52 - 1.29	1.18	0.72 -	1.40
Potassium	%	0.61	0.57 - 0.65	0.56	0.28 -	1.33
Magnesium	%	0.24	0.20 - 0.27	0.36	0.19 -	1.02
Chlorine	%	1.19		0.74		
Sulphur	%	0.47		0.25		
Manganese	mg/kg	12.7	9.0 - 19.0	17.8	9.0 -	23.0
Iron	mg/kg	505	440 - 580	687	433 -	873
Zinc	mg/kg	79	78 - 80	108	89 -	118
Copper	mg/kg	10.5	10.0 - 11.0	12.9	8.3 -	20.0
Selenium	mg/kg	0.44		0.29	0.20 -	0.40
Iodine	mcg/kg	850		50		

Table 30-07: With increasing ash content of meat and bone meal the content of macro minerals increases and level of micro minerals declines⁽¹⁶⁾

Ash	%	23.3	27.7	32.2	37.2	42.9
Protein	%	62.3	57.3	53.8	49.4	47.3

Calcium	%	6.3	8.1	10.2	12.3	14.8
Phosphorus	%	3.4	4.2	5.0	6.0	7.3
Magnesium	%	0.19	0.22	0.25	0.27	0.30

Iron	mg/kg	842	873	781	597	433
Copper	mg/kg	15.1	12.1	10.0	8.7	8.3
Manganese	mg/kg	21	23	19	16	11

Table 30-08: The vitamins of meat meal and meat and bone meal
(1,000 g)^(12, 17, 25, 29)

		Mean	Variation
Vitamin B ₁	mg	0.2	
Vitamin B ₂	mg	4.5	2.2 - 15.5
Vitamin B ₆	mg	1.2	1.0 - 1.4
Vitamin B ₁₂	mcg	64	20 - 135
Biotin	mcg	168	35 - 300
Nicotinic acid	mg	49	28.2 - 82.9
Folic acid	mg	43.5	
Pantothenic acid	mg	12.9	2.0 - 45.0
Choline	mg	1,690	1,320 - 2,000

Table 30-09: Energy values of meat by-product meals per kg

Species	Gross energy		Metabolisable energy		Digestible energy		Reference
	kcal	MJ	kcal	MJ	kcal	MJ	
1. Meat meal							
	4,353	18.2	-	-	-	-	(17,25)
Rainbow trout	-	-	2,837	11.9	3,219	13.5	(18)
Fishes ¹	-	-	-	-	3,173	13.3	(18)

Mean all fishes	-	-	2,837	11.9	3,196	13.4	
2. Meat and bone meal							
	3,657	15.3	-	-	-	-	(17)
Rainbow trout	-	-	2,949	12.3	3,607	15.1	(4,20,23)
Channel catfish	-	-	-	-	3,470	14.5	(20)
Tilapia	-	-	-	-	2,940	12.3	(20)
Fishes ¹	-	-	-	-	3,000	12.6	(18)

Mean all fishes	-	-	2,949	12.3	3,225	13.5	

¹ Species not specified

The apparent protein digestibility of meat and bone meal is lower than of meat meal (Table 30-10). The pepsin digestibility of meat and bone meal is 89.0% and is at an average four units higher than the *in-vivo* digestibility, as found in pigs⁽²⁹⁾. Tiger prawns (*Penaeus monodon*) can possibly digest plant protein better than meat and bone meal because in digestibility tests meat and bone meal showed a lower digestibility rate than plant protein⁽³⁾.

Table 30-10: Apparent digestibility (%) of meat by-product meals

	Dry matter	Crude protein	Crude fat	Energy	Reference
1. Meat meal					
Rainbow trout	78.0	85.0	73.0	85.0	(4)
Pigs	-	88.0	97.0	-	(29)
Poultry	-	61.0	94.0	-	(20)
2. Meat and bone meal					
Salmonids	-	71.2	83.6	72.2	(15,23)
Channel catfish	-	75.0	77.0	80.5	(15)

Mean all fishes	-	72.4	80.3	74.9	
Tiger prawn	47.4	73.6	-	-	(3)
Pigs	-	85.0	-	-	(29)
Poultry	-	78.0	100.0	-	(29)
Pepsin digestibility	-	89.0	-	-	(29)

Other Properties

The pelletising ability of meat meal and meat and bone meal is in the medium range. Parameters used for testing are pellet quality, press capacity, abrasiveness⁽¹³⁾.

30.4 Feeding Value

Fishes

Meat and bone meal is effective as partial component of diets for rainbow trouts (*Salmo gairdneri*). Further improvements were observed when meat and bone meal containing diets for rainbow trouts were supplemented with cystine (10.0 g/kg) and tryptophan (5.0 g/kg)⁽⁶⁾. However, growth response of isonitrogenous diets of meat meal and meat and blood meal, respectively, were not as good as diets with fish meal and/or poultry by-product meal (Table 30-11). The poor results may be due to differences in the biological values of the protein sources⁽¹⁴⁾.

In diets for Nile tilapia (*Oreochromis niloticus*) fry and fingerlings, meat and bone meal could replace 25% of the fish meal without negative effect on performances⁽²⁷⁾. The partial replacement of fish meal by meat and bone meal in practical formulations for juvenile tilapia (*Oreochromis mossambicus*) were equivalent to a full fish meal diet. But replacing all fish meal by meat and bone meal gave poor results (Table 30-12)⁽⁸⁾.

In diets for milkfish (*Chanos chanos*) fry, meat and bone meal protein can successfully substitute up to 8.0% of the shrimp head meal protein⁽²⁾. But in the sea bream (*Sparus aurata*), fingerlings performed well when meat and bone meal replaced up to 40% of the fish meal in practical formulations⁽⁷⁾.

Table 30-11: Replacement of fish meal by meat meal in diets for rainbow trout (*Salmo gairdneri*)⁽¹⁴⁾

		Trial 1		Trial 2		
Protein from:						
- Meat meal	%	-	25.0	-	-	-
- Meat/blood meal	%	-	-	-	75.0	25.0
- Fish meal	%	25.0	-	100.0	25.0	25.0
- Poultry by-product meal	%	75.0	75.0	-	-	50.0

Weight gain	g	189	157	133	108	130
	%	100.0	83.0	100.0	81.0	91.0
Feed conversion	1:	1.36	1.64	1.33	1.59	1.34
	%	100.0	121.0	100.0	120.0	101.0

Table 30-12: Meat and bone meal replaces partially or completely fish meal in diets for tilapia (*Oreochromis mossambicus*) (trial period: 48 days)⁽⁶⁾

Fish meal	%	47.2	21.8	-
Meat and bone meal	%	-	10.0	42.0
Soybean protein concentrate	%	-	15.0	15.0
Crude protein	%	38.8	35.9	35.2
Ash	%	14.2	13.2	17.6

Weight gain	%	314.0	301.8	290.4
Weight gain	mg/day	73.9	76.0	58.4
Specific growth rate	%	2.90	2.84	2.78
PER		1.11	1.14	1.09
Feed conversion	1:	2.29	2.24	2.49

Molluscs

The use of meat and bone meal in formulated diets for abalone (*Haliotis* spp.) is recommended because it provides not only protein but also some fats and carbohydrates⁽¹¹⁾.

30.5 Recommended Inclusion Rates

In feeding experiments the useful range of meat by-product meals is very wide⁽²⁶⁾. However, for field conditions the limiting factor for its application is the high ash content. Recommended inclusion rates for aquaculture feeds, therefore, are:

- Meat meal: 15.0 to 20.0%
- Meat and bone meal: 10.0 to 15.0%

30.6 Legal Aspects

Meat by-product feedstuffs in the U.S.A. are:

- Meat meal (AAFCO No. 9.40)
- Meat and bone meal (No. 9.41)
- Meat meal tankage (No. 9.56)
- Meat and bone meal tankage (No. 9.51)

Quality requirements have to be met for minimum crude protein, pepsin digestibility of protein, minimum crude fat, maximum crude fibre, minimum phosphorus and minimum and maximum calcium. They have to be guaranteed and included in the label⁽¹⁾.

The EU-Directive 92/87/EEC contains only two products: Meat meal (No. 9.01) and meat and bone meal (No. 9.02). Products which contain more than 13.0% fat in the dry matter have to be declared as “high in fat”. The nutritional requirements, according to German feedstuff legislation are given in Table 30-13⁽²⁸⁾.

Table 30-13: Quality requirements (%) for meat by-product meals by the German feedstuff legislation⁽²⁸⁾

		Meat and bone meal	Meat meal	Feed meat meal
Moisture	max.	10.0	10.0	10.0
Crude protein	min.	40.0	55.0	75.0
Pepsin digestibility of crude protein	min.	85.0	85.0	-
Crude fat	max.	14.0	11.0	-
Chloride ¹	max.	2.0	2.0	-
Phosphorus	max.	9.0	5.0	-
Ash ²	max.	-	2.2	-

¹ Computed as NaCl; ² Insoluble in hydrochloric acid

In addition, EU-Directive 90/667/EEC refers to the bacteriological quality of meat by-product meals and differentiates between animal feedstuffs processed from dangerous or non-dangerous raw materials. It is required that a sample of 25 g is absolutely free of salmonella, that not more than 300 entero-bacteria per g of sample can be found, and that it is free of *Clostridium perfringens* (the latter only required for dangerous material)⁽²²⁾.

30.7 References

1. *AAFCO* (1995): Official publication 1995. Ass. of American Feed Control Officials (publisher), Sacramento, CA / USA.
2. *Alava V.R.; Lim, C.* (1988): Artificial diets for milkfish, *Chanos chanos* (Forsskal), fry reared in seawater. *Aquaculture*, 71., 339-346.
3. *Catucatan, M.R.* (1995): Apparent protein digestibility of feedstuffs in *Penaeus monodon* Fabricius. Paper presented at 4th Asian Fish. Forum, Beijing/P.R. China, October.
4. *Cho, C.Y.; Cowey, C.; Watanabe, T.* (1985): Finfish nutrition in Asia: Methodological approaches to research and development. IDRC, Ottawa/Canada, 233e.
5. *Coehl, J.F.S.* (1984): Rainbow trout nutrition: Value of meat and bone meal. *Rev. Prot. Cienc. Vet.*, 79., (472), 269-280.
6. *Dabrowska, H.; Wojno, K.* (1977): Studies on the utilization by rainbow trout of feed mixtures containing soya bean meal and an addition of amino acids. *Aquaculture*, 10., 297-310.
7. *Davis, S.J.; Nengas, I.; Alexis, M.* (1991): Partial substitution of fish meal products in diets for sea bream (*Sparus aurata*). *Proc. Fish Nutrition in Practice, Biarritz/France*, 25-27 June.
8. *Davies, S.J.; Williamson, J.; Robinson, M.; Bateson, R.I.* (1989): Practical inclusion levels of common animal by-products in complete diets for tilapia *Oreochromis mossambicus*, Peters). *Proc. 3rd Int. Symp. on Feeding and Nutrition in Fish, Toba/Japan*, 28.8-1.9, 325-332.
9. *De Boer, F.; Bickel, H.* (1988): Livestock feed resources and feed evaluation in Europe. Elsevier Sciences Publishers, Amsterdam / The Netherlands.
10. *Evans, M.* (1985): Nutrient composition of feedstuffs for pigs and poultry. Queensland Dept. Primary Ind., Brisbane/ Australia (Series Q 185001).
11. *Fallu, R.* (1991): Abalone Farming. Fishing News Books, Oxford/England.
12. *Feltwell, R.; Fox, S.* (1978): Practical poultry feeding. Faber and Faber, London and Boston.
13. *Gill, C.* (1993): Chemistry for high quality pellets. *Feed International*, 14., (3), 10-11.
14. *Gropp, J.; Koops, H.; Tiews, K.; Beck, H.* (1976): Ersatz von Fischmehl im Forellenfutter. *Arb. Deutscher Fischerei-Verb.*, (19), 85-102.
15. *Hepher, B.* (1988): Nutrition of pond fishes. Cambridge University Press, Cambridge/U.K.
16. *Just, A.; Fernandez, J.A.; Jørgensen, H.* (1982): Kødbenmels værdi til svin. *Bert. Statens Husdyrbrugsfor.*, (525), 1-52.
17. *Meyer, H.; Heckötter, Elke* (1986): Futterwerttabelle für Hunde und Katzen. Schlütersche Verlagsanstalt, Hannover/Germany.
18. *New, M.B.* (1987): Feed and feeding of fish and shrimps - A manual on the preparation and presentation of compound feeds for shrimps and fish in aquaculture. UNDP/FAO/ADCP/REP/87/26, Rome/Italy.
19. *Niemann, H.* (1985): Die Verwendung von Schlachtnebenprodukten und Tierkörpern in ihrer Bedeutung für die Wirtschaftlichkeit der Tierproduktion und den Umweltschutz. *Die Fleischmehl-Industrie*, 47., (1), 1-5.
20. *NRC* (1983): Nutrient requirements of warmwater fishes and shellfishes. National Academy Press. Washington, D.C.
21. *Schulz, E.* (1995): Nährstoff- und Energiegehalt in deutschen Tiermehlen. *Die Fleischmehl-Industrie*, 47., (1), 6-10.
22. *Seybold, U.* (1995): Hygienische Aspekte bei der Herstellung und Verarbeitung von Fleischknochenmehlen. *Die Fleischmehl-Industrie*, 47., (1), 17-18.
23. *Smith, R.R.* (1976): Metabolisable feedstuffs for trouts. *Feedstuffs*, 48., (23), 16-17.
24. *Stählin, A.* (1957): Methodenbuch, Beurteilung der Futtermittel, Vol. XII. Die Beurteilung der Futter-

- mittel. Neumann Verlag, Radebeul and Berlin/Germany.
25. *Steffens, W.* (1985): Grundlagen der Fischernährung. VEB Gustav Fischer Verlag, Jena/Germany.
 26. *Tacon, A.G.J.* (1995): The potential for fishmeal substitution in aquafeeds. *Infofish International*, (3), 29-34.
 27. *Tacon, A.G.J.; Jauncy, K.; Falaye, A.; Pantha, M.; MacGowan, C.; Stafford, E.A.* (1984): The use of meat and bone meal, hydrolysed feather meal and soybean meal in practical fry and fingerling diets for *Oreochromis niloticus*. Proc. 1st Intern. Symp. on Tilapia in Aquaculture, Nazareth/Israel, 356-365.
 28. *Weinreich, O.; Koch, V.; Knippel, J.* (1994): Futtermittelrechtliche Vorschriften. Buchedition Agrimedia, Hamburg/Germany.
 29. *Wöhlbier, W.; Tran Thu, D.* (1977): Tiermehle. In: *Kling, M.; Wöhlbier, W.*: Handelsfuttermittel. Verlag Eugen Ulmer, Stuttgart/Germany.

31. MINERAL FEED INGREDIENTS

31.1 Rationale

Mineral elements represent an essential group of nutrients for cultured aquatic animals. The nutritional requirement is covered by inherent minerals of the feed's raw materials and the supplementation with inorganic and organic mineral compounds.

The availability of inherent elements of plants is limited, e.g. only about 30% of the plant phosphorus is non-phytate phosphorus thus may be utilised by the animals^(2, 9). On the other hand the availability of minerals of animal feedstuffs is high, but the mineral content may vary widely (Table 31-01).

There are a wide range of chemical compounds, both inorganic and organic macro and trace minerals, that can be used for the fortification of diets for aquatic animals.

Table 31-01: Variability of phosphorus content (%) in meat and bone meal⁽⁸⁾

Meat and bone meal	Phosphorus content		Coefficient of variation
	Range	Mean	
Source 1	4.5 - 7.1	6.87	11.2
Source 2	2.9 - 6.7	4.86	16.3
Source 3	3.9 - 7.7	4.93	28.3
Di-calcium phosphate	19.5 - 22.1	20.60	4.5

31.2 Macro Mineral Ingredients

Calcium Compounds

Calcium compounds are available as pure calcium or in association with phosphorus as calcium-phosphates or magnesium. Calcium may also serve as a vehicle for compounds with other elements such as iodine and zinc. The most common calcium source is limestone which can be found around the World. The calcium content may vary depending on the structure of the chemical compound (Table 31-02). Calcium oxide and calcium hydroxide are insoluble calcium sources and should not be used in animal diets⁽⁵⁾. The bio-availability of calcium sources ranges from 52 to 103% (Table 31-02)⁽²⁾.

Table 31-02: Bio-availability of calcium in calcium supplements in pigs⁽²⁾

Calcium source	Properties	Calcium Content %	Bio-availability ¹
Calcitic limestone	Hexagonal cristallisation	38.6	103
High Mg-limestone	5.0 - 6.0% magnesium	30.2	82
Dolomitic limestone	12% magnesium, CaMg(CO ₃) ₂	20.7	52
Marble dust		38.9	98
Oyster shell meal		37.9	98
Aragonite	Orthorhombic CaCO ₃	38.8	98
Gypsum	Calcium sulphate (CaSO ₄ ·2H ₂ O)	22.2	99
Alfalfa meal		1.34	21

¹ % of the bio-availability of the calcium in precipitated calcium carbonate, given a value of 100.

Phosphorus Compounds

Calcium phosphates are the prevailing mineral compound because it provides both calcium and phosphorus. Feed phosphates are derived from rock phosphates, which occur naturally in many areas of the World (Table 31-03). In its natural form, rock phosphates can hardly be utilised by animals, particularly, if the fluorine content exceeds 3.0 to 4.0%⁽⁴⁾. For producing technical calcium phosphates rock phosphate has to pass some elementary chemical reactions (Figure 31-01)⁽¹⁹⁾. The diversity of manufacturing processes yields finished products of different properties⁽¹⁰⁾ such as:

- Calcium:phosphorus ratio,
- Physical aspects (granules, powder),
- Availability of phosphorus,
- Purity (levels of fluorine and other heavy metals).

Table 31-03: Chemical composition (%) of rock phosphates⁽⁵⁾

Source	Calcium	Phosphorus		Magnesium	Fluorine
		Content	Availability ¹		
Curaçao	36.0	14.0	14.0	-	-
Nauru island	39.2	16.3	16.3	0.18	3.06
Christmas island	32.0	16.0	16.0	0.21	1.99
Defluorinated rock phosphate	33.3	18.2	16.0	0.17	0.10

¹ For pigs and poultry

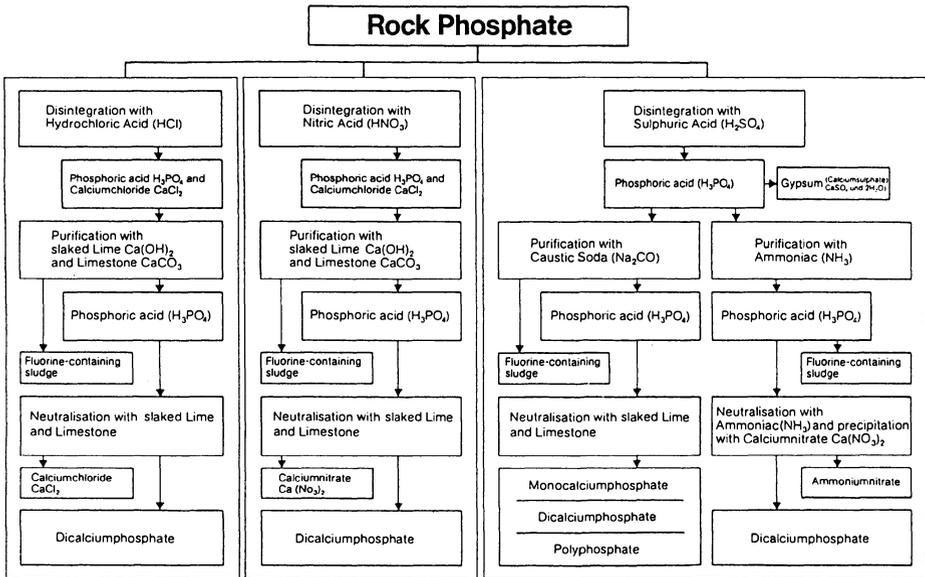


Figure 31-01. Schematic production process of calcium phosphates⁽¹⁰⁾.

There is a wide range of phosphate compounds (Table 31-04). The calcium:phosphorus ratio is important for quality determination e.g. of a commercial mono-calcium phosphate which might be only a mono-di-calcium phosphate. A Ca:P-ratio of more than 0.80 indicates that the product is not a mono-calcium phosphate but rather a mono-di-calcium phosphate⁽¹⁷⁾.

So far there is no uniformity in the determination of the bio-availability of phosphorus in phosphates. Most common tests for the determination of the bio-availability are⁽¹⁰⁾:

- Citric-acid-solubility (provides uncertain indication),
- Relative Biological Value (RBV) (Table 31-05),
- Transposition test.

Table 31-05: The relative biological value of calcium phosphates, tested in broilers⁽³⁾

Di-calcium phosphate-dihydrate ¹	100
Mono-calcium phosphate	99
Di-calcium phosphate, anhydrous	84
Defluorinated rock phosphate)	83

¹ Reference standard

Table 31-04: Chemical composition of phosphate compounds^(4, 17)

	P ¹	Ca	Mg	Na	H ₂ O ²	Ca:P ratio
Mono-calcium phosphate, free of H ₂ O Ca(H ₂ PO ₄) ₂	26.5	17.1	-	-	-	0.65
Mono-calcium phosphatephate- monohydrate Ca(H ₂ PO ₄) ₂ ·H ₂ O	24.6	15.9	-	-	7.2	0.65
Di-calcium phosphate free of H ₂ O CaHPO ₄	22.8	29.5	-	-	-	1.29
Di-calcium phosphate- dihydrate CaHPO ₄ ·2H ₂ O	18.0	23.3	-	-	20.9	1.29
Mono-di-calciumphosphate-hydrate ³	21.3	19.0	-	-	14.1	0.89
Tri-calcium phosphate Ca ₃ (PO ₄) ₂	19.9	38.8	-	-	-	1.95
Di-magnesium phosphate-trihydrate MgHPO ₄ ·3H ₂ O	17.8	-	14.0	-	31.0	-
Mono-sodium phosphate-dihydrate NaH ₂ PO ₄ ·2H ₂ O	19.9	-	-	14.7	23.1	-
Di-sodium phosphatedodecahydrate Na ₂ HPO ₄ ·12H ₂ O	8.7	-	-	12.8	60.4	-
Di-sodium phosphatedihydrate Na ₂ HPO ₄ ·2H ₂ O	17.4	-	-	25.8	20.2	-
Di-sodium phosphate Na ₂ HPO ₄	21.8	-	-	32.4	-	-

¹ Conversion factors: P₂O₅ x 0.4367 = P; P x 2.29 = P₂O₅;

² Crystal water; ³ 50% mono-calciumphosphate-mono-hydrate + 50% di-calcium phosphate-di- hydrate

The scientific value of these test methods is still being discussed. Nevertheless, it can be said that the physiological value of mono-calcium phosphate is superior to di-calcium phosphate and di-calcium phosphate is more effective than tri-calcium phosphate⁽⁷⁾.

Rainbow trout (*Salmo gairdneri*) and carp (*Cyprinus carpio*) utilise effectively mono-calcium phosphate, mono-sodium phosphate or potassium phosphate, whereas di-calcium phosphate and tri-calcium phosphate have shown a low phosphorus availability (Table 31-06). But results of another study show that the phosphorus availability for carp in di-calcium phosphate is higher than that of fish meal and seed grains⁽²⁰⁾. The level of available phosphorus in the diet affected significantly performances of fishes, particularly the mineral composition of the bones and chemical composition of the fish carcass^(15, 16).

Table 31-06: Absorption of dietary phosphates (%) by selected fish species⁽¹⁴⁾

Phosphate	Channel catfish ¹	Common carp ²	Rainbow trout ³	Red sea bream ⁴
Mono-sodium phosphate	90	~94	~98	high
Mono-potassium phosphate	-	~94	~98	high
Mono-calcium phosphate	94	94	94	high
Di-calcium phosphate	65	46	71	high
Tri-calcium phosphate	-	13	64	high

¹ *Ictalurus punctatus*; ² *Cyprinus carpio*; ³ *Salmo gairdneri*; ⁴ *Chrysophrys major*

Fluorine is both an essential element and a toxine because the biological and toxic levels are rather close to each other⁽¹⁰⁾. The degree of absorption of fluorine from the feed and consequently its toxicity is affected by factors such as⁽⁴⁾:

- Solubility and tissue-affinity of fluorine compounds;
- pH of the diet;
- Particle size of the fluorine-containing substances;
- Presence of attendant elements;
- Animal species.

Tolerance levels for aquaculture feeds have not yet been established. However, for ruminants the dietary fluorine tolerance is very low (40 to 60 mg/kg feed) but relatively high for laying hens (400 to 700 mg/kg feed)^(12, 13).

Magnesium Compounds

Magnesium can be found in nature as^(4, 11):

- Serpentine (hydrated magnesium silicate) $Mg_3Si_2O_7 \cdot 2H_2O$,
- Soap-stone (steatite),
- Meerschaum (hydrous magnesium silicate) $H_4Mg_2Si_3O_{10}$,
- Magnesite (magnesium carbonate) $MgCaO_3$
- Dolomite (common rock-forming mineral) $CaMg(CO_3)_2$
- Kieserite (hydrous magnesium sulphate) $MgSO_4 \cdot H_2O$
- Epsom salts (magnesium sulphate) $MgSO_4 \cdot 7H_2O$.

Magnesium oxide is the most common form of magnesium feed ingredient. It is derived by burning magnesium carbonate. Commercial magnesium compounds (Table 31-07) may contain other elements such as iron, aluminium, fluorine, sulphur and boron.

Sodium Compounds

The most common sodium compound is sodium chloride (common salt). Sodium chloride is obtained by mining or by evaporation of sea water. For feeding purposes sodium chloride is denatured, mostly with ferrous oxide (Fe_2O_3) (Table 31-07).

Iodised salt should in U.S.A. contain not less than 70 ppm iodine⁽¹⁾, but in Germany the iodine content of iodised salt should range from 38 ppm (minimum) to 76 ppm (maximum)⁽³⁾.

Table 31-07: Chemically pure magnesium (Mg) and sodium (Na) compounds (%)⁽⁴⁾

Compound	Chemical formula	Pure element
Magnesium chloride	$\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$	12.0 Mg
Magnesium fumarate	$\text{Mg}(\text{CH} \cdot \text{COO})_2$	17.6 Mg
Magnesium oxide	MgO	60.3 Mg
Magnesium sulphate	$\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$	9.9 Mg
Magnesium sulphate	MgSO_4 (free of water)	20.2 Mg

Sodium chloride	NaCl	39.3 Na
Sodium bicarbonate	NaHCO_3	27.4 Na
Sodium propionate	$\text{Na}(\text{COO} \cdot \text{C}_2\text{H}_5)$	23.9 Na

Other Macro Mineral Ingredients

Macro elements such as chlorine, potassium, and sulphur are provided via other chemical compounds of which these elements are part of it, e.g. sodium chloride, copper sulphate, ferrous sulphate and others.

31.3 Trace Mineral Ingredients

In general, trace minerals are sometimes available in the form of sulphates and oxides. Although they are necessary in the diets these compounds can destroy other feed components (vitamins, pigments, antibiotics, fats/oils). The most common technical trace mineral ingredients are listed in Table 31-08.

Most of the technical trace mineral compounds are not pure. They are contaminated with useful as well as harmful elements.

Table 31-08: Common technical trace mineral compounds (%) for aquaculture feeds^(4, 18)

Technical compound	Purity	Content of pure element	Colour
1. Iron compounds (Fe)			
Ferrous sulphate (FeSO ₄ ·7H ₂ O)	97	19.2	light green
Ferrous(II) carbonate (FeCO ₃)	-	48.2	
Ferrous oxide (FeO)	-	77.7	
2. Copper compounds (Cu)			
Copper sulphate (CuSO ₄ ·5H ₂ O)	98 - 100	24.9 - 15.4	dark blue
Copper(II) carbonate (CuCO ₃ ·Cu(OH) ₂)	-	53.0	
Copper(II) oxid (CuO)	78 - 79	78.0 - 79.0	black
Copper(II) hydroxide (Cu(OH) ₂)	-	65.0	
3. Manganese compounds (Mn)			
Manganese sulphate (MnSO ₄ ·H ₂ O)	99	31.0 - 32.2	pale pink
Manganese oxide (MnO)	81	60.0 - 63.0	greenish-black
4. Zinc compounds (Zn)			
Zinc sulphate (ZnSO ₄ ·H ₂ O)	-	36.0	
Zinc oxide (ZnO)	88 - 99	71.0 - 79.5	greyish
Zinc carbonate (ZnCO ₃)	-	55.0 - 56.0	
5. Cobalt compounds (Co)			
Cobalt sulphate (CoSO ₄ ·H ₂ O)	98 - 99	20.6 - 20.8	strong pink
6. Iodine compounds (I)			
Calcium iodate (Ca(IO ₃) ₂ ·H ₂ O)	99	62.0 - 65.0	white crystalline powder
Potassium iodate (KIO ₃)	-	59.0	"
7. Selenium compounds (Se)			
Sodium selenite (Na ₂ SeO ₃)	99 - 100	45.0 - 46.0	pale yellowish tinted powder

31.4 Contaminants in Mineral Ingredients

Almost all elements can be found in the animal organism. Most of them appear accidentally at very low and harmless levels. They are ingested with the feed. The occurrence of many of these elements are conditioned by the chemical production process of feed grade mineral ingredients⁽⁴⁾. *AAFCO*⁽¹⁾ has classified contaminants in mineral ingredients as:

- Highly toxic
- Toxic
- Moderately toxic
- Slightly toxic.

From the total of 21 potential toxic elements (Table 31-09) only ten have been found in commercial products. The most frequent undesirable contaminants are lead and arsenic (Table 31-10).

Table 31-09: Official guidelines for contaminants in individual mineral ingredients in U.S.A.⁽¹⁾

	Typical analysis between ppm	Prohibited level above ppm
1. <u>Highly toxic</u> Cadmium, Mercury, Selenium	5 - 500	500
2. <u>Toxic</u> Cobalt, Molybdenum, Vanadium, Barium, Tungsten, Copper, Lead	100 - 1,000	1,000
3. <u>Moderately toxic</u> Arsenic, Nickel, Iodine, Antimony	500 - 2,000	2,000
4. <u>Slightly toxic</u> Boron, Aluminium, Bromine, Zinc, Bismuth, Manganese, Chromium	>2,000	None

Table 31-10: Contamination levels with highly toxic, toxic, moderately toxic and slightly toxic elements of commercial/technical mineral ingredients for animal feed ^(data from⁴⁾)

	Cadmium	Cobalt	Copper	Lead	Arsenic	Nickel	Alumi- nium	Zink	Manga- nese	Chro- mium
	Cd	Co	Cu	Pb	As	Ni	Al	Zn	Mn	Cr
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	g/kg	mg/kg	mg/kg	mg/kg
Calcium carbonate	-	-	2.0	-	-	-	-	-	-	-
Sodium-calcium- magnesium phosphate	-	-	-	<30.0	<20.0	-	3.5	-	-	200
Potassium chloride	-	-	-	<1.0	<1.0	-	-	-	-	-
Magnesium oxid	-	-	-	-	-	-	1.4	-	-	-
Magnesium sulphate	-	-	-	3.0	<1.0	-	-	-	-	-
Ferrous sulphate	-	-	10.0	4.0	-	-	-	290	440	-
Copper sulphate	-	130	-	60.0	50.0	150	-	400	-	-
Copper oxid	-	-	-	100.0	100.0	-	-	-	-	-
Manganese sulphate	-	-	-	14.0	1.0	-	-	-	-	-
Manganese oxid	-	-	<100.0	<10.0	<10.0	-	-	<100	-	-

Table 31-10: Continued

	Cadmium	Cobalt	Copper	Lead	Arsenic	Nickel	Alumi- nium	Zink	Manga- nese	Chro- mium
	Cd	Co	Cu	Pb	As	Ni	Al	Zn	Mn	Cr
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	g/kg	mg/kg	mg/kg	mg/kg
Zinc oxid (1)	10	-	20.0	150.0	-	-	-	-	10	-
Zinc oxid (2)	400	-	-	1,670	-	-	-	-	-	-
Zinc oxid (3)	-	-	35.0	30.0	<1.0	-	2.2	-	-	<1.0
Cobalt sulphate	-	-	-	10.0	<1.0	400	-	-	10	-
Calcium iodate	-	-	-	10.0	3.0	-	-	-	-	-
Copper iodid	-	-	-	20.0	5.0	-	-	-	-	-

31.5 Chelated Mineral Ingredients

Chelates are chemical compounds in which the central atom, mostly a metal ion, is attached to neighbouring atoms by at least two bonds in such a way as to form a ring structure. Some minerals may have the effect of binding other mineral ions to themselves and thus encountering some of the harmful effects which the latter might possess. This interaction is the chelating effect⁽⁶⁾. Chelates, therefore, are of importance for inactivating heavy metals in technical processes⁽⁴⁾.

Organic mineral ingredients have certain advantages with regard to the physico-chemical conditions in the digestive tract. They are precursors of natural trace mineral complexes such as hemoglobin (containing iron) and Vitamin B₁₂ (containing cobalt). These complex salts are organic chelates. However, chelated mineral ingredients are advantageous only, if the absorption of trace minerals can be improved⁽⁴⁾.

A range of chelated mineral ingredients are in the market. They can be proteinates, gluconates, lactates and others. Practically all minerals can be chelated with organic molecules. Whether these chelates are useful has to be proven.

31.6 Legal Aspects

The list of permitted mineral feed ingredients in the U.S.A. contains not less than 114 definitions of mineral ingredients for 12 elements and their salts. The minimum content of the leading element has to be specified on the label⁽¹⁾. The EU-Directive accordingly describes under the heading "minerals" 13 permitted compounds. The German feedstuff legislation contains 46 approved mineral ingredients together with specified requirements (Table 31-11)⁽²¹⁾.

Table 31-11: Requirements of permitted mineral compounds for animal feeds according to German feedstuff legislation⁽²¹⁾

Compound	Purity	Ca	P	Mg	Na	Cl ¹	S
	min. %	min. %	min. %	min. %	min. %	max. %	min. %
1. Calcium compounds (Ca)							
Calcium acetate	-	22.0	-	-	-	-	-
Calcium aceto-chloride	-	22.0	-	-	-	-	-
Calcium chloride	95.0	17.0	-	-	-	-	-
Calcium formiate	-	29.0	-	-	-	-	-
Calcium fumarate	-	18.0	-	-	-	-	-
Calcium gluconate	-	8.5	-	-	-	-	-
Calcium lactate	-	12.0	-	-	-	-	-
Calcium magnesium- carbonate	-	19.0	-	11.0	-	-	-
Kieserite	-	28.0	16.0	16.0	-	-	21.0
2. Phosphate compounds (P)							
Bone ash	-	28.0	16.0	-	-	-	-
Bone meal	10.0 ²	-	13.0	-	-	-	-
Calcium magnesium phosphate	-	16.0	18.0	2.0	-	-	-
Calcium sodium phosphate	-	10.0	16.0	-	8.0	-	-
Di-calcium phosphate	-	21.0	16.0	-	-	1.0	-
Di-magnesium phosphate	-	-	16.0	12.0	-	-	-
Di-sodium phosphate	95.0	-	8.0	-	11.0	-	-
Light calcium phosphate	-	26.0	21.0	-	-	8.0	-
Mono-ammonia phosphate	-	-	25.0	-	-	-	-
Mono-calcium phosphate	-	15.0	22.0	-	-	-	-
Mono-di-calcium phosphate	-	18.5	19.0	-	-	1.0	-
Mono-magnesium phosphate	-	-	21.0	8.0	-	-	-
Rock phosphate	-	22.0	14.0	-	-	-	-
Mono-sodium phosphate	95.0	-	-	19.0	13.0	-	-
Sodium-calcium-magnesium phosphate	-	5.0	17.0	3.0	11.0	-	-
Sodium-magnesium phosphate	-	-	17.0	8.0	8.0	-	-
Tri-calcium phosphate	-	35.0	18.0	-	-	1.0	-
Tri-magnesium phosphate	-	-	22.0	25.0	-	1.0	-
3. Magnesium compounds (Mg)							
Magnesium aspartate- hydrochloride	-	-	-	9.5	-	-	-
Magnesium chloride	95.0	-	-	11.0	-	-	-
Magnesium citrate	-	-	-	9.5	-	-	-
Magnesium carbonate	95.0	-	-	26.0	-	-	-
Magnesium fumarate	-	-	-	12.0	-	-	-

Table 31-11: Continued

Compound	Purity	Ca	P	Mg	Na	Cl ¹	S
	min.	min.	min.	min.	min.	max.	min.
	%	%	%	%	%	%	%
Magnesium gluconate	-	-	-	5.0	-	-	-
Magnesium lactate	-	-	-	9.0	-	-	-
Magnesium oxide	-	-	-	50.0	-	-	-
Magnesium propionate	-	-	-	14.0	-	-	-
Magnesium sulphate	-	-	-	9.0	-	-	-
Magnesium sulphate, free of water	-	-	-	18.0	-	-	-
4. Sodium compounds (Na)							
Sodium bi-carbonate	-	-	-	-	26.5	-	-
Sodium carbonate	-	-	-	-	41.0	-	-
Sodium sulphate	-	-	-	-	14.0	-	10.0
Sodium sulphate, free of water	-	-	-	-	31.0	-	22.0
Sodium chloride	-	-	-	-	38.0	-	-
5. Other compounds							
Potassium chloride	-	-	-	-	-	-	-

¹ Calculated as NaCl, ² Max. moisture content

31.7 References

1. *AAFCO* (1995): Official publication 1995. Ass. of American Feed Control Officials (publisher), Sacramento, CA/USA.
2. *Cromwell, G.L.* (1989): Requirements and biological availability of phosphorus for swine. *Feed Magazine*, (Nov./Dec.), 20-26.
3. *De Bruyne, K.* (1992): What is the relative biological value of feed phosphates? *Misset-World Poultry*, 8., (6), 29-31.
4. *Dressler, D.* (1971): *Mineralische Elemente in der Tierernährung*. Verlag Eugen Ulmer, Stuttgart/Germany.
5. *Evans, M.* (1985): Nutrient composition of feedstuffs for pigs and poultry. Queensland Dept. Primary Ind., Brisbane/Australia (Series Q 185001).
6. *Feltwell, R.; Fox, S.* (1978): *Practical poultry feeding*. Faber and Faber, London and Boston.
7. *Günther, K.-D.; Tekin, C.* (1986): Zur Wirksamkeit von Calciumphosphaten innerhalb der Mineralergänzung bei der Schweinemast. *Kraftfutter*, 69., (2), 1-4.
8. *Halloran, N.* (1981): Quoted from: *Houseman, R.A.* (1984).
9. *Herstad, O.* (1993): Reduced phosphorus allowance in rearing and laying feed. *Norw. J. Agric. Sci.*, 7., 203-212.
10. *Hertrampf, J.W.* (1985): Feeding phosphates and their biological value. *Proc. 6th Australian Poultry and*

Stock Feed Convention, 22-27 Sept., Melbourne/Australia.

11. *Holtmeier, H.-J.* (1988): Das Magnesiummangelsyndrom. Hippokrates Verlag GmbH, Stuttgart/Germany.
12. *Houseman, R.A.* (1984): Phosphorus, some aspects of phosphorus supply to farm livestock. *The Feed Compounder*, 4., (1), 15-18.
13. *Kurunajeewa, H.* (1977): Quoted from: *Hertrampf, J.W.* (1985).
14. *NRC* (1983): Nutrient requirements of warmwater fishes and shellfishes. National Academy Press, Washington, D.C.
15. *Ogino, C.; Takeda, H.* (1976): Mineral requirement in fish. III. Calcium and phosphorus requirements in carp. *Bull. Jap. Soc. Sci. Fisheries*, 42., 793-799.
16. *Ogino, C.; Takeuchi, L.; Takeda, H.; Watanabe, T.* (1979): Availability of dietary phosphorus in carp and rainbow trout. *Bull. Jap. Soc. Sci. Fisheries*, 45., 1527-1532.
17. *Seibold, R.; Kändler, U.* (1988): Monocalciumphosphat - Klassifizierung, Identifizierung und Bestimmung. *Kraftfutter*, 71. (2), 44-46.
18. *Shorrocks, V.M.; Alloway, B.J.* (1988): Kupfer in der Landwirtschaft. Deutsches Kupferinstitut, Berlin/Germany.
19. *Thomsen, J.* (1995): From rock to feed, production of phosphates. *Feed Mix*, Special Issue, 16-17.
20. *Viola, S.* (1986): Requirements of phosphorus and its availability from different sources for intensive pond culture species in Israel. II. Carp culture. *Bamidgeh*, 38., 44-54.
21. *Weinreich, O.; Koch, V.; Knippel, J.* (1994): Futtermittelrechtliche Vorschriften. Buchedition Agrimedia, Hamburg/Germany.

32. MOLLUSC PRODUCTS

32.1 Rationale

Mussels, clams, oysters and scallops all belong to the *Phylum Mollusca*. Listed under this phylum are six classes one of which is *Lamellibranchiata* or *Bivalvia* to which the former belong⁽²³⁾. Although there are over 7,000 species of bivalves. The more important ones are fished extensively, are cultured or have culture potential for human consumption. These are found in several families and the more common ones are (Figure 32-01):

- *Mytilidae* to which the mussels belong,
- *Ostreidae* which include various oysters,
- *Pectinidae* under which scallops are classified, and
- Other families that include what is commonly called the “clams”.

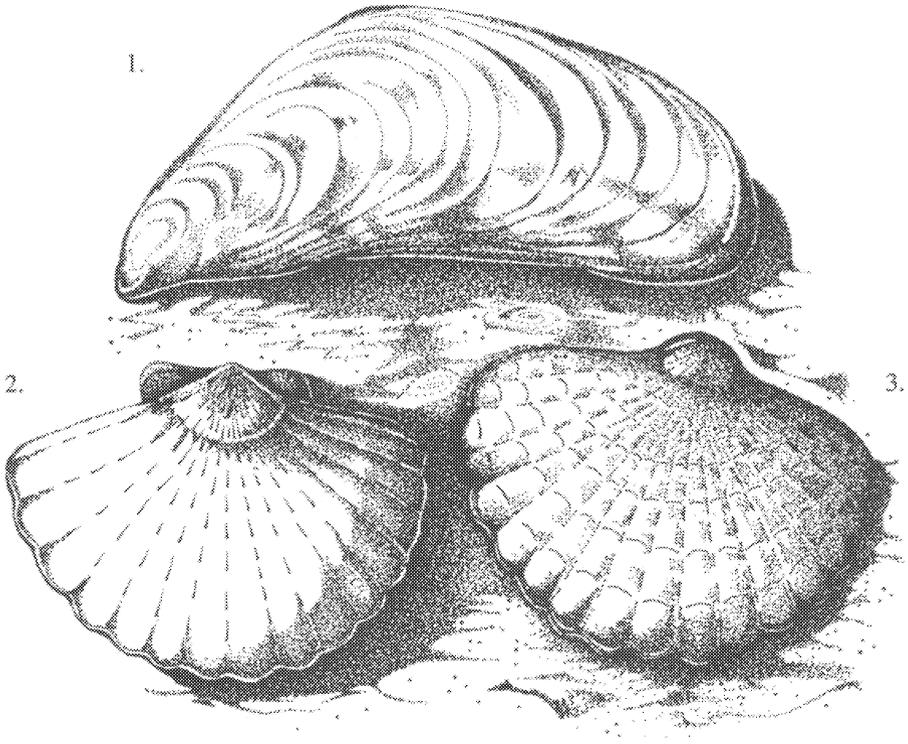


Figure 32-01. Shape of mussels 1. Blue mussel (*Mytilus edulis*); 2. Scallop (family: *PECTINIDAE*); 3. Cockle (*Cardium* spp.)

Mussels are among the most familiar of all bivalves because they are widely distributed throughout all oceans and is typified by the blue mussel, *Mytilus edulis*⁽²³⁾. The main genus being cultured in the Tropics is *Perna* which is also dominantly cultured in western Europe with annual production of around 420,000 MT.

Clams generally include all those species of bivalves not considered to be an oyster, mussel or scallop⁽²³⁾. One of the most important clam is the short-necked clam, *Venerupis philippinarum*. Japanese scientists used this clam as the basis for formulating practical diets for larval rearing and culture of Kuruma prawn, (*Penaeus japonicus*)⁽²⁶⁾.

32.2 Manufacture and Processing

Steaming will release the meat from the shells without individual shucking^(23, 28). Although meat of molluscs can be boiled, dried and ground into a meal, the procedure is tedious. In addition, the live or frozen meat is preferred by the shrimps particularly in larval and broodstock diets. If dried, the meal is added to other ingredients. Drying may be in an oven at less than 100°C preferably at 60°C to minimize nutrient losses. Fatty acid may oxidize when dried under the sun.

32.3 Chemical, Physiological and Other Properties

Chemical Properties

The protein content of mollusc meal varies widely. It is highest for scallop meat and lowest for oyster meat (Table 32-01). Mollusc meat is a good source of essential amino acids. The lysine and methionine content ranges from 3.51 to 5.81 g/16 g N and 1.19 to 1.81 g/16 g N and is highest for scallop meat (Table 32-02). The non-essential glutamic acid, being one of the chemo-attractants in fish diets is high (8.64 g/16 g/N) in the short-necked clam⁽⁴⁾. The essential amino acid index (EAAI) of the New Zealand green mussel and the scallop when compared to tiger prawn (*Penaeus monodon*) ovary is greater and close to 0.9, respectively, indicating the high nutritional value of the protein.

Table 32-01: Chemical composition of mussel meat (% dry matter)

	Blue mussel ¹ (6)	Green mussel ² (5,6, 29)	Brown mussel ³ (10, 19 20)	Clam ⁴ (1, 4)	Oyster ⁵ (6, 29)	Scallops ⁶ (11)
Moisture	-	-	85.6	-	83.1	78.3
Crude protein	60.4	52.5	62.7	56.5	48.0	83.5
Crude fat	8.5	15.4	7.9	8.8	10.8	1.9
Crude fiber	-	3.1	11.6	-	3.8	-
Ash	11.6	9.3	5.1	9.6	10.8	14.4
N-free extract	19.5	19.7	12.7	11.2	24.6	-
Carbohydrates	-	-	-	13.9	-	-

¹*Mytilus edulis*; ²*Perna spp.*; ³*Modulus metcalfei*; ⁴*Sunnepta scripta/Venerupis philippinarum*;

⁵Species not stated; ⁶*Amusium balloti*

Table 32-02: Essential amino acid profile of mussel meat^(4, 11)

	Green	Shortnecked clam ¹	Scallop ¹	Mean
Arginine	4.85	3.95	8.65	5.82
Histidine	1.95	0.89	1.31	1.38
Isoleucine	2.40	2.15	3.19	2.58
Leucine	3.83	3.37	5.96	4.39
Lysine	3.97	3.51	5.81	4.40
Methionine	1.19	1.38	1.81	1.46
Phenylalanine	2.36	1.85	2.72	2.31
Threonine	2.51	2.30	3.00	2.60
Valine	2.48	2.22	3.01	2.57

¹ For scientific name see Table 32-01

The lipid content of mollusc meat ranges from 1.9 to 15.4 (Table 32-01) and is rich in unsaturated fatty acids. The lipids of the short-necked clam contains⁽⁴⁾:

- Saturated fatty acids 38.5%
- Mono-unsaturated fatty acids 21.3%
- Poly-unsaturated fatty acids 36.4%
- Unknown fatty acids 36.4%
- n-3:n-6 ratio: 2.8

In the short-necked clam, cholesterol is with 33.3% the dominant sterol (total sterol 16.2%) of the lipid fraction⁽⁴⁾.

The mean calcium:phosphorus ratio of mollusc meat is 1:1 (Table 32-03), although green mussels and oysters may be higher in phosphorus than in calcium^(6, 29). Data on vitamins of mollusc meal is scanty (Table 32-03).

Table 32-03: Mineral and vitamin contents (in dry matter) of mussel meat^(6, 29)

Minerals			Vitamins (per 1,000g)		
Calcium	%	0.48	Vitamin A	I.U.	18,000
Phosphorus	%	0.48	Vitamin B ₁	mg	8.8
Sodium	%	0.23	Vitamin B ₂	mg	16.5
Potassium	%	1.16	Vitamin C	mg	837.0
Magnesium	%	0.77	Nicotinic acid	mg	77.0
Iron	mg/kg	549			
Copper	mg/kg	0.12			

Physiological Properties

Energy values of molluscs are scarce. Gross energy for the blue mussel (*Mytilus edulis*) is as follows⁽²⁸⁾:

- Gross energy: 4,421 kcal/kg (18.4 MJ/kg)
- Gross energy from protein: 2,622 kcal/kg (11.0 MJ/kg)

Clam meat meal (*Sunnepta scripta*) has a true protein digestibility of 81.2%⁽¹⁾.

The enzyme-inhibitor thiaminase which breaks up Vitamin B₁ (thiamine) and makes it ineffective, can be found in mussel and clam. Heating can inactivate the thiaminase^(8, 14, 16, 17, 28).

Molluscs are able to accumulate heavy metals as well as radionuclides in the body. They have also been shown to concentrate low levels of cadmium in seawater to as much as 20,000 to one million times when calculated on dry weight content of tissues⁽¹³⁾.

Gymnodinium breve, *Gonyaulax catenella* and *Gonyaulax tarenensis* are toxic algae that are well-liked by some molluscs that store toxins in their tissues⁽²⁷⁾. Toxicity could result when toxic algae contaminated molluscs are used in feeds for fish and crustaceans.

Other properties

Molluscs have chemo-attractant properties^(5, 15). The concentrations of glycine betaine in mussel is 964 mg; clam 679 to 727 mg; oysters 600 per 100 g meat⁽¹⁵⁾.

The mussel, *Modiolus modiolus*, has been reported to contain 16 carotenoids including astaxanthin⁽²⁾ while *Mytilus edulis* contains 20 different carotenoids⁽²²⁾. The total carotenoid content of *Perna viridis* is reported to be 99 mg/kg of freeze-dried mussel meat⁽²⁴⁾.

32.4 Feeding Value

The gut content of wild tiger prawns (*Penaeus monodon*) contained 76% remains of molluscs and bivalve and formed 31% of total food⁽¹²⁾.

An important part in hatchery operations is the maintenance of broodstock of fish and shrimp. Although there are artificial prawn maturation diets available best results are obtained when they are supplemented with live or fresh frozen food. Among these fresh frozen food are mussel meat and clams. The oyster larvae (trochophore) are also used for feeding fish larvae.

Mussel Meat

Fresh or frozen mussel meat is used in feeding tiger prawn broodstock, post-larvae and as food supplement in grow-out ponds^(10, 19, 20). The green mussel (*Perna viridis*) is used in broodstock diets in combination with squid or pelletised feed⁽⁶⁾.

Broodstock of ablated tiger prawns maintained under laboratory conditions and allowed to spawn in tanks were fed 3.0% of body weight frozen mussel meat in the morning and formulated pellets in the afternoon. The mussel-pellet combination followed by mussel-mussel and squid-pellet combinations gave the better reproductive performances than the pellet-pellet feeding regime (Table 32-04)^(20, 21, 22).

Table 32-04: Mean survival, spawning, fecundity, and hatching rate of ablated tiger prawn (*Penaeus monodon*) broodstock fed various diets with various feeding regimes⁽²⁰⁾

Feeding regime:					
Morning		Pellets	Frozen brown mussel meat	Frozen brown mussel meat	Frozen chopped squid
Afternoon		Pellets	Frozen brown mussel meat	Pellets	Pellets
Survival					
Male	%	56	40	52	52
Female	%	16	20	14	8
Spawnings	nos.	7	16	16	12
Eggs/spawning	1.000 nos.	136.8	179.3	180.3	140.3
Total eggs	1.000 nos.	957.4	2,868.4	2,884.5	1,683.8
Total nauplii	1.000 nos.	195.2	266.2	598.7	308.4
Hatching rate	%	20.4	9.3	20.8	78.3

The positive effect on ovarian maturation of penaeid shrimps in captivity of fresh mussel meat in combination with formulated pelletised feed was found in pond-reared tiger prawns⁽²⁴⁾, white leg shrimps (*Penaeus vannamei*) and blue shrimp (*Penaeus stylirostris*)⁽⁷⁾.

Banana shrimps (*Penaeus merguensis*) grew significantly better on fresh mussel meat than on formulated feed⁽²⁵⁾. Fresh mussel meat is also comparable to shrimp meal as the sole source of protein when fed to tiger prawns^(10, 19). However, departures from this kind of rule are possible (Table 32-05).

Table 32-05: Performances of tiger prawn (*Penaeus monodon*) post-larvae fed frozen brown mussel meat and shrimp meal⁽¹⁰⁾

		Mussel meat	Shrimp meal
Weight gain	g	13.73	13.82
Feed conversion	1:	2.38	2.46
PER ¹		0.66	0.91
Survival rate	%	16.00	48.00

¹Protein efficiency ratio

Clam Meat

The short-necked clam (*Venerupis philippinarum*) is a very important species in the development of practical diets for the kuruma prawn (*Penaeus japonicus*). Its chemical

composition was the basis of a basal artificial diet for determining nutrient requirements of kuruma prawn prior to the formulation of practical diets^(4, 10). It was also used in the fresh form, minced and given to kuruma prawn larvae in the early years of prawn culture in Japan⁽²⁶⁾.

Fresh frozen clams (*Mercenaria mercenaria*) were fed to white leg shrimp and blue shrimp singly or in a composite diet consisting of adult and juvenile squid (*Loligo* sp. and *Loligo* sp.), blood worms (*Glycera dibranchiata*) and penaeid shrimps primarily *Penaeus aztecus*. With regard to ovarian maturation, spawning, molting rate, and survival the composite diet was the best while the best single-food diet was squid. Clams gave the poorest results⁽³⁾.

Juveniles of Indian shrimp (*Penaeus indicus*) (length 26 mm, weight 75 mg) were fed various animal and plant protein sources. The clam meat (*Sunneta scripta*) diet gave higher weight gain than the fish meal diet. The feed:gain ratio, was the same than for fish meal diet but net protein utilisation (NPU), biological value and survival of shrimps on the clam meat diet was lower than that of the fish meal diet⁽¹⁾.

32.5 Recommended Application and Precaution

Recommended Application

Fresh and frozen molluscs meat have a higher feeding value in diets for crustaceans than in fish. This applies particularly to maturation diets of shrimp spawners. Preferably mollusc meat, fresh or frozen, from two or more species is fed either *ad libitum* or as a combination of 50% mollusc meat and 50% formulated diet. Mollusc meal is used in shrimp diets at levels of 5.0 to 10.0%.

Precautions

Fresh mollusc meat is prone to decay. In order to minimise bacterial growth it has to be well chilled or even better if deep-frozen. In addition, molluscs for feeding purposes should not come from areas infested with toxic algae.

32.6 References

1. Ali, A.S. (1992): Evaluation of some animal and plant protein sources in the diet of the shrimp *Penaeus indicus*. Asian Fish. Science, 5., 277-289.
2. Bjerkeng, B.; Hertzberg, S.; Liaaen-Jensen, S. (1993): Carotenoids in food chain studies-IV. Carotenoids of the bivalves *Modiolus modiolus* and *Pecten maximus* - structural, metabolic and food chain aspects. Comp. Biochem. Physiol., 106B., 243-290.
3. Chamberlain, G.W.; Lawrence, A.L. (1981): Maturation, reproduction, and growth of *Penaeus vannamei* and *Penaeus stylirostris* fed natural diets. J. World Maricul. Soc., 12., 209-224.
4. Deshimaru, O. (1981): Studies on nutrition and diet for prawn, *Penaeus japonicus*. Mem. Kagoshima Pref. Fish. Expe. Station (12), 118.
5. Feed Development Section (1994): Feeds and feeding of milkfish, Nile tilapia, Asian sea bass and tiger shrimp. (SEAFDEC Aquaculture Department, Tigbauan, Iloilo, Philippines).

6. *Food and Nutrition and Research Institute* (1968): Food Composition Table Handbook I, National Science Development Board, Manila, Philippines. 134.
7. *Galgani, M.L.; Aquacop* (1989): Influence du Regime Alimentaire sur la reproduction en captivite de *Penaeus vannamei* et *Penaeus stylirostris*. *Aquaculture*, *80*, 97-109.
8. *Gnaedinger, R.J.* (1965): Thiaminase activity in fish: An improved assay method. *U.S. Fish. Wildl. Ser. Fish Ind. Res.*, *2*, 55-59.
9. *Kanazawa, A.; Teshima, S.; Tokiwa, S.; Endo, M.; Abdel Razeq, F.A.* (1979): Effects of short-necked clam phospholipids on the growth of prawn; *Bull. Jap. Soc. Fish.*, *45*, 961-965.
10. *Lim, C.; Suraniranat, P.; Platon R.R.* (1979): Evaluation of various protein sources for *Penaeus monodon* post-larvae. *Kalikasan, Philipp. J. Biol.*, *8*, 29-36.
11. *Marsden, G.; McGuren, J.M.; Sarac, H.Z.; Neill, A.R.; Brock, I.J.; Palmer, C.L.* (1992): Nutritional composition of some natural marine feeds used in prawn maturation. *Proc. Aquaculture Nutrition Workshop, Salamander Bay, 15-17 April 1991*, 82-86. (NSW Fisheries, Brackishwater Fish Culture Research Station, Salamander Bay/Australia).
12. *Marte, C.* (1980): The food and feeding habit of *Penaeus monodon* Fabricius collected from Makato River, Aklan, Philippines (Decapoda Natantia) *Crustaceana*, *38*, 225-235.
13. *McLesse, D.W.* (1980): Uptake and excretion of cadmium by marine organisms from seawater with cadmium at low concentrations: A review. *Cadmium Pollution of Belledune Harbour, New Brunswick, Canada. Can. Tech. Rep. Fish. Aquat. Sci.*, *963*, 55-64.
14. *Melnick, D.; Hochberg, M.; Oser, B.L.* (1945): Physiological availability of the vitamins: II. The effect of dietary thiaminase in fish products. *J. Nutr.*, *30*, 81.
15. *Meyers, S.P.* (1982): Attractants, aquatic diet development examined. *Feedstuffs*, *58*, 11-12.
16. *Miller Jones, J.* (1992): Food Safety. Eagan Press, St. Paul, Minnesota/USA.
17. *New, M.* (1987): Feed and feeding of fish and shrimp - A manual on the preparation and presentation of compound feeds for shrimp and fish in aquaculture. *UNDP/FAO/ADCP/REP/87/26 Rome/Italy*.
18. *Partali, V.; Tangen, K.; Liaaen-Jensen, S.* (1989): Carotenoids in food chain studies: III. Resorption and metabolic transformation of carotenoids in *Mytilus edulis* (edible mussel). *Comp. Biochem. Physiol.*, *92B*, 239-246.
19. *Piedad-Pascual, F.P.; Destajo, W.H.* (1979): Growth and survival of *Penaeus monodon* post-larvae fed shrimp head meal and fish meal as primary animal sources of protein. *Fish. Res. F. Philipp.*, *4*, 1-23.
20. *Primavera, J.H.; Lim, C.; Borlongan, E.* (1979): Feeding regimes in relation to reproduction and survival of ablated *Penaeus monodon*. *Kalikasan Philipp. J. Biol.*, *8*, 227-235.
21. *Pudadera, R.A.; Primavera, J.H.; Borlongan, E.* (1980): Effect of substrate types on fecundity and nauplii production of ablated *Penaeus monodon* Fabricius. *Philipp. J. Sci.*, *109*, 15-18.
22. *Pudadera, R.A.; Primavera, J.H.* (1981): Effect of light quality and eyestalk ablation on ovarian maturation in *Penaeus monodon*. *Kalikasan, Philipp. J. Biol.*, *10*, 231-241.
23. *Quayle, D.B.; Newkirk, G.F.* (1989): Farming bivalve molluscs: methods for study and development. *Advances in World Aquaculture, Vol. 1. World Aquaculture Soc. In association with the Int'l. Dev. Res. Center, Canada*.
24. *Quinitio, E.T.; Parado-Esteva, F.D.; Millamena, O.M.; Biona, H.* (1994): Reproductive performance of captive *Penaeus monodon* fed various sources of carotenoids. *National Seminar-Workshop on Fish Nutrition and Feeds, 1 to 2 June. SEAFDEC Aquaculture Department, Tigbauan, Iloilo, Philippines*.
25. *Sedgewick, R.W.* (1980): The requirements of *Penaeus merguensis* for vitamin and mineral supplements in diets based on freeze-dried *Mytilus edulis* meal. *Aquaculture* *19*, 127-237.
26. *Shigueno, K.* (1975): Shrimp culture in Japan. *Asso. International Technical Promotion, Tokyo/Japan*.

27. *Sparks, A.K. (1972): Invertebrate pathology. Non-communicable disease. N.Y. Academic Press.*
28. *Täufel, A.; Ternes, W.; Tunger, L.; Zobel, M. (1993): Lebensmittel-Lexikon. Behr's Verlag, Hamburg/Germany.*
29. *Watt, B.K.; Merrill, A.L. (1963): Composition of Foods. Agricultural Handbook No. 8, United States Dep. of Agri. Washington D.C. 190.*

33. PIG BRISTLE MEAL (HYDROLYSED)

33.1 Rationale

The hair of pigs are bristles. In the past, pig bristles were used for making brushes. They have been replaced by synthetic bristles. Contrary to the secondary hair (wool hair), the primary hair (bristles) of the pig has a thick rind and contains marrow. There are differences in the length of the bristles between summer and winter and between sexes⁽³⁾.

33.2 Processing and Properties

Processing

Pig bristles can be converted into a suitable feedstuff by hydrolysis. This method is similar to the processing of feather meal (see chapter 15.2.). The bristles can also be pulverised in a hammermill.

Properties

Pig bristles contain in the dry matter about⁽⁷⁾:

- Crude protein: 90.0%
- Crude fat: 2.0 to 7.0%
- Ash: 2.0%

The hydrolysis of pig bristles damages the amino acids as Table 32-01 demonstrates. The mineral content of bristles is affected by the pig breed, mineral supply in the feed, season, age of the animals and pregnancy⁽²⁾. However, the amount of minerals in pig bristles is negligible⁽⁷⁾.

Keratin is the principal matter of pig bristle. The utilisation of this fibrous protein is low⁽²⁾. The digestibility of raw, pulverised pig bristles in land animals is below 50%⁽⁷⁾.

33.3 Feeding Value

In rations for chicken and turkeys 2.5% of the protein could be replaced by hydrolysed pig bristle meal. However a supplementation with lysine and methionine was required. Encephalomalacia, the degenerative disease of the brain, has been observed when chicken were fed with raw, pulverised pig bristles. Provision with Vitamin E could cure the illness which is also known as "crazy chick"^(6, 7).

Rainbow trout (*Salmo gairdneri*) were fed hydrolysed pig bristle meal as replacement for feather meal (as protein source) at two different levels for 172 days. The substitution of 50% feather meal with 7.25% pig bristle meal did not affect growth and feed conversion

of fish. However, total replacement of feather meal with pig bristle meal depressed the performances by around 8.0% (Table 32-02)⁽⁴⁾.

Table 33-01: Essential amino acid profile of raw and hydrolysed pig bristles (g/16 g N)⁽⁷⁾

Amino acid	Pig bristles	
	Raw	Hydrolysed
Arginine	9.1	5.5
Histidine	1.1	1.1
Isoleucine	3.6	2.2
Leucine	7.9	5.1
Lysine	3.1	2.7
Methionine	0.7	0.5
Phenylalanine	2.8	1.9
Threonine	6.2	2.2
Tryptophan	-	-
Valine	5.8	3.5

Table 33-02: Pig bristle meal (hydrolysed) as a protein source in diets for rainbow trout (*Salmo gairdneri*)⁽⁴⁾

Bristle meal	%	-	7.25	14.50
Feather meal	%	13.50	6.80	-
Fish meal	%	34.60	34.60	34.60
Poultry by-product meal	%	17.90	17.60	17.60

Growth	g	212.1	211.3	195.6
	%	100.0	99.6	92.2
Feed conversion	1:	1.18	1.18	1.28
	%	100.0	100.0	108.5

33.4 Recommended Inclusion Rates

The use of pig bristle meal as protein source for aquaculture diets is not recommendable. However, when used as a partial substitute for high quality protein sources, supplementation with certain amino acids is advisable.

33.5 Legal Aspects

AAFCO⁽¹⁾ has listed hydrolysed hair as No. 9.54 under the heading “Animal Proteins”. It is described as a product prepared from clean, undecomposed hair, by heat and pressure to produce a product suitable for animal feeding. Not less than 80% of the crude protein must be pepsin-digestible.

In the German feedstuff law pig bristle meal is not listed as a permitted feedstuff⁽⁶⁾.

33.6 References

1. AAFCO (1995): Official publication 1995. Ass. of American Feed Control Officials (publisher), Sacramento, CA/USA.
2. Kolb E. (1989): Lehrbuch der Physiologie der Haustiere (I). VEB Gustav Fischer Verlag, Jena/Germany.
3. Meyer, W. (1986): Die Haut des Schweines. Schlütersche Verlagsanstalt und Druckerei GmbH & Co., Hannover/Germany.
4. Tiews, K.; Koops, H.; Beck, H.; Schwalb-Bühling, A.; Gropp, J. (1981): Entwicklung von Ersatzfutter für die Regenbogenforelle. Bundesforschungsanstalt für Fischerei, Veröffentl. des Inst. für Küsten- und Binnenfischerei, Hamburg/Germany, Publ. No. 75.
5. Weinreich, O.; Koch, V.; Knippel, J. (1994): Futtermittelrechtliche Vorschriften. Buchedition Agrimedia, Hamburg/Germany.
6. West, G.P. (1992): Black's veterinary dictionary. A & C Black, London, 17th Edition.
7. Wöhlbier, W. (1977): Keratinhaltige Futtermittel. In: Kling, M.; Wöhlbier, W.: Handelsfuttermittel. Verlag Eugen Ulmer, Stuttgart/Germany.

34. POTATO-PROTEIN

34.1 Rationale

The recovery of protein from potato-processing waste is an active contribution to the improvement of the environment. It is an efficient use of resources, since these wastes have simply been dumped in the past. The volume of waste material is substantial. It is estimated that about 35% of the pre-processed potato, which is the World's fourth largest human food staple, after wheat, rice and maize, is discarded during processing.

34.2 Manufacture and Processing

Potato-protein is a by-product of starch processing from potatoes (*Solanum tuberosum*). By a special thermal coagulation, followed by a controlled separation technique, the potato-protein is precipitated from the potato-juice for further processing (Figure 34-01). The risk of bacteriological infection is low due to this production process⁽³⁾.

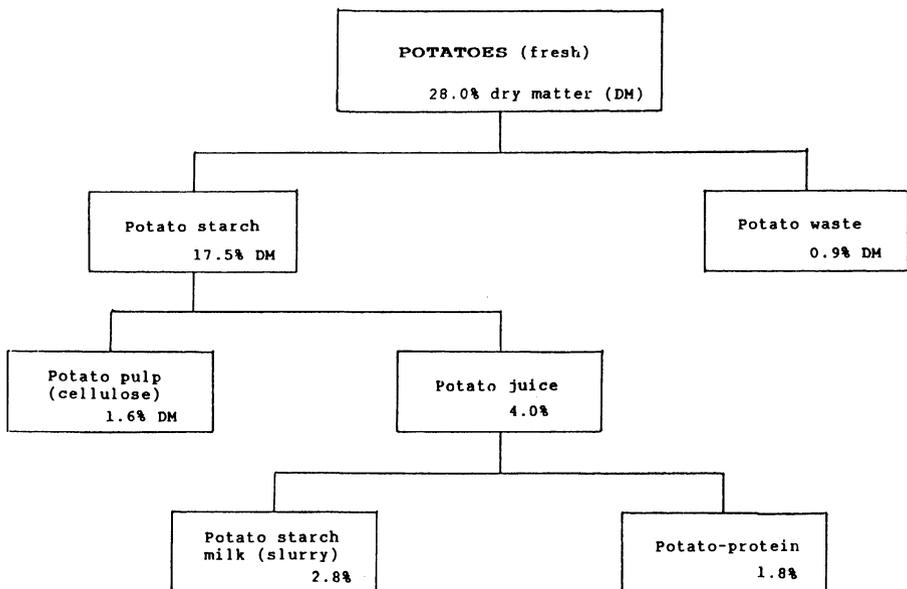


Figure 34-01. Approximate amounts of potato processing products^(data from:8).

Potato-protein is not like other potato protein sources which are by-products of consumer products. The latter is produced by applying a special strain of *Aspergillus niger* to enhance the fermentation. The finished product contains only approximately 37% crude protein⁽¹⁰⁾.

34.3 Chemical, Physiological and Other Properties

Chemical Properties

Potato-protein is an excellent protein source of high biological value. Not only does its protein content exceed levels in animal proteins, but it can also replace the most common protein sources in animal feed (Table 34-01). In addition, the amino acid profile is not only well balanced but the amino acid content is also high. This particularly applies to lysine, methionine, threonine and tryptophan. The amino acid level is higher than those of other protein feedstuffs (Figure 34-02).

Table 34-01: Chemical composition of potato-protein and some other protein sources^(4, 5, 8, 9)

	Potato-protein	Fish meal	Skimmilk powder	Soybean meal
1. Nutrients (%)				
Dry matter	89.4	90.6	94.4	94.5
Crude protein	81.8	65.0	34.1	47.0
Crude fat	2.8	7.5	-	0.7
Crude fibre	0.6	-	-	5.0
Ashes	2.6	16.0	8.2	6.7
2. Essential amino acids (g/16 g N):				
Arginine	4.9	5.7	3.6	7.2
Histidine	3.8	2.3	2.8	2.5
Isoleucine	5.3	4.4	5.6	4.9
Leucine	9.2	7.4	9.8	7.6
Lysine	6.8	7.5	8.2	6.4
Methionine	2.2	2.8	2.6	1.4
- Methionine + Cystine	2.9	3.7	3.5	3.9
Phenylalanine	5.2	4.2	4.8	4.9
Threonine	4.4	4.3	4.6	4.2
Tryptophan	1.4	1.1	1.3	1.3
Valine	5.5	5.5	6.9	5.0

The crude fibre content is insignificant. Potato protein is rich in phosphorus. It contains three times more phosphorus than calcium (Table 34-02).

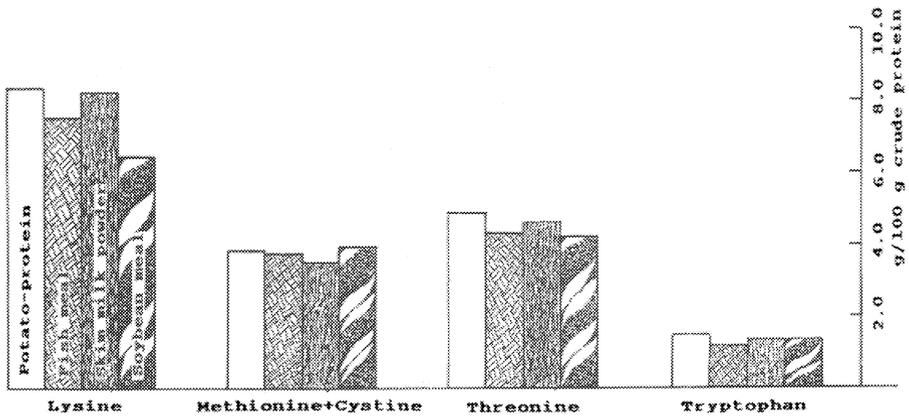


Figure 34-02. Essential amino acids of potato-protein compared with some important protein sources.

Table 34-02: Mean mineral content of potato-protein^(1, 5)

Calcium	Ca	%	0.15
Phosphorus	P	%	0.45
Sodium	Na	%	0.05
Potassium	K	%	0.80
Magnesium	Mg	%	0.10
Iron	Fe	mg/kg	40.0

Physiological Properties

The gross energy of potato protein, measured in the bomb calorimeter is 5,320 kcal/kg (22.3 MJ/kg). The digestible and metabolisable energy in pigs is 4,150 kcal/kg (17.4 MJ/kg) and 3,750 kcal/kg (15.7 MJ/kg), respectively⁽⁵⁾. Except for the fat, the digestibility of potato-protein in piglets is high as shown below and increases with the age of the animals⁽³⁾:

- Dry matter: 93.8%
- Organic matter: 94.5%
- Crude protein: 96.1%
- Crude fat: 43.3%
- Other carbohydrates: 92.9%

Other Properties

Potato-protein contains an antinutritional factor, “glycoalkaloid”. It is found in many plants and has a performance depressing property. At high levels it has a strong toxic effect.

The glycoalkaloid content, therefore, restricts the application rate to a maximum of 7.5% potato-protein in terrestrial animal feeds⁽²⁾.

34.4 Feeding Value

Potato-protein is a first rate source of protein due to its high protein content combined with the excellent digestibility and the superior content of balanced essential amino acids. In trials with terrestrial animals potato-protein has been compared with the best sources of protein used in animal feeding. The results suggest that the nutritional value of potato-protein is superior to soybean meal and equal to skim milk powder^(6, 7,11).

Cultured aquatic animals are highly demanding with regard to the protein content of the feed, its digestibility and essential amino acid profile. These needs can be met by potato-protein. But data from scientific experiments in aquatic animals are not yet available.

34.5 Recommended Inclusion Rates

Potato-protein is an excellent protein feed component for starter, grower and finisher feed for cultured aquatic animals (crustacean and fish). Recommended inclusion rates are:

- Starter feed: 5.0 to 6.5%
- Grower feed: 3.0 to 4.5%
- Finisher feed: 2.0 to 3.0%

34.6 Legal Aspects

The EU-Directive for feed ingredients has listed potato protein as no. 4.11 and described as a dried by-product of starch processing from potatoes and containing predominantly protein matters. The German feedstuff legislation follows this description, but requires also nutritional information⁽¹²⁾. These are:

- Crude protein: min. 75.0%
- Moisture: max. 14.0%
- Ash: max. 0.5%

34.7 References

1. *Anonymous* (1990): Protamyl PF high quality potato protein. AVEBE, The Netherlands, Ref. No. 05.52.31.603 EF/9005 SP&A/109484.
2. *Anonymous* (1991): Potato by-products as a protein source. *Feed International*, 12., (6), 27-28.
3. *Anonymous* (1993): Protamyl PF. AVEBE, The Netherlands, Ref. No. 05.52.32.603 EF/9303 SP&A.
4. *Anonymous* (1993): Potato protein specification. Emsland-Stärke GmbH (Mimeograph).
5. *Anonymous* (w/o year): Tubermine potato protein. Roquette, Lestrum/France (Mimeograph).
6. *Anonymous* (w/o year): Potato protein and fish protein in milk replacers for veal calves (unpublished)

manuscript).

7. *Borggreve, G.J.; Veen, W.A.G.* (1978): Nutritional value of potato protein in feed for piglets. C.L.O.-Inst. for Animal Nutrition, De Schoothorst/The Netherlands, No. 104 (March).
8. *De Boer, F.; Bickel, H.* (1988): Livestock feed resources and feed evaluation in Europe. E.A.A.P. Publication No. 37. Elsevier, Oxford, New York, Tokyo.
9. *Evans, M.* (1985): Nutrient composition of feedstuffs for pigs and poultry. Queensland Dept. of Primary Ind., Brisbane/Australia, Information Series Q 185001.
10. *Gillies, M.T.* (1978): Animal feeds from waste materials. Noyes Data Corporation, Park Ridge, NJ/USA.
11. *Lenis, N.P.; Diepen, J.T.M. van* (1992): Ileal amino acid digestibility and the nutritional value of potato protein. Dutch Res. Inst. for Livestock Feeding and Nutrition (IVVO-DLO) (unpublished Manuscript).
12. *Weinreich, O.; Koch, V.; Knippel, J.* (1994): Futtermittelrechtliche Vorschriften. Buchedition Agrimedia, Hamburg/Germany.

35. POULTRY BY-PRODUCT MEAL

35.1 Rationale

Poultry by-product meal is made from the rendered parts of slaughtered poultry. It consists of heads, feet, undeveloped eggs and viscera. From the latter, the chyme content should preferably be removed. Feathers are not used for processing poultry by-product meal which is also called poultry offal meal.

About 70% of the liveweight of a laying hen and a broiler are consumed by man. Head, feet and intestines amount to 19.7% in laying hens and 16.5% in broilers. The portion of unconsumable rejects declines by 0.4% per 100 g increase in liveweight of a broiler⁽⁵⁾.

World-wide more than 30 billion broilers are slaughtered annually. About 9.0 million MT of fresh offal in the form of heads, feet and viscera are obtained by assuming an average liveweight at slaughter of 1.8 kg which gives about 300 g offal per broiler. This figure does not include the offal from culled laying hens.

In countries where there is no market for poultry meat from culled laying hens, the birds are processed into the so called “whole poultry meal”. The product includes the whole, feathered carcass. The fat is usually removed⁽⁷⁾.

35.2 Manufacture and Processing

Wet-rendering is the classical procedure in processing the offals. The raw material is cooked under steam pressure at 110° to 130°C for three to six hours. After removal of the fat, the material is dried and ground.

This process has been widely replaced by dry-rendering, whereby the raw materials are chopped to hasten heat penetration and the release of fat. Batch or continuous cooking starts with an initial temperature of 100°C which gradually increases to 125°C. The water evaporates and the fat is separated by screw pressing or solvent extraction. Finally the material is ground and screened^(5, 7). Dangerous pathogens, such as salmonella which is killed by heating above 82°C for 20 minutes are destroyed completely⁽⁵⁾.

Poultry by-product meal is golden to medium brown in colour with a fresh poultry odour. The poultry by-product meal should be preferably treated with an antioxidant⁽¹⁷⁾.

35.3 Chemical and Physiological Properties

Chemical Properties

Poultry by-product meal is a rather heterogeneous material. The protein is predominantly from connective tissues⁽¹⁴⁾. The mean crude protein content of 61% ranges from

56.4 to 84.2. "Whole poultry meal" is much lower in protein and almost equal to its fat content (Table 35-01). Poultry by-product meal always contains some urea from the intestines. A content of 0.5% is considered normal. Higher levels of urea in poultry by-product meal indicate adulteration. Raw feathers are also used to adulterate the product which decreases the protein quality⁽³¹⁾. Poultry by-product meal is a good source of essential amino acids (Table 35-02)^(7, 20).

Table 35-01: Chemical composition (%) of poultry by-product meal^(3, 4, 6, 7, 15, 16, 17, 19, 21, 31) and "whole poultry meal"⁽⁷⁾ (as fed)

	Whole poultry meal	Poultry by-product meal	
		Mean	Variation
Dry matter	98.3	92.4	89.9 - 95.0
Crude protein	45.2	61.0	56.4 - 84.2
Crude fat	44.5	17.5	10.0 - 29.4
Ash	8.4	13.9	3.0 - 18.0
Crude fibre	-	2.1	0.4 - 3.6
N-free extract	0.2	3.5	2.0 - 5.4

Table 35-02: Essential amino acid profile of poultry by-product meal (g/16 g N)
(2, 6, 15, 16, 19, 20, 21, 31)

	Mean	Variation
Arginine	4.21	2.64 - 6.60
Histidine	1.17	0.75 - 1.43
Isoleucine	3.43	1.92 - 10.70
Leucine	4.68	3.34 - 9.50
Lysine	3.04	2.40 - 3.77
Methionine	1.16	0.77 - 2.80
Phenylalanine	2.46	1.67 - 5.30
Threonine	2.23	1.68 - 2.90
Tryptophan	0.55	0.46 - 0.80
Valine	2.81	2.18 - 3.50

The fat content of poultry by-product meal depends not only on the method of processing but also on the raw materials, particularly if meat chickens have a large amount of abdominal fat⁽⁷⁾. The fat content, therefore, varies widely but it is high in unsaturated fatty acids as follows^(7, 15, 16):

- Total saturated fatty acids: 32.6%
- Total unsaturated fatty acids: 63.1%
- PUFA: 17.6%
- Linoleic acid: 16.5%
- Linolenic acid: 1.1%

The crude fibre content of poultry by-product meal is merely from the chyme crude fibre and the keratin of the feet.

The variation of the ash content is high and may rise since consumers increasingly prefer processed poultry meat rather than whole carcasses so that more bones go to the offal⁽¹⁷⁾. Poultry by-product meal is a good source of iron and zinc as well as choline (Table 35-03).

Table 35-03: Mineral and vitamin contents of poultry by-product meal (as fed basis)

Minerals ^(7, 15, 16, 19, 21, 31)			Vitamins (per 1,000 g ^(7, 19))		
Calcium	%	3.36	Vitamin E	mg	2.05
Phosphorus	%	1.77	Vitamin B ₁	mg	0.20
Sodium	%	0.50	Vitamin B ₂	mg	10.50
Potassium	%	0.42	Vitamin B ₆	mg	4.40
Magnesium	%	0.13	Vitamin B ₁₂	mcg	306
Chlorine	%	0.54	Folic acid	mg	0.75
Sulphur	%	0.52	Nicotinic acid	mg	43.40
Manganese	mg/kg	11.0	Pantothenic acid	mg	9.95
Iron	mg/kg	506.0	Choline	g	4.10
Zinc	mg/kg	99.8			
Copper	mg/kg	9.7			
Selenium	mg/kg	0.78			

Physiological Properties

Due to high levels of abdominal fat in both broilers and culled laying hens poultry by-product meal has a high gross energy content (35-04)⁽⁷⁾. There is a tendency for digestible energy to decline with increasing levels of poultry by-product meal in the diet⁽²²⁾.

Table 35-04: Energy values of poultry by-product meal per kg

Species	Gross energy		Metabolisable energy		Digestible energy		Reference
	kcal	MJ	kcal	MJ	kcal	MJ	
	5,554	23.3	-	-	-	-	(15,24)
Rainbow trout	-	-	2,870	12.0	3,964	16.4	(4,18,22, 24)
Carp	-	-	3,554	14.9	-	-	(28)
Fishes ¹	-	-	2,561	10.7	3,926	16.4	(16,18)
Mean/all fishes	-	-	2,919	12.4	3,917	16.4	
Chicken	-	-	3,991	16.1	-	-	(7)

¹ Fish species not specified

In salmonids the digestibility of poultry by-product is negatively affected because of the keratin from the feet (Table 35-05). Adulteration with raw feathers reduces the digestibility further⁽¹⁴⁾, so that in general the protein quality of poultry by-product meal is considered to be low^(8, 22).

Table 35-05: Apparent digestibility (%) of poultry by-product meal in salmonids^(3, 4, 11, 22)

Dry matter	52.0	-
Crude protein	63.3	50.7 - 74.7
Crude fat	81.5	78.0 - 83.6
Energy	71.9	71.0 - 73.1

35.4 Feeding Value

Salmonids

Results of trials with poultry by-product meal in diets for Pacific salmon are inconsistent. Poultry by-product meal in moist diets for the chinook salmon (*Oncorhynchus tshawytscha*) depressed appetite⁽³⁰⁾, but in a dry diet for the coho salmon (*Oncorhynchus kisutch*) the appetite was enhanced⁽¹²⁾. Coho salmon utilises fat of non-defatted poultry by-product meal to the same extent as marine oil⁽¹²⁾. Equivalent growth rates with that of the control was observed when the moist diet for the coho salmon contained 60% poultry by-product meal⁽¹³⁾. An all herring meal diet fully replaced with defatted poultry by-product meal decreased growth rate, increased appetite and lowered feed and protein conversion in coho salmon, but substitution of 35% or 75% of the herring meal protein had no major effects on recorded parameters (Table 35-06)⁽¹²⁾.

Table 35-06: Response of coho salmon (*Oncorhynchus kisutch*) on diets containing increasing levels of poultry by-product meal and declining levels of herring meal (trial period: 168 days)⁽¹²⁾

Herring meal ¹	%	40.0	27.0	13.5	-
Poultry by-product meal ²	%	-	14.0	28.5	42.5
Crude protein	%	50.0	49.5	49.0	48.6
Crude fat	%	11.9	11.6	11.3	11.0

Initial weight	g	4.05	4.44	4.35	4.20
Final weight	g	26.5	27.2	27.5	25.9
Growth rate ³	%	1.100	1.074	1.093	1.057
Weight gain/dry feed	g	0.95	0.90	0.84	0.79

Body composition:					
- Protein	%	17.5	17.4	18.0	17.6
- Fat	%	5.5	5.5	5.0	4.6

¹ 70% crude protein; ² 66% crude protein; ³ % wet weight per day

In diets for rainbow trouts (*Salmo gairdneri*) poultry by-product meal may replace 50% to 75% of fish meal protein without negative effects on performances^(9, 25, 27). However, the full (100%) substitution of fish meal and a standard protein, respectively, by poultry by-product meal or combinations with feather meal and blood meal provoked poorer performances, even when the diet was supplemented with amino acids (Table 35-07)^(9, 23, 25, 27).

The body composition of salmonids is not affected by feeding poultry by-product meal (Table 35-06) unless the diet has a higher fat content (Table 35-07).

Table 35-07: Replacement of fish meal with poultry by-product meal in diets for fry and fingerlings rainbow trouts (*Salmo gairdneri*)⁽²⁵⁾

Fish meal	%	51.5	-
Poultry by-product meal	%	-	50.0
Methionine	%	-	1.5
Lysine	%	-	1.7
Crude protein	%	50.3	52.3
Fat	%	7.6	13.0
Digestible energy	kcal/kg	2,901	3,353

Initial weight	g	16.4	17.2
Final weight	g	45.8	44.8
Weight gain	g	29.4	27.6
Weight gain/feeding day	%	2.33	2.17
Feed conversion	1:	1.39	1.62

Body composition:			
- Crude protein	%	15.9	15.8
- Crude fat	%	5.9	10.0

Carp

Significant positive results for growth, feed conversion and protein utilisation were obtained in diets for Indian major carp (*Cirrhinus mrigala*) fry when poultry by-product meal at levels between 50% and 75% replaced the same amount of fish meal protein. The histological examinations of gills, liver, muscle, kidneys and intestines of fish revealed no noticeable changes at these levels⁽¹⁰⁾.

35.5 Recommended Inclusion Rates

Poultry by-product meal as the sole protein source depresses performances. For practical diets the following inclusion rates of poultry by-product meal are recommended:

- Carnivorous fish: max. 25%
- Omnivorous fish: max. 35%
- Crustaceans: max. 15%.

The supplementation of the formulation with lysine, methionine and tryptophan should be considered. The use of an antioxidant is advisable to avoid rancidity.

35.6 Legal Aspects

Poultry by-product meal is defined by EU-Directive as a product of dried and ground offal from slaughterings of poultry. It should be almost free of feathers (No. 9.05). A product which contains more than 13% fat has to be labelled as “rich in fat”⁽²⁹⁾. The German feedstuff law differentiates between two qualities (Table 35-08).

Table 35-08: Quality criteria for poultry by-product meal as required by German feedstuff legislation (%)⁽²⁹⁾

		Poultry by-product meal	Poultry by-product meal (high in fat)
Crude protein	min.	60.0	56.0
Digestible protein ¹	min.	80.0	80.0
Fat		<12.0	>12.0
Moisture	max.	10.0	10.0
Ash	max.	3.3	3.3
Sodium chloride	max.	2.0	2.0

¹ Pepsin digestibility

In U.S.A. *AAFCO*⁽¹⁾ has listed two products:

- Poultry by-product meal (No. 9.10)
- Poultry meal (No. 9.71)

The manufacturer of poultry by-product meal has to guarantee minimum crude protein, minimum crude fat, maximum crude fibre, minimum phosphorus and minimum/maximum calcium. The calcium level should not exceed the phosphorus content by more than 2.2 times. Poultry meal is produced predominantly from whole carcasses (culled laying hens).

35.7 References

1. *AAFCO* (1995): Official publication 1995. Ass. of American Feed Control Officials (publisher), Sacramento, CA/USA.
2. *Behm, G.; Dressler, D.; Gaus, G.; Herrmann, H.; Küther, K.; Tanner, H.* (1988): Amino acids in animal nutrition. Arbeitsgemeinschaft für Wirkstoffe in der Tierernährung, Bonn/Germany (Publisher).
3. *Cho, C.Y.; Slinger, S.J.* (1979): Apparent digestibility measurement in feedstuffs for rainbow trout. Proc. World Symp. on Finfish Nutr. and Fishfeed Techn., Hamburg/Germany, Vol. II, 20-23 June, 1978.
4. *Cho, C.Y.; Cowey, C.; Watanabe, T.* (1985): Finfish nutrition in Asia: Methodological approaches to research and development. IDRC, Ottawa/Canada, 233e.
5. *De Boer, F.; Bickel, H.* (1988): Livestock feed resources and feed evaluation in Europe. Elsevier Sciences Publishers, Amsterdam / The Netherlands.
6. *Dupree, H.K.; Huner, J.V.* (1984): Third report to the fish farmers. Publ. U.S. Fish and Wildlife Service, Washington, D.C.
7. *Evans, M.* (1985): Nutrient composition of feedstuffs for pigs and poultry. Queensland Dept. Primary Ind., Brisbane / Australia (Series Q 185001).
8. *Friesecke, H.* (1984): Handbuch der praktischen Fütterung von Rind, Schaf, Pferd, Schwein, Geflügel und Süßwasserfischen. BLV Verlagsges., München/Germany.
9. *Gropp, J.; Koops, H.; Tiews, K.; Beck, H.* (1976): Ersatz von Fischmehl im Forellenfutter. Arb. Deutscher Fischerei-Verb., (10), 85-102.
10. *Hasan, M.R.* (1992): A preliminary study of the use of poultry offal meal as dietary protein source for Indian major carp *Cirrhinus mrigala* (Hamilton). Abstr. 3rd Asian Fish. Forum, Singapore, 26-30 October, 96.
11. *Hepher, B.* (1988): Nutrition of pond fishes. Cambridge University Press, Cambridge/U.K.
12. *Higgs, D.A.; Markert, J.R.; Macquarrie, D.W.; McBride, J.R.; Dojanjh, C.; Hoskins, G.* (1979): Development of practical diets for coho salmon, *Oncorhynchus kisutch*, using poultry by-product meal, feather meal, soybean meal and rape seed meal as major protein sources. Proc. World Symp. on Finfish Nutr. and Fishfeed Techn., Hamburg/Germany, Vol. II, 20-23 June, 1978, 191-216.
13. *Markert, J.R.; et al.* (1977): Quoted from *Higgs, D.A.; et al.* (1979).
14. *Meyer, H.* (1990): Ernährung des Hundes. Verlag Eugen Ulmer, Stuttgart/Germany (2nd ed.).
15. *Meyer, H.; Heckötter, Elke* (1986): Futterwerttabelle für Hunde und Katzen. Schlütersche Verlagsanstalt, Hannover/Germany.
16. *New, M.B.* (1987): Feed and feeding of fish and shrimps - A manual on the preparation and presentation of compound feeds for shrimps and fish in aquaculture. UNDP/FAO/ADCP/REP/87/26, Rome/Italy.
17. *NRA* (1993): Pocket information manual - a buyers guide to rendered products. NATIONAL Renderers Ass., Inc., Alexandria, Vir./USA.
18. *NRC* (1981): Nutrient requirements of coldwater fishes. National Academy Press, Washington, D.C.
19. *NRC* (1983): Nutrient requirements of warmwater fishes and shellfishes. National Academy Press. Washington, D.C.
20. *Paulraj, R.* (1995): Aquaculture feed (2nd edition). Marine Prod. Export Dev. Authority, Kochi/India (Publ.).
21. *Pesti, G.M.; Dubuc, P.G.* (1986): The relationship between poultry by-product meal content and market value. Proc. Arkansas Nutr. Conference, Little Rock, Arkansas/USA, 18-19 September.
22. *Pfeffer, E.* (1993): Ernährungsphysiologische und ökologische Anforderungen an Alleinfutter für Regenbogenforellen. Übers. Tierernährung, 21., 31-54.
23. *Schulz, D.; Hartfiel, W.; Greuel, E.* (1982): Verwendung von Nebenprodukten tierischer Herkunft in der Ernährung von Regenbogenforellen (*salmo gairdneri*). II. Einsatz von Blut-, Feder- und Geflügel-

- schlachtabfallmehl sowie Gelatine in einer gereinigten Diät. Z. Tierphysiol., Tierernährung, Futtermittelkd., 48., 267-275.
24. *Smith, R.R.; Peterson, M.C.; Allred, A.C.* (1980): Effect of leaching on apparent digestion coefficients of feedstuffs for salmonids. *Progr. Fish-Culturist*, 42., 195-199.
 25. *Steffens, W.* (1987): Further results of complete replacement of fish meal by means of poultry by-product meal in feed for fry and fingerling (*Salmo gairdneri*). *Arch. Tierernährung*, 37., 1135-1139.
 26. *Tacon, A.G.J.* (1993): Feed ingredients for warmwater fish, fish meal and other processed feedstuffs. FAO Fisheries Circular No. 856 (FIRI/C856), FAO-UN, Rome/Italy. -23-
 27. *Tiews, K.; Koops, H.; Beck, H.; Schwalb-Bühling, A.; Gropp, J.* (1981): Entwicklung von Ersatzfutter für die Regenbogenforelle. Bundesforschungsanstalt für Fischerei, Veröffentl. des Inst. für Küsten- und Binnenfischerei, Hamburg/Germany, Publ. No. 75.
 28. *Viola, S.* (1977): Energy values of feedstuffs for carp. *Bamidgeh*, 29., 29-30.
 29. *Weinreich, O.; Koch, V.; Knippel, J.* (1994): Futtermittelrechtliche Vorschriften. Buchedition Agrimedia, Hamburg/Germany.
 30. *Whitmore et al.* (1962): Quoted from: *Higgs, D.A., et al.*(1979).
 31. *Wöhlbier, W.* (1977): Geflügelschlachtabfälle. In: *Kling, M.; Wöhlbier, W.*: Handelsfuttermittel. Verlag Eugen Ulmer, Stuttgart/Germany.

36. PULSES

36.1 Rationale

Pulses are the edible seeds of plants having pods. They belong to the comprehensive botanical family of *Leguminosae*. Most of the pulses are primarily for human consumption but certain species are cultivated mainly for animal feed. Compared to cereals, some pulses yield much less energy and protein per ha. While wheat yields per ha 510 kg protein, chick peas (*Cicer arietinum*) only yield 140 kg/ha⁽⁵⁾.

Pulses are mainly produced in Asia and Africa. World production of pulses range from 55 to 60 million MT per annum, excluding legumes cropped for their vegetable oil such as soya beans and ground nuts. The major producers are India (23.5% of World production), P.R. China (10.2%), Brazil (4.1%), Turkey (3.5%) and Nigeria (2.4%).

Species of pulses produced vary from area to area and cropping is related to the climatic requirements of the species and the customs of the people who use them as food. The main common pulses produced are listed according to their genus:

- Black gram (*Phaseolus mungo*)
- Field bean (*Phaseolus vulgaris*)
- Green gram (*Phaseolus aureus*)

- Faba bean (*Vicia faba*)
- Vetch (*Vicia sativa*)

- Cow pea (*Vigna catiang, Vigna unguiculata*)
- Mung bean (*Vigna radiata, Vigna mungo*)

- Blue (sweet) lupin (*Lupinus angustifolius*)
- White lupin (*Lupinus albus*)
- Yellow lupin (*Lupinus luteus*)

- Chick pea (*Cicer arietinum*)
- Jack bean (*Canavalia ensiformis*)
- Lentils (*Lens esculenta*)
- Pea (*Pisum sativum*)
- Sesbania (*Sesbania grandiflora*)
- Velvet beans (*Stizologium sp.*)

36.2 Harvesting and Processing

In advanced agricultural systems pulses are harvested at the optimum degree of ripeness by a combine-harvester. Seeds have to be artificially dried depending on the moisture content.

Since almost all pulses contain anti-nutritional substances, various treatments can be applied for the removal of these factors⁽⁵⁾.

De-hulling of pulses reduced the crude fibre content and improves the feeding value. For example, crude fibre in non-dehulled lupin seeds is 16%, 3.0% in dehulled and 51% in the hulls⁽¹²⁾. Pulses have to be ground before using them in aquaculture feed.

36.3 Chemical, Physiological and Other Properties

Chemical Properties

The seeds of pulses are rich in crude protein whereby peas have the lowest protein content and lupins the highest (Table 36-01). The quality of the protein differs between species and cultivars. Generally, pulses are deficient in the sulphur-containing amino acids, but may also contain low levels of tryptophan (Table 36-02)^(5, 9).

The oil of blue (sweet) lupins is rich in mono (31.2% of total fat) and poly-unsaturated fatty acids (53.7%)⁽¹²⁾.

While faba beans, lupins and sesbania seeds have a high crude fibre content, some of the *Phaseolus* beans and cow peas are low in crude fibre and make them more suitable for aquaculture feed (Table 36-01).

Pulses are a fair source of phosphorus but the calcium content is lower than the phosphorus. Cow peas and field beans are high in iron (Table 36-03). Pulses contain significant amounts of Vitamin B₁, Vitamin B₂ and nicotinic acid (Table 36-04).

Table 36-01: Chemical composition of selected pulses (% in dry matter)

	Moisture	Crude protein	Crude fat	Crude fibre	N-free extract	Ash	Reference
Black gram	-	25.8	1.7	6.1	62.0	4.4	(2, 7)
Chick peas	9.2	20.6	4.4	7.7	64.0	3.3	(2)
Cow peas	7.4	25.1	4.9	7.2	58.7	4.1	(7, 17)
Green gram	9.0	24.2	2.0	5.0	64.7	4.1	(2, 7, 17)
Faba beans	9.9	28.3	8.4	24.8 ¹	34.9	3.6	(11, 22)
Lupin, white	10.4	34.5	6.1	15.5	40.2	3.7	(9, 11, 12, 15)
Lupin, blue	9.0	29.8	5.5	15.0	46.9	2.8	(26)
Peas	11.2	23.7	1.7	6.8	64.3	3.5	(11)
Sesbania seeds	12.3	30.1	2.6	10.3	51.7	5.3	(17, 19)

¹non-detergent fibre, ash free

Table 36-02: Amino acid profile of various pulses (g/16 g N)

	Chicken Pea ⁽²⁾	Cow pea ⁽²⁾	Green gram ⁽²⁾	White lupin ⁽¹⁵⁾	Blue lupins ⁽¹²⁾
Arginine	12.79	11.74	9.76	11.21	10.53
Histidine	3.94	4.59	3.09	1.77	2.17
Isoleucine	6.14	6.65	5.15	3.85	3.72
Leucine	8.75	8.97	7.49	7.69	6.81
Lysine	11.53	6.68	14.26	4.87	5.08
Methionine	2.83	3.02	2.35	0.50	1.00
Phenylalaline	6.87	7.07	5.70	3.77	6.02
Threonine	4.17	4.71	3.26	4.02	3.92
Tryptophan	-	-	-	0.74	1.20
Valine	5.75	6.85	5.89	3.47	4.02

Table 36-03: Macro and trace mineral contents of selected pulses ^(9, 12)

		Chick Peas	Cow peas	Field beans	Lupines	Mung beans	Peas
Calcium	%	0.05	0.27	0.19	0.20	0.22	0.25
Phosphorus	%	0.12	0.42	0.43	0.30	-	0.28
Sodium	%	0.16	0.30	0.05	0.05	-	0.16
Potassium	%	0.60	2.00	1.24	0.74	-	0.72
Magnesium	%	0.26	0.39	0.25	0.17	-	0.12
Chlorine	%	-	-	0.04	-	-	-
Sulphur	%	-	-	0.23	0.23	-	-
Manganese	mg/kg	-	-	17.0	29.2	-	24.0
Iron	mg/kg	100	1,000	820	40	-	270
Zinc	mg/kg	-	-	42.0	26.8	-	52.0
Copper	mg/kg	-	-	7.0	3.4	-	6.8
Selenium	mg/kg	-	-	-	0.80	-	-

Table 36-04: The vitamins of selected pulses (per 1,000 g)⁽⁹⁾

		Chick Peas	Cow peas	Field beans	Lupines	Mung beans	Peas
Vitamin A	I.U.	16,500	-	-	6,400	900	-
Vitamin E	mg	-	-	1.0	-	-	-
Vitamin B ₁	mg	5.3	0.9	6.0	-	5.7	-
Vitamin B ₂	mg	1.8	0.1	1.8	-	2.2	1.9
Vitamin B ₆	mg	-	-	0.3	-	-	0.7
Biotin	mg	-	-	90.0	-	-	-
Folic acid	mg	-	-	1.3	-	-	17.1
Nicotinic acid	mg	20.0	44.0	23.6	-	26.0	-
Pantothenic acid	mg	-	-	3.0	-	-	5.3
Choline	mg	-	-	1,714	-	-	700

Physiological Properties

Pulses are both a protein and an energy feedstuff. The gross energy content of pulses is high. Digestible energy of pulses seems to be related to the individual species of pulses, and for fish ranges from 1,362 to 2,414 kcal/kg (5.7 to 14.7 MJ/kg) (Table 36-05). The digestible energy of pulses, is affected by their level in the diet as well as the manner of treatment applied, as found in rainbow trout (*Oncorhynchus mykiss*)^(21, 22). The digestible energy of untreated pulses is so low that they are unsuitable for aquaculture feed (Table 36-06)⁽²¹⁾.

Table 36-05: The energy contents of pulses per kg

Species	Gross energy		Metabolisable energy		Digestible energy		References
	kcal	MJ	kcal	MJ	kcal	MJ	
Black gram	4,923	20.6	-	-	-	-	(7)
- Fish ¹	-	-	-	-	2,323	9.7	(6)
Chick peas	-	-	-	-	-	-	(12)
- Chicken	-	-	2,920	12.2	3,320	13.9	(9)
Cow peas	4,756	19.9	-	-	-	-	(7, 12, 17)
- Fish ¹	-	-	-	-	2,354	9.8	(6)
- Chicken	-	-	2,930	12.2	3,220	13.5	(9)
Green gram	4,182	18.9	-	-	-	-	(2, 7, 17)
- Fish ¹	-	-	-	-	2,331	9.8	(6)
Faba beans	4,517	18.9	-	-	-	-	(11, 22)
- Rainbow trout	-	-	-	-	1,840	7.1 ^{2,3}	(11, 20)
	-	-	-	-	1,365	5.7 ^{2,4}	(11, 20)
	-	-	-	-	2,083	11.8 ^{5,3}	(11, 20)
	-	-	-	-	2,414	10.7 ^{4,5}	(11, 20)
Lupins, white	4,553	19.0	-	-	-	-	(11, 19)
- Chicken	-	-	2,930	12.3	3,390	14.2	(9)
Lupins, blue	4,300	18.0	-	-	-	-	(26)
- Chicken	-	-	2,008	8.4	-	-	(9)
Mung beans	-	-	2,750	11.5 ⁶	-	-	(2, 7, 17)
- Chicken	-	-	2,796	11.7	3,400	14.2	(9)
Peas	4,015	16.8	-	-	-	-	(11)
- Chicken	-	-	2,870	12.0	3,400	14.2	(9)
- Rainbow trout	-	-	-	12.0	2,055	8.6 ^{2,3}	(11, 20)
	-	-	-	-	1,840	7.1 ^{2,4}	(11, 20)
	-	-	-	-	2,700	11.3 ^{3,5}	(11, 20)
	-	-	-	-	1,625	6.8 ^{4,5}	(11, 20)

¹Not specified; ²De-hulled seeds; ³25% in the diet; ⁴50% in the diet; ⁵Pulsed treated (autoclaved); ⁶Dehulled seeds

The effect of treatment and inclusion rate applies also to the digestibility of pulses. Regardless of the treatment and the inclusion rate, the carbohydrate digestibility with salmonids as carnivores is low while it is higher for the common carp (*Cyprinus carpio*). It also digests lupins better than peas (Table 36-06).

Table 36-06: Digestibility (%) of selected pulses

	Dry matter	Protein	Fat	Crude fibre	Carbo-hydrates	Energy	Reference
Faba beans							
- Rainbow trout	-	78.0	-	-	18.0	43.0 ^{1,2}	(21)
	-	89.0	-	-	35.0	67.0 ^{1,3}	(21)
	-	70.0	-	-	8.0	32.0 ^{2,4}	(21)
	-	86.0	-	-	35.0	57.0 ^{3,4}	(21)
Lupins, bitter							
- Common carp	-	97.5	80.5	86.5	80.5	-	(14)
Lupins, sweet							
- Common carp	-	96.0	91.0	81.5	80.7	-	(14)
	-	-	-	-	57.0	-	(14, 23)
Peas							
- Rainbow trout	-	86.0	-	-	21.0	47.0 ^{1,2}	(21)
	-	91.0	-	-	42.0	65.0 ^{1,3}	(21)
	-	83.0	-	-	13.0	39.0 ^{2,4}	(21)
	-	86.0	-	-	18.0	40.0 ^{3,4}	(21)
- Common carp	-	71.7	-	40.8	60.0	-	(14, 23)
	44.3	-	-	-	45.0	-	(14, 23)

¹Pulses untreated; ²25% in the diet; ³50% in the diet; ⁴Pulses treated (autoclaved)

Other Properties

Pulses contain a number of anti-nutritional factors. Among the chemical compounds that can create problems in feeding pulses are⁽⁵⁾:

- Protease inhibitors,
- Phenolic compounds (tannins, isoflavonols),
- Goitrogens,
- Anti-vitamins,
- Cyanogens,
- Metal-binding factors,
- Lathrogens,
- Lectins (phytohemagglutinins).

Trypsin inhibitor is an important anti-nutritional factor that can be eliminated by heat treatment (roasting or autoclaving)⁽⁹⁾. The lupins of Western Australia have a particularly low alkaloid content. The mean alkaloid level is 0.007% with a range from 0.002 to 0.025%⁽¹²⁾.

The pelletising ability of pulses is variable. While faba beans contribute to a good pellet quality, locust beans have a low pelletising ability⁽¹⁰⁾.

36.4 Feeding Value

Extensive research has been done in countries where pulses are commonly produced and have been found to be valuable. Experiments in aquaculture are rather limited.

Green gram (Phaseolus aureus: synonym Vigna radiata)

In a 10-week feeding period with tilapia (*Oreochromis niloticus*) fry (2.9 g) the best daily weight gain and feed conversion was obtained at the 25% level of green gram substitution⁽⁶⁾. Protein deposition in the carcass was higher in all fish meal diet (Table 36-07).

Table 36-07: Performance of tilapia (*Oreochromis niloticus*) fry (2.92 g) on diets containing green gram (*Phaseolus aureus*) (crude protein, 25%)⁽⁶⁾

Green gram	%	0	13	25	37	50
Fish meal	%	30	24	19	14	8

Final weight	g	18.1	11.1	11.4	10.9	11.6
Feed conversion	1:	1.55	2.13	1.92	2.24	2.02
PER ¹		2.52	1.85	2.12	1.84	2.08
NPU ²	%	40.91	32.37	33.80	30.72	33.87

¹Protein efficiency ratio; ²Net protein utilisation

Faba Beans (Vicia faba)

Faba beans are also known as field beans, broad beans and horse beans. There are summer and winter varieties.

Various treatments of faba beans do not affect much of their nutrient content. Only cystine was negatively affected by all manner of treatments when compared to the untreated control (Table 36-08)⁽²²⁾. Tests on their protein quality parameters and apparent digestibility were done on rats. In diets for rainbow trout (*Oncorhynchus mykiss*), faba beans have a potential as a partial replacement for a brown fish meal (Table 36-09)^(11, 25). At high levels of faba beans (45%), supplementation with amino acids is needed⁽²⁵⁾.

Table 36-08: Various treatments of faba beans (*Vicia faba*) and their effects on the chemical composition (in dry matter)⁽²²⁾

Nutrient		Raw	Roasted	Sprouted cooked	Pressure	De-hulled
Crude protein	g	25.8	25.8	25.5	24.4	24.5
Lysine available	g/16 gN	6.0	4.6	5.3	4.8	5.6
Methionine	g/16 gN	0.5	0.4	0.4	0.3	0.4
Cystine	g/16 gN	1.3	1.2	1.3	1.2	1.3
Tryptophan	g/16 gN	1.1	0.8	0.9	0.6	0.9
Calcium	mg %	0.18	0.18	0.16	0.18	0.16
Phosphorus	mg %	0.42	0.42	0.40	0.33	0.42
Iron	mg/kg	40	39	29	26	37
Ionisable iron	mg/kg	17	16	18	11	15
Copper	mg/kg	7	7	6	6	7
Manganese	mg/kg	11	11	10	11	9
Zinc	mg/kg	57	56	54	50	57

Table 36-09: Responses of rainbow trout (*Oncorhynchus mykiss*) fed untreated and treated faba beans and sweet lupin, respectively⁽¹¹⁾

Brown fish meal	%	57.1	45.7	45.7	45.7	45.7
Faba bean meal raw	%	-	26.0	-	-	-
Faba bean cooked/expanded	%	-	-	26.0	-	-
Lupin meal raw	%	-	-	-	22.2	-
Lupin meal cooked/expanded	%	-	-	-	-	22.2
Crude protein	%	42.5	39.1	39.8	41.5	41.3
Crude fat	%	12.7	13.5	13.5	14.2	14.0

Initial weight	g	24.9	25.0	24.6	25.3	24.5
Weight gain	g	61.9	76.5	78.9	87.4	84.3
Specific growth rate	%/day	1.7	2.0	2.0	2.1	2.1
Protein efficiency ratio		0.95	0.91	1.16	1.5	1.4
Feed conversion	1:	2.19	1.70	1.88	1.6	1.7
Liver somatic index		2.83	2.77	2.61	2.5	2.3
Carcass composition	(DM)					
- Crude protein	%	54.6	50.6	53.0	51.9	53.9
- Crude fat	%	29.7	28.7	33.4	35.2	34.7

Cow peas (*Vigna catiangu*)

The effects of cow peas also “black-eyed peas” on the ovarian development of Nile tilapia (*Oreochromis niloticus*) by substituting part of the fish meal is uncertain. Cow pea meal 18 or 42% in the diet in a 25% protein diet fed for⁽⁴⁾ nine weeks *ad libitum* had smaller and less mature vitellogenic oocytes than the control fish fed fish meal. Lack of “vitellogenic proteins” and/or lipids in cow peas may be the cause for negative effects. But enhanced gonadal development of Nile tilapia males and females were observed when fed diets with cow peas and 28% total protein⁽³⁾.

Tiger prawn (*Penaeus monodon*) juveniles fed unde-hulled and dehulled cow pea diets that replaced around 15.5% of the animal protein in the diet tended to grow better on the dehulled rather than on the unde-hulled cow pea diet (Figure 36-01)⁽⁸⁾.

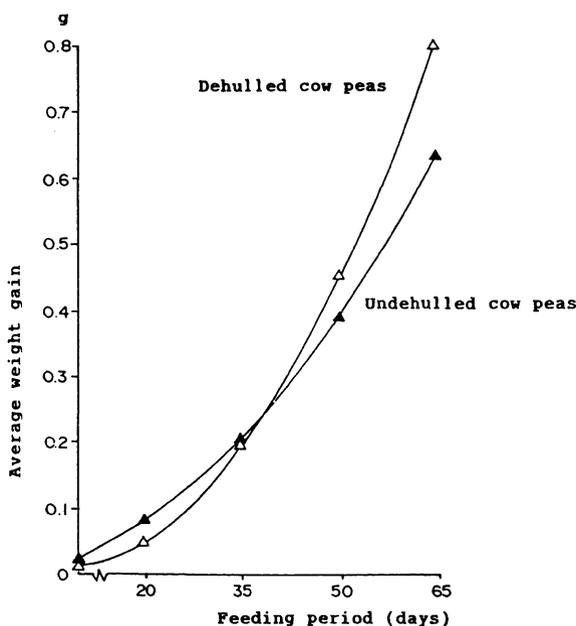


Figure 36-01. Growth of juvenile tiger prawn (*Penaeus monodon*) fed unde-hulled and dehulled cow peas (*Vigna catiangu*) diets^(Data from: 8).

Lupins (*Lupinus spp*)

There are two basic varieties of lupins. The bitter variety (*Lupinus luteus*) is unsuitable as a feedstuff due to its high alkaloid content but the sweet lupins (*Lupinus angustifolius*) particularly the Australian cultivars are almost free of alkaloids^(9, 12).

Sweet lupin meal can partially replace fish meal in diets for rainbow trouts. Up to 30% of diet's protein from lupins can be used without any negative effect on performances^(13, 15, 25). Supplementation with methionine and lysine is required⁽¹⁵⁾.

Heating, cooking and expanding did not improve the nutritional quality of lupin meal (Table 36-09)^(11, 15).

The combination of lupin meal and fish meal was even significantly better than feeding fish meal alone as the only protein source. However, lupin feeding increased the fat content of the carcass (Table 36-09)⁽¹¹⁾.

Sweet lupins (*Lupinus angustifolius*) at 30% and 45% level in pelletised feeds for intensive culture of carp performed as well as the respective control diet (without lupin) (Table 36-10)⁽²⁶⁾.

Table 36-10: Growth performance of carp (Israeli strain Dor-70) fed diets with lupin meal⁽²⁶⁾

Herring meal	%	15.0	15.0 ¹	20.0	35 ¹
Lupin meal	%	30.0	-	45.0	-

Weight gain	g	171.3	133.5	114.5	117.0
Specific growth rate	%/day	1.03	0.85	1.00	1.00
Feed conversion	1:	3.20	4.10	3.25	3.2
Body composition					
- Moisture	%	72.0	72.1	73.6	73.9
- Protein	%	14.8	15.2	15.4	15.0
- Fat	%	9.6	10.3	5.8	7.4
- Ash	%	2.7	3.0	3.1	2.9

¹Controls

Jack Beans (Canavalia ensiformis)

Jack beans have the potential as a partial substitute for fish meal in diets for tilapia (*Oreochromis mossambicus*). There is a direct relationship between fish mortality and the increase of jack bean meal in the diet. Eliminating the non-thermolabile toxic factors by boiling (30 min. at 125°C) or soaking the beans in a 1:1 ethanol-sulfuric acid solution improved the feeding value when 25% of the fish meal was replaced with the treated beans. Non-treated beans depressed appetite and lethargic movements were observed after three weeks of feeding (Figure 36-02)⁽¹⁶⁾.

Peas (Pisum sativa)

Peas also called field peas has been found to give rainbow trout a significantly better performance than those fed the fish meal control diet⁽¹¹⁾. No differences were observed in feed conversion and food intake⁽¹¹⁾.

Sesbania Seed Meal (Sesbania grandiflora)

Sesbania meal contains thermolabile toxins. Different treatments are costly, but the feeding value of treated seed is not comparable to fish meal. In addition, there is a direct relation between mortality and the level of sesbania meal in the diet (Table 36-11)⁽¹⁹⁾.

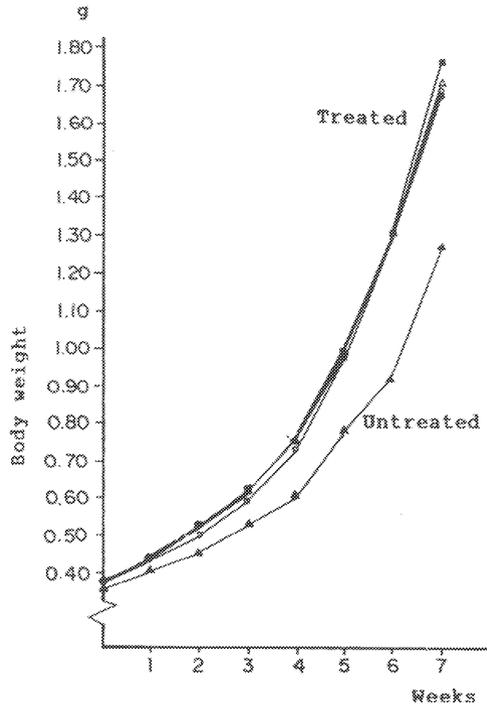


Figure 36-02. Growth of tilapia (*Oreochromis mossambicus*) fed 25% treated (various treatments) and untreated seed meal of jack beans (*Canavalia ensiformis*)^(Data from: 16)

Table 36-11: Effect of 25% sesbania seed (*Sesbania grandiflora*), differently treated as replacement for fish meal in diets fed to tilapia (*Oreochromis mossambicus*)⁽¹⁹⁾

Treatment		Control	1.	2.	3.
Weight gain	%	288	134.91	145.29	114.48
Survival	%	98.3	77.89	40.00	15.00
SGR	%/day	2.5	1.57	1.65	1.4
FCR	1:	1.06	1.70	1.82	2.1
PER		2.44	1.58	1.46	1.29

1. Raw seed meal autoclaved for 30 min. and then soaked for 12 h in distilled water;
2. Sesbania meal boiled in distilled water by autoclaving for 30 min.;
3. Sesbania meal treated by autoclaving at 125°C for 30 min.

36.5 Recommended Inclusion Rate

Untreated seeds of pulses cannot be recommended as ingredients for aquatic animals⁽²⁰⁾. Even the inclusion rate of treated seeds have to be restricted. A general guideline for the use of pulses in aquaculture feed is:

- Untreated seeds of pulses should not be used;
- Treated pulses should be avoided in diets for young animals;
- Treated seeds in diets for older aquatic animals should not exceed 15%;
- The amino acids, particularly these sulphur-containing, have to be balanced.

36.6 Legal Aspects

EU-Directive 92/87/EEC of 26 October 1992, describes under Section 3 a total of 13 products of pulses. The Directive requires that seeds *Phaseolus* and *Vigna* species have to be heat-treated in order to destroy the toxic lectins⁽²⁷⁾.

Presently in the U.S.A. under the heading “Miscellaneous Products” are tentatively listed in the Feed Ingredients Definitions of AAFCO⁽¹⁾:

- Sweet lupin meal (No. T60.78)
- Sweet lupin meal, de-hulled (No. T60.79)
- Sweet lupin meal, solvent extracted (No. T60.80)

The pulses products defined by the German feedstuff legislation is compiled in Table 36-12. The compulsory heat treatment as mentioned above is compulsory⁽²⁷⁾.

Table 36-12: Minimum/maximum requirements for pulse products (%) by the German feedstuff law⁽²⁷⁾

	Moisture Max.	Crude protein min.	Crude fibre max.	Starch min.
Bean flakes ¹	13.0	-	6.0	35.0
Bean hulls	13.0	-	-	-
Faba beans flakes ¹	13.0	-	-	-
Lentil flakes	14.0	-	-	-
Phaseolus beans ¹	13.0	-	-	-
Pea flakes ¹	13.0	-	-	-
Pea feed meal	14.0	21.0	8.0	-
Pea bran	13.0	-	28.0	-
Pea hulls	13.0	-	-	-
Vitch flakes ¹	13.0	-	-	-

¹Heat treatment for these products is compulsory by law

36.7 References

1. *AAFCO* (1995): Official publication 1995. Ass. Of American Feed Control Officials (publisher) Sacramento, CA/USA.
2. *Anonymous* (1968): Food Composition Table [Recommended for use in the Philippines]. Food and Nutr. Res. Inst., Handbook No. 1, 3rd revision.
3. *Cumaranatunga, P.R.T.; Mallika, K.L.G.P.* (1991): Effects of different levels of dietary protein and a legume (*Vigna catianga*) on gonadal development in *Oreochromis niloticus* (L.). Proc. Fourth Asian Fish Nutrition Workshop. Asian Fish. Soc. Spec. Publ. 5, Asian Fish. Soc, Manila/Philippines. 125.
4. *Cumaranatunga, P.R.T.; Thabrew, H.* (1989): Effects of legume (*Vigna catianga*) substituted diets on the ovarian development of *Oreochromis niloticus*. Proc. Third Int. Symp. on Feeding and Nutrition in Fish, Toba, 28 Aug. to 1 Sept. (1.), Japan. 333-344.
5. *De Boer, F.; Bickel, H.* (1988): Livestock feed resources and feed evaluation in Europe. Elsevier Sciences Publishers, Amsterdam/The Netherlands.
6. *De Silva, S.S.; Gunasekera, R.M.* (1989): Effect of dietary protein level and amount of plant ingredient (*Phaseolus aureus*) incorporated into the diets on consumption, growth performance and carcass composition in *Oreochromis niloticus* (L.) fry. *Aquaculture*, 80., 121-133.
7. *De Silva, S.S.; Keembiyahetty; Gunasekera, R.M.* (1988): Plant ingredient substitutes in *Oreochromis niloticus* (L.) diets: Ingredient digestibility and effect of dietary protein content on digestibility. *J. Aqua. Trop.*, 3., 127-138.
8. *Eusebio, P.* (1991): Effect of dehulling on the nutritive value of some leguminous seeds as protein sources for tiger prawn (*Penaeus monodon*) juveniles. *Aquaculture*, 99., 297-308.
9. *Evans, M.* (1985): Nutrient composition of feedstuffs for pigs and poultry. Queensland Dept. Primary Ind., Brisbane/Australia (Series Q 185001).
10. *Gill, C.* (1993): Chemistry for high quality pellets. *Feed International*, 14., (3), 10-11.
11. *Gouveia, A.; Oliva, T.A.; Gomes, E.; Rema, P.* (1991): Effect of cooking/expansion of three legume seeds on growth and food utilization by rainbow trout. Proc. Fish Nutrition in Practice. Biarritz (France). 24 to 27 June. 933-938
12. *GPWA* (1989): Grain Pool of Western Australia, Perth/Australia (Private communication).
13. *Groop, J.; Beck, H.; Koops, H.; Tiews, K.* (1979): Quoted from: *Higuera et al.* (1988).
14. *Hepher, B.* (1988): Nutrition of pond fishes. Cambridge University Press, Cambridge/U.K.
15. *Higuera, M. de la; Garcia-Gallego, M.; Sanz, A.; Cardenete, G.; Suarez, M.D.; Moyano, F.J.* (1988): Evaluation of lupin seed meal as an alternative protein source in feeding of rainbow trout (*Salmo gairdneri*). *Aquaculture*, 71., 37-50.
16. *Martinez-Palacios, C.A.; Cruz, R.G.; Olvera, N.A.; Novoa, M.A.; Chavez-Martinez, C.* (1988): The use of jack bean (*Canavalia ensiformis* Leguminosae) meal as a partial substitute for fish meal in diets for tilapia (*Oreochromis mossambicus* Cichlidae). *Aquaculture*, 68., 165-175.
17. *New, M.B.* (1987): Feed and feeding of fish and shrimp - a manual on the preparation and presentation of compound feeds for shrimp and fish in aquaculture. UNDP/FAO/ADCP/REP/87/26. Rome/Italy.
18. *NRC* (1981): Nutrient requirements of coldwater fishes. National Academy Press, Washington D.C./USA.
19. *Olvera, N.A.; Martinez, P.; Galvan, R.C.; Chavez, C.S.* (1988): The use of seed of the leguminous plant (*Sesbania grandiflora*) as a partial replacement for fish meal in diets for tilapia (*Oreochromis mossambicus*). *Aquaculture*, 71., 51-60.
20. *Pfeffer, E.* (1993): Ernährungsphysiologische und Ökologische Anforderungen an Alleinfutter für Regenbogenforellen. Übers. Tierernährung, 21., 31-54.

21. *Pfeffer, E.; Kinzinger, S.; Rodehutschord, M.* (1995): Influence of the proportion of poultry slaughter by-products and of untreated or hydrothermically tested legume seeds in diets for rainbow trout (*Oncorhynchus mykiss*) on apparent digestibilities of their energy and organic compounds. *Aquaculture Nutrition*, *1.*, 111-117.
22. *Rani, N.; Hira, C.K.* (1993): Effect of various treatments on nutritional quality of faba beans (*Vicia faba*). *J. Food Sci. Technol.*, *30.*, (61), 413-416.
23. *Scerbina, M.A.* (1973): Quoted from: *Steffens, W.* [1985].
24. *Steffens, W.* (1985): *Grundlagen der Fischernahrung* VEB Gustav Fischer Verlag, Jena/Germany.
25. *Tiews, K.; Koops, H.; Beck, H.; Schwalb-Bühling, A.; Gropp, J.* (1981): *Entwicklung von Ersatzfuttern für die Regenbogenforelle*. Veröffentl. Inst. Küsten- und Binnenfischerei, Hamburg/Germany, No. 75/1981.
26. *Viola, S.; Arieli, Y.; Zohar, G.* (1988): Unusual feedstuffs (tapioca and lupin) as ingredients for carp and tilapia feeds in intensive culture. *Bamidgeh*, *40.*, (1), 29-34.
27. *Weinrich, O.; Koch, V.; Knippel, J.* (1994): *Futtermittelrechtliche Vorschriften*. Buchedition Agrimedia, Hamburg/Germany.

37. RICE BY-PRODUCTS

37.1 Rationale

Rice (*Oryza sativa*) of the family *Poaceae* is a cereal with more than 10,000 cultivars that can be subdivided into three sub-species (ssp. *indica*, ssp. *japonica*, ssp. *javanica*)⁽⁵¹⁾. Rice is the staple food for about 2/3 of the world population. World-wide, more than 500 million MT rice are produced annually, of which 92% is harvested in Asia.

Individual products of rice are⁽¹⁸⁾:

- Paddy (or rough rice) 100%
 - Rice hulls 20%
 - Brown rice 80%
 - ♦ Rice bran 10%
 - ♦ Broken rice 6%
 - ♦ White rice 64%

Rice is composed of several layers: the edible portion is a small, dry one-seeded kernel that remains joined with the seed hence, is called a caryopsis (Figure 37-01)⁽²²⁾.

Rice bran collected under hygienic conditions and not mixed with hulls may be used for rice cakes, cookies, croquettes⁽³⁸⁾. An extract from rice bran is made for the cure of infantile beri-beri.

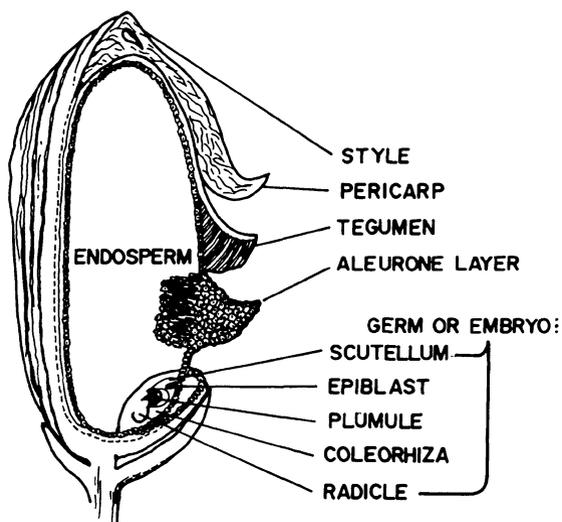


Figure 37-01. Structure of the rice grain fruit^(re-designed from:23)

37.2 Milling and Processing

The old way of processing rice was to pound the rice with mortar and pestle and the resulting grain is unpolished, brown and sometimes only the hull is removed.

The conventional milling of rice sometimes called “abrasive milling” includes cleaning the paddy of straw and dirt, shelling or dehulling to remove the hull thus producing the brown or unpolished rice. Bran-removal which involves dry mechanical grinding or frictional pressure machinery to remove the pericarp, tegumen, aleurone layers, embryo and part of the outer endosperm produces what is known as polished rice and a by-product, called rice bran composed of bran, germ and polishings (Figure 37-02)⁽³⁾.

A newer method of milling rice is solvent or hexane milling which produces superior grain, bran and bran oil from the rice.

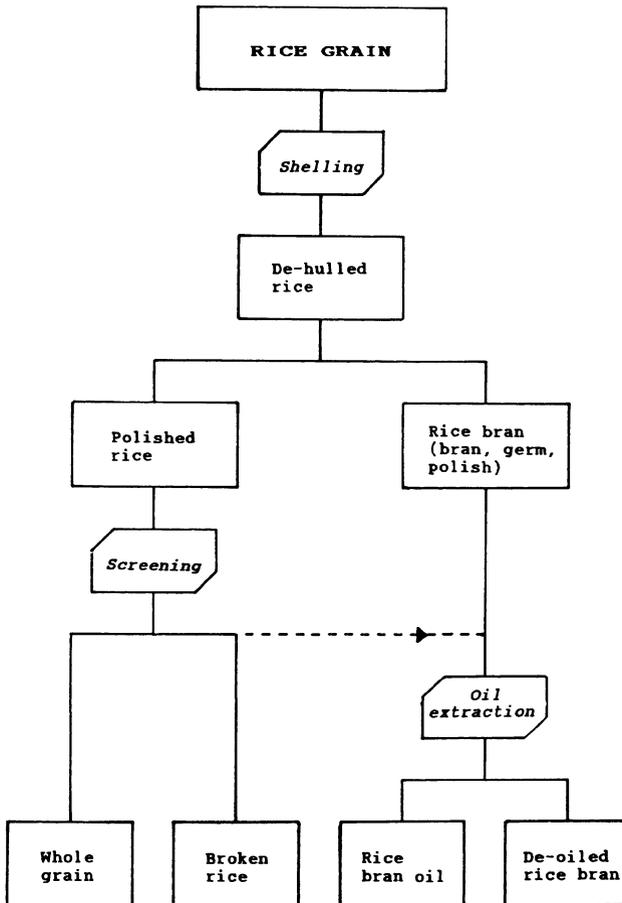


Figure 37-02. Flow diagram of rice milling process.

37.3 Rice Bran

37.3.1 Description

Rice bran contains the bran layer together with the germ of the rice kernel. It is an energy feedstuff. Rice pollard is the product which in addition to the bran and the germ, also contains the husks and the polishings⁽⁷⁾. Rice bran (inclusively the germ) has an oil content of 12 to 15% with high levels of unsaturated fatty acids⁽⁵¹⁾. The oil deteriorates very fast into free fatty acids. "Unde-oiled" rice bran, therefore, has a very short shelf-life, but if the oil is solvent extracted, then the "de-oiled" bran can be stored much longer⁽⁸⁾. Rancidity is prevented by the addition of any anti-oxidant⁽¹⁹⁾.

37.3.2 Chemical, Physiological and Other Properties

Chemical Properties

The removal of the oil from the bran has direct effect on the concentration of other nutrients by more than 20% (Tables 37-01, 37-02)⁽⁸⁾. In unde-oiled rice bran, about 5.0 to 6.0% of oil is converted into free fatty acids daily⁽⁵⁶⁾. Its content in fresh rice bran is 13.7%, and increased to 43.0% when stored at 23°C for three months.

The high fibre content of rice bran is a limiting factor in its use.

Table 37-01: Chemical composition of by-products (1% in of dry matter)

	Rice bran		Broken rice (30, 32, 35)	Rice Polishing (30, 31, 32, 33)	Rice hulls (8, 18, 49)
	De-oiled (31, 32, 33, 36)	Unde-oiled (36)			
Crude protein	15.1	9.0	8.1	13.6	3.1
Crude fat	1.7	7.4	0.6	14.5	1.0
Ash	16.7	24.7	0.7	8.3	17.4
Crude fibre	13.7	17.9	0.4	4.2	44.3
N-free extract	52.8	41.0	90.2	59.4	34.2

Table 37-02: Essential amino acid composition of rice by-products (g/16 g N)

	Rice bran		Broken rice (6, 7, 30, 31, 32, 49)	Rice Polishing (30, 31, 32, 33, 49)
	De-oiled (6, 33)	Unde-oiled (6, 30, 31, 32, 49)		
Arginine	1.1	0.9	0.6	0.6
Histidine	0.4	0.3	0.2	0.2
Isoleucine	0.6	0.5	0.4	0.4
Leucine	1.1	0.9	0.7	0.8
Lysine	0.7	0.6	0.3	0.5
Methionine	0.3	0.3	0.2	0.2
Phenylalanine	0.7	0.5	0.4	0.5
Threonine	0.6	0.5	0.3	0.4
Tryptophan	0.2	0.1	0.1	0.1
Valine	0.8	0.7	0.5	0.8

Rice bran is high in phytate phosphorus amounting to 3.0 to 5.0%. Of a phosphorus content of 0.79% in de-oiled rice bran only 25% is available for the common carp (*Cyprinus carpio*) and 19.0% for rainbow trout (*Salmo gairdneri*)⁽³⁹⁾. Rice bran, unde-oiled and de-oiled, is relatively high in iron and manganese (Table 37-03), and is particularly rich in the B-vitamins (Table 37-04).

Table 37-03: Macro and trace minerals of rice by-products.

		Rice bran		Broken	Rice
		De-oiled	Unde-oiled	rice	Polishing
		(32, 33, 49)	(8, 30, 31, 49)	(7, 30, 49)	(30, 31, 33, 49)
Calcium	%	0.61	0.08	0.08	0.04
Phosphorus	%	1.47	1.60	0.13	1.13
Sodium	%	0.11	0.04	0.06	0.10
Potassium	%	1.60	1.90	0.15	0.71
Magnesium	%	1.04	0.93	0.02	0.57
Chlorine	%	0.08	0.08	0.04	0.11
Sulphur	%	0.19	0.20	0.15	0.12
Manganese	mg/kg	255.0	398.0	12.3	74.7
Iron	mg/kg	205.0	210.0	12.2	95.5
Zinc	mg/kg	33.0	38.0	2.1	25.8
Copper	mg/kg	14.3	14.7	3.3	6.0
Selenium	mg/kg	-	0.4	-	0.3
Iodine	mg/kg	-	-	-	0.07

Table 37-04: Vitamin content of rice by-products (per 1,000 g)

		Rice bran		Broken	Rice
		De-oiled	Unde-oiled	rice	Polishing
		(32, 33, 49)	(8, 30, 31, 49)	(7, 30, 49)	(30, 31, 33, 49)
Vitamin E	mg	66.7	65.95	8.10	65.4
Vitamin B ₁	mg	24.8	24.75	1.00	15.30
Vitamin B ₂	mg	3.2	2.85	0.60	1.46
Vitamin B ₆	mg	32.0	32.12	0.40	30.81
Biotin	mg	0.5	0.46	0.09	0.48
Nicotinic acid	mg	312.1	329.90	19.70	395.40
Folic acid	mg	2.4	2.40	0.10	1.22
Pantothenic acid	mg	25.3	25.30	3.80	32.40
Choline	g	1.2	1.4	1.0	1.2

Physiological Properties

Un-deoiled rice bran has 2,760 kcal/kg (11.5 MJ/kg) gross energy⁽²¹⁾.

The common carp digests rice bran better than the grass carp (*Ctenopharyngodon idella*)⁽¹⁵⁾. Tropical catfish (*Mystus nemurus*) uses rice bran protein more efficiently than channel catfish (*Ictalurus punctatus*) (Table 37-05)⁽²³⁾.

Dry matter digestibility of rice bran in white leg shrimp (*Penaeus vannamei*) is 40% and protein digestibility is 76.4% while amino acid digestibility ranges between 73 and 85% (Table 37-05)⁽²⁾.

Table 37-05: Digestibility (%) of rice bran

	Common carp (15)	Grass carp (15)	Channel catfish (15)	Tropical catfish (23)	White leg shrimp (2)
Dry matter	-	-	-	85.8	40.0
Crude protein	89.5	71.1	71.0	81.0	70.4
Fat	91.5	73.4	-	-	-
Crude fibre	91.5	-	-	-	-
Carbohydrates	90.0	-	-	-	-
Energy	-	21.5	-	-	-

Arginine	-	-	-	-	85.1
Histidine	-	-	-	-	82.6
Isoleucine	-	-	-	-	73.4
Leucine	-	-	-	-	74.9
Lysine	-	-	-	-	81.0
Phenylalanine	-	-	-	-	74.9
Threonine	-	-	-	-	73.2
Valine	-	-	-	-	75.9

Other Properties

The retention of dietary calcium and other minerals is depressed by high levels of rice bran in the diet⁽⁶⁾. Phytic acid renders phosphorus unavailable. The anti-nutritional factors lectins and thiaminase are also present in rice bran⁽⁵⁰⁾.

The pelletising ability of rice bran is low to very low. Its abrasiveness is high and is a key factor to the life of a die^(11, 16, 17).

37.3.3 Feeding Value

Fishes

Rice bran is more often used in diets for omnivorous and herbivorous rather than in carnivorous fish diets. It is an inexpensive feedstuff for simple fish production systems producing species such as: Catla (*Catla catla*), rohu (*Labeo rohita*), mrigal (*Cirrhinus mrigala*),

grass carp (*Ctenopharyngodon idellus*), silver carp (*Hypophthalmichthys molitrix*), goldfish (*Carassius auratus*), channel catfish (*Ictalurus punctatus*), Nile tilapia (*Oreochromis niloticus*), milkfish (*Chanos chanos*), grey mullet (*Liza parsia*), paddle fish (*Polydon spathula*).

However, rice bran has been hardly used in comparison to diets without rice bran. But in combination with oil cakes, pulses, fish meal and even cattle and chicken manure, fish performed well and early broodstock maturity could be induced^(12, 13, 14, 41, 42, 43, 46).

Rice bran as a single feedstuff has proven to be more economical than commercial fish feeds^(27, 28). Channel catfish grew faster and had better feed conversion and protein efficiency when fed 40% rice bran than 30% wheat bran⁽¹⁰⁾. On the other hand, rice bran was not as good as groundnut cake when fed to loach (*Paramisgurnus dabrynus*) fingerlings⁽²⁵⁾.

In experimental diets, rice bran has been used at levels between 10% and 70.0% whereby diets for carp contained the highest levels and milkfish^(18, 47) and grey mullet (*Liza parsia*) the lowest⁽⁵⁾.

Crustaceans

Rice bran is not often used in shrimp diets because of its poor pelletability and relatively high fibre content. However, it is used in marine and freshwater shrimp diets^(4, 9) and in supplementary diets for shrimps reared extensively or semi-intensively⁽⁹⁾. In Indonesia, shrimp farmers use 20% rice bran in home-made formulated feed for tiger prawn (*Penaeus monodon*)⁽⁴⁷⁾.

For experimental purposes, rice bran has been used in diets for marine shrimps at levels from 3.0 to 52.0%.

Live Food Organisms

In the initial stage of rearing marine species different kinds of live food is used. These live food organisms such as brine shrimp (*Artemia salina*) copepods, (*Arcatia tonsa*) and Chironomid larvae, have been found to grow better on rice bran diet than on manure and other commercial feeds and may eliminate the need to culture phytoplankton separately⁽⁵²⁾.

Artemia larvae yielded best growth when fed with rice bran than three different algal species⁽⁴⁶⁾. For *Daphnia* (*Daphnia similis*), Cladocera (*Simocephalus vetulus*), water flea (*Moina macrocopa*) and *Ceriodaphnia cornuta*, rice bran is a better food than poultry or cattle manure⁽²⁶⁾. High fecundity and bigger size of daphnia were obtained when rice bran was added to the pond water. It alone affected positively egg production of daphnia⁽⁵³⁾. Rice bran also provides all the nutrients necessary to raise Calanoid copepod (*Arcatia tonsa*) in seawater⁽⁵²⁾.

37.4 Broken Rice and Rice Polishings

37.4.1 Description

Broken rice results from the milling and polishing of rice. Three different grades of broken rice are obtained⁽⁵¹⁾:

- Second head (large fragments);
- Screenings (medium-sized fragments);
- Brewer's milled rice (semolina).

Broken rice is a useful component of aquaculture feed and often used by small scale farms in on-farm made feeds^(20, 34, 39, 44). However, it is not readily available as a feedstuff. It is a raw material for the food industry for producing extruded breakfast cereals, rice flour and for beer brewing⁽⁸⁾.

Rice polishings constitute 10% of the total quantity of rice bran and is sometimes used in aquaculture diets⁽³⁴⁾.

37.4.2 Chemical, Physiological and Other Properties

Chemical Properties

The chemical composition of broken rice is similar to that of whole, white rice. Broken rice is relatively low in crude protein compared to rice bran. Crude protein, fat and crude fibre are lower than in rice polishings, but crude fibre content of rice polishings is lower than of rice bran (Table 37-01)⁽³⁶⁾. The essential amino acid profile of broken rice and rice polishings are similar (Table 37-02).

Except for iron, manganese, potassium and zinc which are higher in rice polishings the mineral content of broken rice and rice polishings are similar (Table 37-03).

Broken rice and rice polishings contain relatively high amounts of choline just like rice bran (Table 37-04). Rice polishings have more Vitamin B₁, B₆ and nicotinic acid than broken rice.

Physiological Properties

The digestible energy of broken rice for pigs amounts to 3,480 kcal/kg (14.6 MJ/kg) and is lower than for polished rice being 3,700 kcal/kg (15.5 MJ/kg)⁽⁸⁾.

Other Properties

The pelletising ability of broken rice is better than of rice bran. The pellet quality factor is five in a scale of 10 as the best rating⁽¹¹⁾. Rice polishings has a medium pelletising ability but the abrasiveness is high^(16, 17).

37.4.3 Feeding Value

Fishes

Broken rice is used as an energy source in diets for catfish (*Pangasius sutchi*, *Clarias* sp.), snakehead (*Channa striatus*, *Channa maculatus*), milkfish and other herbivore fishes at levels of up to 50%^(44, 55). When broken rice is cooked, it acts as a binder in moist diets⁽⁵⁶⁾. At low levels, broken rice is also incorporated in shrimp feeds⁽⁴⁴⁾.

37.5 Rice Hulls

37.5.1 Description and Properties

Rice hulls is the largest quantity of by-products from the first stage of milling paddy. Fine ground rice hulls are a suitable carrier for vitamin and mineral premixes. Rice bran and tapioca flour, may be adulterated with ground rice hulls.

Crude fibre and ash contents of rice hulls are high but crude protein and fat contents are very low (Table 37-01). The ash is mainly silica (SiO_2), a hard glassy mineral. Silicium is an essential element and important for the development of bones⁽²⁴⁾. In the form of silica it is a deleterious substance⁽⁷⁾.

Digestible energy amounts to only 650 kcal/kg (2.7 MJ/kg)^(8, 18).

37.5.2 Feeding Value

Rice hulls at levels of 8.0 to 15.0% are used in pig feeds for reducing the nutrient intake of the animals. No deleterious effect of the rice hulls were observed⁽⁸⁾. Rations for laying ducks may also contain rice hulls at levels of 16 to 30%⁽¹⁸⁾.

Using rice hulls in fish feeding is merely suitable for extensive production systems and when other feedstuffs are in short supply, respectively.

Rice hulls containing feed (20%) is considered as a supplemental food in diets for grass carp (*Ctenopharyngodon idellus*)⁽¹⁸⁾.

For rearing juvenile milkfish in ponds at a stocking density of 7,000 fingerlings per hectare, rice hulls may be used at levels of 15.0 to 30%^(9, 45).

37.6 Recommended Inclusion Rates

Recommendation of rice by-products in practical diets for cultured aquatic animals are listed in Table 37-06.

Table 37-06: Maximum inclusion rate (%) of by-products in practical aquaculture diets

	Rice bran	Broken rice/ rice polishings	Rice hulls
Carnivorous fish	15	10	0
Omnivorous fish	35	50	5
Herbivorous fish	35	60	10
Crustaceans	10	20	0

37.7 Legal Aspects

EU-Directive 92/87 EEC of 26 October 1992, approves the following by-products of rice milling⁽⁵⁴⁾:

- Broken rice (1.07)
- Yellow rice bran (1.08)
- White rice bran (1.09)
- Rice bran, high limestone content (1.10)
- Parboiled rice bran (1.11)
- Rice germ cake (1.12)
- Rice germ meal, solvent extracted (1.13)

The American Feed Ingredients Definition contains the following rice products⁽¹⁾:

- Rice polishings (75.1 = AAFCO No.)
- Ground rough rice or ground paddy (75.2)
- Rice bran, solvent extracted (75.3) (not less than 14% crude protein, not more than 14% crude fibre,
- Chipped or broken or brewer's rice (75.4)
- Ground brown rice (75.5)
- Rice hulls (75.6)
- Rice bran (75.7) (not more than 13% crude fibre, more than 1.2% calcium has to be declared on the label)
- Rice mill by-product (75.8) (not more than 32% crude fibre)
- Parboiled rice bran (75.9)
- Rice by-products fractions (87.6) (at least 5.0% crude protein and crude protein and 1.5% fat, not more than 25% crude fibre)

The minimum/maximum requirements for rice by-products, as laid down in the German feedstuff legislation, are compiled in Table 37-07. The German feedstuff law does not list rice hulls as a permitted single feedstuff. Its use is illegal, even as a carrier for pre-mixes. Rice by-products having a higher content of rice hulls as permitted (Table 37-07) are considered to be adulterated with them. Specification for rice bran in Thailand are in Table 37-08.

The maximum tolerance, set by FDA for aflatoxin is 20 ppb and 7.0 ppm for lead. USA regulations require for zero tolerance on salmonella in any kind of feed⁽²⁹⁾

Table 37-07: Minimum/maximum requirements for rice by-products (%) by the German feedstuff law⁽⁵⁴⁾

	Moisture max.	Crude protein min.	Fat min.	Crude fibre max.	Ash max.	Hulls max.	CaCO ₃ max.
Yellow rice bran	13.0	-	-	12.5	1.7	3.0	-
Yellow rice bran (low in limestone)	13.0	-	-	12.5	1.7	3.0	3.0
Rice bran	13.0	-	-	-	1.25	2.0	-
Rice bran, de-oiled	13.0	-	-	12.5	1.7	4.0	-
White rice bran	13.0	-	-	8.0	0.6	1.0	-
White rice bran (high in limestone)	13.0	-	-	-	1.2	2.0	23.0
Rice germs	12.0	20.0	-	-	-	1.0	-
Rice germ meal (solvent extracted)	13.0	24.0	-	4.0	-	1.5	-
Rice germ meal (with added oil)	13.0	-	-	4.0	-	1.0	-
Rice germ cake	13.0	23.0	-	5.0	-	1.0	-

Table 37-08: Specifications for rice bran in Thailand (%)⁽⁴⁸⁾

	Moisture max	Crude protein min	Fat max	Crude Fibre max	Ash max
Fine rice bran	11	12	16	8	10
Rough rice bran	11	5	2	28	18
Rice bran extract	13	14	3	12	14

37.8 References

1. AAFCO (1995): Official publication 1995 Asso. Of American Feed Control Officials (Publisher). Sacramento, CA/USA
2. Akiyama, D.M.; Coelo, S.R.; Lawrence, A.L.; Robinson, E.H. (1989): Apparent digestibility of feedstuffs by the marine shrimp, *Penaeus vannamei* Boone. Bull. Japan Soc. Sci. Fish, 55., 91.
3. Arroyo, P.T. (1974): Rice. (1st ed.): The Science of Philippine Foods (Abaniko Enterprises, Araneta Center, Quezon City, Phil., 321.

4. *Boonyaratpalin, M.; New, M.B.* (1993): On-farm feed preparation and feeding strategies for marine shrimp and freshwater prawns, 120-134. Proc. FAO/AADCP Regional Export Consultation on Farm-Made Aquafeeds, 14 to 18 December 1992, Bangkok/Thailand, 434. (FAO-RAPA/AADCP, Bangkok, Thailand).
5. *Chakrabarti, N.M.; Karnakar, H.C.; Roy, A.K.* (1984): Observations on the effect of supplementary feed on growth and survival of grey mullet (*Liza parsa*, Hamilton) fry in brackishwater nursery ponds at Kakdurip. Proc. Symp. Coastal Aquaculture, 12 to 18 January 1980, Cochin (Part 3: Finfish Culture Marine Biological Assoc. of India, Cochin/India, 1985), 3., 797-802.
6. *Creswell, D.* (1988): Amino acid composition of feedgrade rice by-products from several countries. Proc. World Congress On Vegetable Protein Utilization in Human Foods and Animal Feedstuffs. American Oil Chemists' Society. Champaign, Illinois/USA.
7. *Evans, M.* (1985): Nutrient composition of feedstuffs for pigs and poultry. Queensland Dept. of Primary Ind., Brisbane/Australia, Info. Series Q185001.
8. *Farrell, D.J.; Hutton, K.* (1990): Rice and rice milling by-products. In: *Thacker, P.A.; Kirkwood, R.N.*; (eds.): Nontraditional feed sources for use in swine production. Butterworth Publishers, Stoneham/USA.
9. *Feed Development Section* (1994): Feeds and feeding of milkfish, Nile tilapia, Asian sea bass and tiger shrimp. SEAFDEC Aqua. Dept., Tigbauan, Iloilo/Philippines. 97.
10. *Garcia, M.C.; Toledo, J.* (1989): Effect of rice bran on growth of channel catfish fingerlings (*Ictalurus punctatus*). Rev. Latin Ame. Agricult., 39., 10-13.
11. *Gill, C.* (1993) Chemistry for high quality pellets. Feed International 14., 10-11.
12. *Gupta, S.D.; Khan, H.A.; Bhowmick, R.M.* (1987): Observations on the effect of Vit. E and growth hormone on the gonadal maturity of carps. J. Inland Fish. Soc. India, 19., 26-31.
13. *Gupta, S.D.; Reddy, P.V.G.K.; Pani, K.C.* (1990): Advancing maturity and spawning in Asiatic carps through broodstock management. In: *Keshavanath, P., Rabhakrishnan, K.V.* (eds.): Carp Seed Prod. Tech., 2., 34-37.
14. *Gupta, V.K.; Sharma, J.P.; Sristava, J.B.* (1990): Polyculture of Indian and exotic carps using cattle manure with and without supplementary feed. In: *Agrawal, V.P.; Das, P.* (eds.): Recent trends in limnology (Muz Affarnagar India Society of Biosciences), 439-446.
15. *Hepher, B.* (1988): Nutrition of pond fishes. Cambridge University Press, Cambridge/England.
16. *Hertrampf, J.W.* (1992): On the water durability of aquaculture feed pellets - A Review. Advances in Feed Tech. 7., 18-38.
17. *Hertrampf, J.W.* (1994): Futtermittel von tropischen und sub-tropischen Standorten. Paper pres. At a Colloquium, Inst. für angewandte Botanik, University of Hamburg/Germany. 29 Aug.
18. *Hertrampf, J.W.* (1994): Abschlussbericht über einen Senior-Experten-Einsatz in der V.R. China. Projekt: TIC-ZXSSFEED (Mimeograph).
19. *Hussein, A.S.; Kratzer, F.U.* (1982): Effect of rancidity on the feeding value of rice bran for chicken. Poultry Sci., 61., 2450-2455.
20. *Jantrarotai, W.; Jantrarotai, P.* (1993): On-farm feed preparation and feeding strategies for catfish and snakehead, 101-119. Proc. FAO/AADCP Regional Export Consultation on Farm-Made Aquafeeds, 14 to 18 December 1992, Bangkok/Thailand, 434. (FAO-RAPA/AADCP, Bangkok, Thailand).
21. *Jauncey, K.; Ross, B.* (1982): Quoted from: *Paulraj, R.* (1995).
22. *Juliano, B.O.* (1972): Rice caryopsis and its composition. In: *Houston, D.F.* (ed.): Rice: Chemistry and Technology. Ame. Asso. Cereal Chemists. St. Paul, Minnesota, 16-74.
23. *Khan, M.S.* (1994): Apparent digestibility coefficients for common feed ingredients in formulated diets for tropical catfish, *Mystus nemurus* (Curvier and Valenciennes). Aquacult. Fish. Manage., 25., 167-174.
24. *Kolb, E.* (1989): Lehrbuch der Physiologie der Haustiere. VEB Gustav Fischer Verlag, Jena/Germany.

25. Liang, Z.; Liang, J.; Chen, C.; Li, Z.; Lim, J. (1988): The embryonic development and fingerling culture of loach, *Paramisgurnus dabrynus* Sawage. Acta Hydrobiol. Sin-Shuishen, Shengwu-Xuebao, 12., 27-42.
26. Malhotra, Y.R.; Langer, S. (1993): Nutritional and density - dependent responses of some Cladocera. Aquacult. Fish. Manage., 24., 631-640.
27. Middendorp, H.A.J.; Verreth, J.A.J. (1991): The development of small-scale hapa culture of tilapia (*Oreochromis niloticus*) in Northeastern Thailand. 2. The feasibility using low-cost compound feeds. Asian Fish. Sci., 4., 317-327.
28. Mims, S.D.; Clark, J.A.; Williams, J.C.; Rose, D.B. (1993): Comparisons of two by-products and a prepared diet as organic fertilizers on growth and survival of larval paddle fish, *Polyodon spathula*, in earthen ponds. J. Appl. Aquacult., 2., 171-187.
29. NRA (1993): Pocket information manual - a buyers guide to rendered products. National Renderes Asso., Inc. Alexandria, Virg/U.S.A.
30. NRC (1977): Nutrient requirements of warmwater fishes. Nutrient requirement of domestic animals. Nat. Acad. Press Wash. D.C./USA.
31. NRC (1983): Nutrient requirements of warmwater fishes and shellfishes (revised ed.). Nutrient requirement of domestic animals. Nat. Acad. Press Wash. D.C./USA.
32. NRC (1991): Nutrient requirements of coldwater fish. Nutrient requirement of domestic animals. Nat. Acad. Press Wash. D.C./USA.
33. NRC (1993): Nutrient requirements of fish. Nutrient requirement of domestic animals. Nat. Acad. Press Wash. D.C./USA.
34. Nandeesh, M.C. (1993): Aquafeeds and feeding strategies in India. Proc. FAO/AADCP Regional Expert Consultation on Farm-Made Aquafeeds, 14 to 18 December 1992, Bangkok/Thailand, 434. (FAO-RAPA/AADCP, Bangkok, Thailand). 213-254
35. New, M.B. (1987): Feed and feeding of fish and shrimp. A manual on the preparation and presentation of compound feeds for shrimp and fish in aquaculture. UNDP/FAO/ADCCP/REP/87/26, Rome/Italy.
36. New, M.B.; Singholka, S. (1982): Freshwater prawn farming: A manual for the culture of *Macrobrachium rosenbergii*. Rome, FAO, FAO Fisheries Technical paper (225) Rev. 1
37. Ogino, C.; Takeuchi, L.; Takeda, H.; Watanabe, T. (1979): Availability of dietary phosphorus in carp and rainbow trout. Bull. Jap. Soc. Sci. Fisheries, 45., 1527-1532.
38. Orosa-del Rosario, H. (1970): Maria Y. Orosa - wife and her works (1st ed): Quezon City, Phil. Garcia Publishing Co., 170-187.
39. Pantha, P. (1993): Aquafeeds and feeding strategies in Nepal. Proc. FAO/AADCP Regional Export Consultation on Farm-Made Aquafeeds, 14 to 18 December 1992, Bangkok/Thailand, 434. (FAO-RAPA/AADCP, Bangkok, Thailand). 297-316.
40. Paulraj, R. (1995): Aquaculture feed (2nd ed.). Marine Prod. Export Dev. Authority, Kochi, India (publishers).
41. Sanchai, S. (1979) Level of Vit. E content suitable for gonad developing and spawning of goldfish *Carassius auratus* (Lim). Master of Science Theses. Fisheries Science, 12., 2 (Abstr.).
42. Shackell, N.L.; Doyle, R.W. (1991): Scale morphology as an index of developmental stability and stress resistance of tilapia (*Oreochromis niloticus*). Can. J. Fish. Aquat. Sci., 48., 1662-1669.
43. Somashekarrapa, B.; Chandrashekararish, H.N.; Nandeesh, M.C. (1990): In: Keshavanath, P., Rabhakrishnan, K.V. (eds.): Carp Seed Production Tech., 2., 29-33.
44. Somsueb, P. (1993): Aquafeeds and feeding strategies in Thailand. Proc. FAO/AADCP Regional Export Consultation on Farm-Made Aquafeeds, 14 to 18 December 1992, Bangkok/Thailand, 434. (FAO-RAPA/AADCP, Bangkok, Thailand). 365-385.
45. Sumagaysay, N.S.; Chiu-Chern, Y.N. (1991): Effects of fiber in supplemental feeds on milkfish (*Chanos*

- chanos* Forsskal) production in brackishwater ponds. Asian Fisheries Sci., Asian Fisheries Soc., Manila/Philippines, 4., 189-199.
46. Sumitra, V.; Krishnakumari, L.; Royan, J.P. (1987): Evaluation of different feeds for optimal growth and survival of parthenogenetic brine shrimp, *Artemia*. Indian J. Mar. Sci., 16., 253-255.
 47. Suprayitno, H.; Widagdo, D. (1989): Preliminary study on the effect of formulated feed using fermented aquatic meal ingredients to growth rate of red tilapia. Workshop on Shrimp and Finfish *Feed Dev.*, 25 to 29 October 1988 (Johore Bahru/Malaysia), 115.
 48. Sitasit, P. (1993): Feed ingredients and quality control. Farm-made aquafeeds. Proc. FAO/AADCP Regional Export Consultation on Farm-Made Aquafeeds, 14 to 18 December 1992, Bangkok/Thailand, 434. (FAO-RAPA/AADCP, Bangkok/Thailand). 75-86.
 49. Tacon, A.G.J. (1987): The nutrition and feeding of farmed fish and shrimp 2 - A training manual on nutrient sources and composition. Field Document 5/E GCP/RLA/075/ITA, FAO. 129 PP. Brasilia/Brazil).
 50. Tacon, A.G.J. (1993): Feed ingredients for warmwater fish, fish meal and other processed feedstuffs, 64. (FAO Fisheries Circular No. 856, FAO, Rome.)
 51. Täufel, A.; Taynes, W.; Tunger, L.; Zobel, M. (1993): Lebensmittel-Lexikon Behr's Verlag, Hamburg/Germany.
 52. Turk, P.E.; Krejci, M.E.; Yang, W.T. (1982): Laboratory method for the culture of *Acartia tonsa* (Crustacea: Copepoda) using rice bran. J. Agricult. Aquat. Sci., 3., 25-27.
 53. Venkataraman, K.; Kesary, M.; Krishnaswamy, S. (1986): Influence of various concentrations of rice bran with tap water and pond water on the longevity, egg production and body size of *Daphnia similis* Claus (Crustacea:Cladocera). 1986 Proc. Indian Acad. Sci., Anim. Sci., 95., 163-170.
 54. Weinreich, O.; Koch, V.; Knippel, J. (1994): Futtermittelrechtliche Vorschriften. Buchedition Agremedia. Hamburg/Germany.
 55. Wiang, C.; Pothisoong, T. (1985): Protein requirements of catfish fry, *Pangassius sutchi*, Fowler. In: Cho, C.Y.; Cowey, C.B.; Watanabe, T. (eds.): Finfish nutrition in Asia. IDRC, 233e, 103-106.
 56. Williams, M.A. (1989): Extrusion of rice bran. Proc. World Congr. Vegetable Protein Utilization in Human Foods and Animal Feedstuffs. Singapore, October 1988. 100-102.

38. SHRIMP MEAL

38.1 Rationale

Shrimp meal is a big by-product of the shrimp industry. Head-on world shrimp production for shrimp is estimated to be 983,000 MT by year 2000⁽²⁴⁾. The head constitutes 34 to 45% of the whole shrimp⁽⁵⁾. Assuming 40% waste and 50% of the production is commercially processed, there would be about 200,000 MT or even more of the estimated 983,000 MT head-on production. This waste is a valuable feedstuff for aquaculture.

38.2 Manufacture and Processing

Heads and shells, by-products of shrimp processing and marine-caught crustaceans not fit for human consumption are made into a meal. Shrimp meal is manufactured by directly drying the material under the sun or in an oven. A more professional method is by blanching the fresh or wet material in boiling water, or steaming and then drying the cooked product in a drier. The dried product is marketed unground or ground. Wet (raw or ensiled) shrimp material may also be co-extruded with soybean meal by passing the mixture through an extrusion machine twice. There are several types of shrimp meal available in the market depending on the kind of raw material used.

38.3 Chemical, Physiological and Other Properties

Chemical Properties

The chemical composition of shrimp meal varies widely depending on the source (whether whole shrimps or heads) (Table 38-01) and method of processing (raw, dried, etc) (Table 38-02). Shrimp meal is a good source of lysine and methionine (Table 38-03). Its ratio varies between 1.0:2.5 to 3.7.

Shrimp meal is rich in highly unsaturated fatty acids (HUFA) (Table 38-04). Of the fat content are 10% cholesterol and, 35 to 50% phospholipids. Oven-drying may damage the fatty acids, particularly that of linolenic acid^(2, 9, 15).

Shrimp meal is a good source of choline (Table 38-05)^(25, 26). The calcium content of shrimp meal particularly depends on the amount of shells in the product. The phosphorus content is much lesser affected by the amount of shells in the meal. Shrimp meal made from whole shrimps contained 3.03% and 1.13% calcium and phosphorus, respectively⁽¹⁶⁾ while that from shrimp head were 12.21% and 1.63%, respectively⁽²³⁾.

Table 38-01: Chemical composition of shrimp meals (% in dry matter)

	Crude Protein	Crude fat	Crude fibre	NFE	Ash
Shrimp meal:					
- Whole ^(11, 33)	70.9	3.3	3.1	4.4	18.3
- Head ^(11, 13, 14, 34)	43.2	5.6	15.8	2.4	33.0
- Waste ^(22, 37)	31.2	4.1	20.0	15.8	28.9
- Process residue ^(25, 26, 27, 28, 39)	46.0	3.5	14.6	4.9	31.0
Acetes ^(11, 14)	72.0	3.8	3.1	5.2	15.9
Shrimp head silage dried ⁽³⁹⁾	74.2	7.4	-	-	18.4

Table 38-02: Chemical composition of shrimp head meals differently processed⁽¹⁵⁾.

Method of processing	Moisture %	Crude protein %	Crude lipid %	Ash %	Chitin %	Asta-xanthin mg/kg	Canta-xanthin mg/kg
Solar ¹	5.8	44.4	8.4	27.8	15.0	11	39
Oven ²	4.4	46.0	9.8	26.1	14.3	7	27
Cook press ³	8.0	42.2	6.2	29.7	17.6	12	37
MBDD ⁴	7.2	51.9	9.5	20.6	10.4	17	72
Cook MBDD ⁵	8.2	52.1	12.8	22.2	12.6	14	62

Raw *Penaeus monodon* head stored at -20°C and thawed prior to processing was used

- ¹Solar - Dried for 24 hours under solar simulator
²Oven - Dried for 12 hours in ventilated oven at 80°C
³Cook press - Blanched for 20 seconds in boiling water, drained and partially de-watered by pressing, then dried in warm air, 50°C, 14 hours
⁴MBDD - Shell separated from meat and drum-dried, additional drying of flakes in warm air stream at 40°C 14 hours to <10% moisture
⁵Cook MBDD - Blanched in boiling water for 20 seconds before processing as in MBDD

Table 38-03: Essential amino acid profile of shrimp meal (g/16 g N)

	Process residue meal ^(11, 21, 25, 26, 27, 28, 31, 39)	Shrimp head meal ^(11, 21, 39)	Muscle meal ⁽²¹⁾	Acetes meal ^(11, 39)
Arginine	3.9	56.1	4.8	6.4
Histidine	1.3	1.9	1.7	1.4
Isoleucine	2.3	6.3	2.9	3.5
Leucine	4.1	5.9	7.0	6.8
Lysine	4.2	4.8	7.2	5.3
Methionine	1.4	1.3	2.9	2.0
Phenylalanine	2.5	4.1	3.9	3.6
Threonine	8.2	3.6	3.6	3.2
Tryptophan	0.6	3.6	0.5	-
Valine	2.6	5.4	2.9	3.8

Table 38-04: Fatty acids (%) of total fat in shrimp meal as compared to wild tiger prawn (*Penaeus monodon*) muscle^(9, 15).

	Wild tiger prawn	Shrimp meal Mean	Range
Total n-6	14.8	18.9	17.6 - 19.9
Total n-3 PUFA	31.2	19.9	18.6 - 22.2
n-3/n-6	2.11	1.06	0.99 - 1.12
Linoleic 18:2n-6	1.9	8.9	0.5 - 12.3
Linolenic 18:3n-3	0.6	0.8	0.1 - 1.0
Eicosapentaenoic 20:5n-3	13.6	6.5	1.35 - 10.60
Docosahexaenoic 22:6n-3	15.5	9.3	1.45 - 11.8

Table 38-05: Mineral and vitamin contents of various types of shrimp meals

Minerals ^(9, 11, 25, 26, 27, 38, 39)			Vitamins (per 1,000g) ^(25, 26)		
Calcium	%	6.3	Riboflavin	mg	4.4
Phosphorus	%	1.6	Pantothenic acid	mg	5.8
Potassium	%	0.7	Choline	g	6.0
Chlorine	%	1.2			
Magnesium	%	0.7			
Sodium	%	1.7			
Iron	mg/kg	64.0			
Manganese	mg/kg	33.2			
Zinc	mg/kg	32.0			

Physiological Properties

The variability in digestible energy of shrimp meal depends on the composition and country of origin (Table 38-06).

Table 38-06: The digestible energy of shrimp meal⁽³⁸⁾

Product from ...	Product	kcal/kg	MJ/kg
India	Whole	3,656	15.3
Madagascar	Whole	2,151	9.0
India	Heads	2,080	8.7
Malaysia	Heads	2,100	8.8
India	Waste	2,262	9.5

The apparent protein and dry matter digestibilities of shrimp meal in the tiger prawn (*Penaeus monodon*) and white leg shrimp (*Penaeus vannamei*) is higher for tiger prawn

than for the latter (Table 38-07). The apparent essential amino acid digestibility is highest for lysine (85.79%) and lowest for histidine (25.4%)⁽³⁾.

The apparent mineral digestibility of shrimp meal is generally poor. For magnesium, the utilisation is negative as found in the white leg shrimps⁽⁴⁾.

Table 38-07: Apparent digestibility of shrimp meals^(3, 10)

Apparent digestibility	Protein	Dry matter
Tiger prawn (<i>Penaeus monodon</i>):		
- Shrimp head meal, high protein	96.0	80.2
- Shrimp head meal, low protein	89.9	78.7
- <i>Acetes</i> meal	95.4	86.5
White leg prawn (<i>Penaeus vannamei</i>):		
- shrimp meal	74.6	56.8

Other Properties

Shrimp meal and shrimp head meal have “chemo-attractant” properties^(30, 35).

Farmed crustaceans preferred fresh, and frozen crustaceans⁽⁴⁰⁾. Diets with shrimp meal were more attractive and enhanced feed consumption by tiger prawn than diets without shrimp meal⁽³²⁾. White leg shrimps were most attracted to *Artemia* and krill, both crustaceans⁽²⁹⁾.

Shrimp meals are used in trout and salmon diets as a “pigmenter” to improve their fleshy colour. They contain at an average 12.2 mg/g astaxanthin and 47.4 mg/kg cantaxanthin (Table 38-02).

“Chitin” (N-acetyl-D-glucosamine) which is the major structural component of the exoskeleton of crustaceans is believed to have a growth promoting effect in shrimps. The mean chitin content of crustacean meal is 14.0% (Table 38-02)⁽⁴⁾. Due to the high chitin content shrimp meals have a poor pelletising ability⁽³⁶⁾.

Dietary “cholesterol” is needed by shrimps because they cannot synthesize it. About 10% of the organism’s fat content is cholesterol⁽³⁷⁾.

38.4 Feeding Value

Shrimp meals have multi-purpose functions in feeds for cultured aquatic animals. They are protein feedstuffs but are also used for their other properties. Shrimp meals are more commonly used in crustacean feed rather than fish feed.

Fishes

Shrimp meal (30%) in rainbow trout (*Salmo gairdneri*) diets gave a reddish pigmentation to the skin and muscle⁽¹²⁾. This was also the case when shrimp head meal was fed to Nile tilapia (*Oreochromis niloticus*)⁽⁶⁾. Nile tilapia’s growth was stimulated by shrimp head meal while survival rate was essentially similar for all the test diets that included marigold

petal meal, turmeric and *spirulina* alone. It was also used in the development of a suitable amino acid test diet for red drum (*Sciaenops ocellatus*)⁽⁷⁾.

Crustaceans

Shrimp meal as the sole source of protein in the diet for tiger prawn (*Penaeus monodon*) juveniles did not perform as good as the combination of shrimp meal and molluscan meal (Table 38-08)⁽²⁹⁾. The combination of shrimp head meal and fish meal at the ratio of 1:1 or 2:1 was also significantly better than shrimp head meal alone at a level of 60% when fed to tiger prawn post-larvae^(32, 33).

Growth of tiger prawn post-larvae fed shrimp meal compared to mussel meal was comparable to the latter fed animals but PER and survival was inferior⁽¹⁹⁾. Feeding tiger prawn larvae Acetes meal gave highest survival rate (68%) compared to larvae fed zooplankton (*Chaetoceros*) (48%) or fresh Acetes (39%)⁽¹⁸⁾.

Table 38-08: Growth response of tiger prawn (*Penaeus monodon*) to two levels of shrimp meal⁽¹⁷⁾

Shrimp Meal	%	66.7	32.7
Molluscan meal	%	-	32.7
Crude protein of diet	%	46.0	46.0

Mean weight gain	g	0.716	0.828
Growth rate	%	140.4	162.3
SGR	%	3.41	3.94
PER		1.57	1.83
Survival	%	86	94

The red swamp crayfish (*Procambarus clarkii*) decreased consumption when fed 30% shrimp head meal in addition to menhaden fish meal⁽⁸⁾.

Otherwise, shrimp meals are standard components of shrimp diets. In experimental diets for crustaceans, shrimp meal is used at levels between 3.0 and 30%.

38.5 Recommended Inclusion Rates

Dietary inclusion levels may be limited by the high crude fibre, chitin and ash content of shrimp meal in crustacean diets^(4, 20). Recommended inclusion rates for practical diets should not be more than 20% and 10% for carnivorous and omnivorous/herbivorous species, respectively.

38.6 Legal Aspects

The use of shrimp meal and shrimp head meal is not prohibited. No legal hindrance is recorded for their use. Commercial shrimp meal should contain a minimum of 32% crude protein and 4.0% crude fat and a maximum of 14% crude fibre⁽⁴⁾.

German legislation prescribes that shrimp meal should have not more than 5.0% ash and 12% moisture⁽⁴¹⁾.

Shrimp meal (No. 51.5) is listed in USA by AAFCO. It is the undecomposed ground dried waste of shrimp. The salt content (NaCl) of more than 3.0% has to be declared on the label and must not exceed 7.0%⁽¹⁾.

38.7 References

1. AAFCO (1995): Official publication 1995. Ass. of American Feed Control Officials (publisher). Sacramento, CA/USA.
2. Akiyama, D.M. (1988): Soybean meal utilization by marine shrimp. Proc. AOCS World Cong. Veg. Protein Utilization in Human Food and Animal feedstuffs, Singapore, 2 to 7 October.
3. Akiyama, D.M.; Coelho, S.R.; Lawrence, A.L.; Robinson, E.H. (1989): Apparent digestibility of feedstuffs by the marine shrimp, *Penaeus vannamei* Boone. Bull. Japan. Soc. Sci. Fish 55., (1), 91.
4. Akiyama, D.M.; Dominy, W.G.; Lawrence, A.L. (1991): Penaeid shrimp nutrition for the commercial feed industry (revised). Proc. Aquaculture Feed Processing and Nutrition Workshop, Thailand and Indonesia, 19 to 25 Sept. 1991. 80.
5. Barrat, A.; Montano, R. (1986): Shrimp heads - a new source of protein. Infofish Marketing Digest, (4/86), 21-22.
6. Boonyaratpalin, M.; Unprasert, N. (1989): Effects of pigments from different sources on color changes and growth of red *Oreochromis niloticus*. Aquaculture, 79., (1/4), 375-380.
7. Brown, P.B.; Davis, D.A.; Robinson, E.H. (1988): An estimate of the dietary lysine requirement of juvenile red drum *Sciaenops ocellatus*. J. World Aquacult. Soc. 19., (3), 109-112.
8. Brown, P.B.; Robinson, E.H.; Clark, A.E.; Lawrence, A.L. (1989): Apparent digestible energy coefficients and associative effects in practical diets for red swamp crayfish. J. World Aquacult. Soc. 20., (3), 122-126.
9. Carver, L.A.; Akiyama, D.M.; Dominy, W.G. (1988): Processing of wet shrimp heads and squid viscera with soy meal by a dry extrusion process. Proc. World Congress on Vegetable Protein Utilization in Human Foods and Animal Feedstuffs. Ame. Oil Chemists Soc. Champaign, Illinois. 167-170.
10. Catacutan, M. (1995): Apparent protein digestibility of feedstuffs in *Penaeus monodon* Fabricius. Paper presented at 4th Asian Fisheries Forum, Beijing, Oct. 1994.
11. Chou, R. (1993): Aquafeeds and feeding strategies in Singapore. Proc. FAO/AADCP Regional Expert Consultation on Farm-Made Aquafeeds, 14 to 18 Dec. 1992, Bangkok/Thailand. FAO-RAPA/AADCP, Bangkok, Thailand. 354-364.
12. Choubert, G. Jr.; Luquet, P. (1983): Utilization of shrimp meal for rainbow trout (*Salmo gairdneri* Rich.) pigmentation influence of fat content of the diet. Aquaculture, 32., (1/2), 19-26.
13. Djunaidah, I.S. (1993): Aquafeeds and feeding strategies in Indonesia. Proc. FAO/AADCP Regional Expert Consultation on Farm-Made Aquafeeds, 14 to 18 Dec. 1992, Bangkok/Thailand. FAO-RAPA/AADCP, Bangkok, Thailand. 255-281.
14. Feed Development Section (FDS) (1994): Feeds and feeding of milkfish, Nile tilapia, Asian sea bass, and tiger shrimp. SEAFDEC Aquaculture Dept., Tigbauan, Iloilo/Philippines. Extension Manual No. 21.
15. Fox, C.J.; Blow, P.; Brown, J.H.; Watson, I. (1994): The effect of various processing methods on the physical and biochemical properties of shrimp head meals and their utilization by juvenile *Penaeus monodon* Fab. Aquaculture, 122., 209-2226.
16. Göhl, B. (1981): Tropical Feeds. FAO Animal Prod. Health Ser. (12), FAO, Rome.

17. *Hajra, A.; Ghosh, A.; Mandel, S.K.* (1988): Biochemical studies on the determination of optimum dietary protein to energy ratio for tiger prawn, *Penaeus monodon* (Fab.) juveniles. *Aquaculture*, 71., 71-79.
18. *Kungvankij, P.; Tacon, A.G.J.; Corre, K.; Pudadera, B.P.; Talen, G.; Borlongan, E.; Potestas, I.D.* (1986): Acetes as prime food for *Penaeus monodon* larvae. Proc. First Asian Fisheries Forum. Asian Fish. Soc., Manila/Philippines.
19. *Lim, C.; Surarinat, P.; Platon, R.* (1979): Evaluation of various protein sources for *Penaeus monodon* post-larvae. *Kalikasan, Philipp. J. Biol.*, 8., (1), 29-36.
20. *Meyers, S.P.* (1981): Quoted from: *Fox et al.* (1994).
21. *Meyers, S.P.; Benjamin, G.* (1987): Feeding value of crustacean wastes can be improved through proper ensilage treatment. *Feedstuffs*, 30 Mar. 12-13.
22. *Nandeesh, M.C.* (1993): Aquafeeds and feeding strategies in India. Proc. FAO/AADCP Regional Expert Consultation on Farm-Made Aquafeeds, 14 to 18 Dec. 1992, Bangkok/Thailand. FAO-RAPA/AADCP, Bangkok, Thailand. 213-254.
23. *New, M.* (1987): Feed and feeding of fish and shrimp - a manual on the preparation and presentation of compound feeds for shrimp and fish in aquaculture. UNDP/FAO/ADCP/REP/87/26 Rome/Italy.
24. *New, M.B.* (1991): Where will feeds be in the year 2000? *Fish Farmer*, 5., (3), 38-40.
25. *NRC* (1977): Nutrient requirements of warmwater fishes. *Nutrient Requirements of Domestic Animals*, Nat. Acad., Washington D.C./USA.
26. *NRC* (1983): Nutrient requirements of warmwater fishes and shellfishes (revised ed.). *Nutrient Requirements of Domestic Animals*, Nat. Acad., Washington D.C./USA.
27. *NRC* (1991): Nutrient requirements of coldwater fishes. *Nutrient Requirements of Domestic Animals*, Nat. Acad., Washington D.C./USA.
28. *NRC* (1993): Nutrient requirements of fish. *Nutrient Requirements of Domestic Animals*, Nat. Acad., Washington D.C./USA.
29. *Ogle, I.J.; Beaugez, K.* (1991): Quoted from: *Tacon, A.G.J.* (1993).
30. *Pan, B.S.* (1990): Quoted from *Fox et al.* (1994).
31. *Peñaflores, V.D.* (1989): An evaluation of indigenous protein sources as potential component in the diet formulation for tiger prawn *Penaeus monodon*, using essential amino acid index (EAAI). *Aquaculture*, 83., 319-330.
32. *Piedad-Pascual, F.; Destajo, W.H.* (1979): Growth and survival of *Penaeus monodon* post-larvae, fed shrimp head meal and fish meal as primary animal source of protein, 4., (1), 23.
33. *Piedad-Pascual, F.; Bandonil, L.* (1977): Preliminary biological evaluation of some formulated feeds for *Penaeus monodon*. Quarterly Res. Report. 1st quarter (January-March). 32.
34. *Piedad-Pascual, P.* (1993): Aquafeeds and feeding strategies in the Philippines. In: *New, M.B.; Tacon, A.G.J.; Csavas, I.* (eds.): Farm-made aquafeeds Proc. FAO/AADCP Regional Expert Consultation on Farm-Made Aquafeeds, 14 to 18 Dec. 1992, Bangkok/Thailand. FAO-RAPA/AADCP, Bangkok, Thailand. 317-353.
35. *Pradhu, P.V.; Madhava, P.N.* (1985): Quoted from *Fox et al.* (1994).
36. *Randall R.H.; Dearing, A.S.* (1978): Shrimp by-product meal in diets of channel catfish. *Prog. Fish. Cult.*, (40), 39-40.
37. *Sidewell, V.D.* (1981): Quoted from: *Akiyama et al.* (1991).
38. *Somsueb, P.* (1993): Aquafeeds and feeding strategies in Thailand. Proc. FAO/AADCP Regional Expert Consultation on Farm-Made Aquafeeds, 14 to 18 Dec. 1992, Bangkok/Thailand. FAO-RAPA/AADCP, Bangkok, Thailand. 365-385.
39. *Tacon, A.G.J.* (1987): The nutrition and feeding of farmed fish and shrimp - A training manual. 2. Nutrient

Sources and Composition, GCP/RLA/075/I+A, FAO, Brasilia/Brazil.

40. *Tacon, A.G.J.* (1993): Feed ingredients for crustaceans natural foods and processed feedstuffs. FAO Fisheries Circular No. 866, FAO, Rome/Italy.
41. *Weinreich, O.; Koch, V.; Knippel, J.* (1994): Futtermittelrechtliche Vorschriften, Buchedition Agrimedia, Hamburg/Germany.

39. SILKWORM PUPAE MEAL

39.1 Rationale

Silkworm pupae is the by-product after the silk-thread has been wound-off from the cocoon and can serve as a feedstuff. Seri culture has its origin in China where it has been known for almost 5,000 years. Major silk producing countries are P.R. China (57.5% of World production), Japan (13.2%), India, (10.3%), Republic of Korea (South) (5.4%) and Thailand (2.1%)⁽²⁶⁾.

The most common species for commercial silk production is the mulberry silkworm (*Bombyx mori*) of the sub-phylum *Tracheata* (articulated animals)⁽²⁴⁾. The caterpillar of the moth feed chiefly on mulberry leaves. The white mulberry (*Morus alba*) of the family *Moraceae* is most common in Japan. This family includes more than 1,000 species⁽²⁶⁾.

39.2 Processing

Prior to reeling-off of the silk-thread the cocoon is heated in order to kill the pupae. One cocoon supplies about 800 m of silk-thread which is a fibroine, peculiar elongated molecule thread⁽¹⁹⁾. The pupae remains and is dried and milled. Fat can be removed by solvent extraction^(5, 24). The cocoons have no feeding value⁽²⁰⁾.

39.3 Chemical, Physiological and other Properties

Chemical Properties

The crude protein content of silkworm pupae meal varies widely. The mean crude protein content of fat extracted silkworm pupae meal is higher (72.8%) than that of the fat containing meal (55.1%) (Table 39-01). The limiting amino acids are lysine, methionine, arginine, histidine and threonine (Table 39-02). The protein of silkworm pupae meal is not of high value⁽⁵⁾ based on the EAA-Index (essential amino acid) (61.3) and the biological value (BW) (51.6%)⁽²⁵⁾.

The silkworm pupae meal fat has a lecithin content of 2.12%⁽²⁵⁾ and its fatty acid profile is as shown below⁽²⁵⁾:

- Saturated fatty acids: 20.7%
- Unsaturated fatty acids: 70.1%
- thereof: ▪ Palmitic acid: 14.0%
- Oleic acid: 9.1%
- Linoleic acid: 24.6%

- Linolenic acid: 14.0%
- Other fatty acids: 8.4%^c

Table 39-01: Chemical composition of silkworm pupae meal (% in dry matter)
(5, 19, 20, 24, 30)

	Unde-oiled		De-oiled	
	Mean	Variation	Mean	Variation
Dry matter	88.9	68.5 - 95.1	91.9	90.4 - 98.5
Organic matter	89.6	87.9 - 91.8	86.4	84.2 - 88.8
Crude protein	55.1	49.4 - 60.9	72.8	44.5 - 77.6
Crude fat	23.2	14.2 - 30.3	2.0	0.7 - 7.0
Ash	3.8	2.2 - 7.5	5.6	4.4 - 9.1
Crude fibre	5.5	3.9 - 8.8	6.2	4.6 - 9.8
N-free extract	6.4	5.5 - 10.8	7.3	6.7 - 9.8

Table 39-02: Essential amino acid profile of silkworm pupae meal
(g/16 g N)^(3, 14, 20, 25)

	Mean	Variation
Arginine	6.0	3.6 - 7.8
Histidine	3.3	3.2 - 3.3
Isoleucine } Leucine }	7.8	7.5 - 8.0
Lysine	6.1	2.5 - 10.1
Methionine	1.9	1.8 - 1.9
Phenylalanine	2.5	1.8 - 3.2
Threonine	4.6	3.6 - 5.6
Tryptophan	1.1	0.6 - 1.5
Valine	4.7	-

The crude fibre of silkworm pupae meal is mostly chitin which is hardly utilised by animals⁽⁵⁾. Information on the mineral and vitamin content of silkworm pupae meal are limited (Table 39-03).

Table 39-03: Mineral and vitamin contents of silkworm pupae meal

Minerals ^(5, 20, 30)			Vitamins (per 1,000 g) ⁽²³⁾		
Calcium	%	0.63	Vitamin E	mg	1,000
Phosphorus	%	1.25	Vitamin B ₁	mg	15.0
Sodium	%	0.03	Vitamin B ₂	mg	80.0
Potassium	%	1.07	Vitamin B ₁₂	mg	0.5

Physiological Properties

The digestible energy of the solvent extracted silkworm pupae meal is lower than of the unde-oiled meal:

- Gross energy: 5,939 kcal/kg (24.8 MJ)⁽³⁰⁾
- Digestible energy, unde-oiled: 4,190 kcal/kg (17.5 MJ)⁽²⁰⁾
- Digestible energy, de-oiled: 3,672 kcal/kg (15.4 MJ)⁽²⁰⁾

The mean digestibility of silkworm pupae meal with fishes is 70.6% and is much lower than that with chicken. Salmonids utilise the protein of silkworm pupae meal much better than the common carp (*Cyprinus carpio*). The true digestibility of protein in the Indian shrimp (*Penaeus indicus*) is even lower. The high fat content of silkworm pupae meal may depress the protein digestibility⁽²⁴⁾ as demonstrated in chicken (Table 39-04).

Table 39-04: Apparent digestibility (%) of silkworm pupae meal

Species	Dry matter	Crude protein	Crude fibre	Reference
Salmonids	71.1	84.4	-	(7,8)
Common carp	-	63.9	-	(12)
Goldfish	-	80.0	-	(7)

Mean/all fish species	71.1	70.6	-	
Indian shrimp	-	61.0 ¹	-	(1)
Pig	79.0 ²	85.0	92.0	(27)
Chicken ³	58.3	88.0	100.0	(15)
Chicken	61.7	84.9	97.2	(15)

¹ True digestibility; ² Organic matter; ³ De-oiled silkworm pupae meal

Other Properties

Silkworm pupae meal contains food attractants and appetite stimulants for fish⁽²⁸⁾. Since the phagostimulatory property is attached to the oil fraction of silkworm pupae, the attractant capacity in the de-oiled product is negligible.

The physiological value of silkworm pupae oil is favourable, but the high level of unsaturated fatty acids tend to cause rapid autoxidation.

39.4 Feeding Value

In terrestrial animals the feeding value of silkworm pupae meal is unsatisfactory. Most probably the high fat content causes the negative responses. De-oiled silkworm pupae meal is a more suitable protein feedstuff for land animals^(5, 24).

Fishes

Chum salmon (*Oncorhynchus keta*) fry had poor growth when fed silkworm pupae meal but feed efficiency was found to be satisfactory⁽¹⁾.

Replacing fish meal with silkworm pupae meal in diets for the common carp as well as the grass carp (*Ctenopharyngodon idellus*) gave better responses^(9, 13). However, with increasing levels of silkworm pupae meal the performances declined. Not more than 10% of the fish meal should be replaced by silkworm pupae meal (Table 39-05)⁽¹⁸⁾ although in exceptional cases up to 30% silkworm pupae meal in the diet showed good growth⁽¹¹⁾.

Table 39-05: De-oiled silkworm pupae meal replaces fish meal at increasing levels in diets for common carp (*Cyprinus carpio*) (trial period: 126 days)⁽¹⁸⁾

Silkworm pupae meal	%	-	10.0	15.0	20.0	25.0
Fish meal	%	25.0	15.0	10.0	5.0	-
Crude protein	%	28.6	28.3	28.4	28.1	27.9
Fat	%	7.7	7.2	7.8	7.5	7.8

Final weight	g	157.4	129.2	105.4	119.9	117.2
Net weight gain	g	156.4	128.2	104.4	118.9	116.2
Daily weight gain	g	1.35	1.03	0.84	0.95	0.93
Feed conversion	1:	2.85	2.96	3.07	3.03	3.06

The Indian major carp (*Catla catla*) grew better on diets containing non-de-oiled silkworm pupae meal (30%) than the de-oiled quality and the fish meal-fed fish, but feed conversion of the former was poor⁽¹⁶⁾.

Feeding the catla x rohu hybrid (*Catla catla* male x *Labeo rohita* female) with 15% silkworm pupae meal in partial replacement for fish meal gave best responses (Table 39-06), but performances of fish given higher levels of silkworm pupae meal were unfavourable^(11, 17). On the other hand, the Indian carp, Tor khudree, effectively utilised silkworm pupae meal even when local fish meal was totally replaced⁽²²⁾.

Table 39-06: Non-defatted silkworm pupae meal replaces fish meal in diets for catla-rohu hybrids (trial period: 112 days)⁽¹⁷⁾

Silkworm pupae meal	%	-	15.0	20.0	25.0	35.0
Fish meal	%	20.0	10.0	10.0	-	-
Crude protein	%	27.3	27.2	27.1	24.7	27.4
Fat	%	6.3	7.5	8.2	8.5	9.7

Final weight	g	86.2	118.2	84.8	84.7	87.0
Net weight gain	g	84.2	116.2	82.8	82.7	85.0
Daily weight gain	g	0.75	1.04	0.74	0.74	0.76
Feed conversion	1:	2.39	2.48	2.12	2.07	2.42

In diets for the catfish *Heteropneustes fossilis* and *Clarias batrachus*, silkworm pupae meal at increasing levels can significantly replace fish meal (Table 39-07). Up to 75% of the protein requirement of catfish may be provided by silkworm pupae meal⁽¹⁰⁾ and was found to be a better source of protein than other fish meal substitutes⁽⁶⁾.

Ornamental fish can be fed satisfactorily with silkworm pupae meal⁽²⁴⁾.

Table 39-07: Fish meal replacement by silkworm pupae meal in diets for the catfish *Heteropneustes fossilis*⁽¹⁰⁾

Silkworm pupae meal	%	-	11.3	22.7	34.0	45.3
Fish meal	%	61.0	45.7	30.5	14.3	-
Crude protein	%	31.5	32.0	32.5	32.3	32.9
Fat	%	11.9	11.9	11.7	12.0	12.1

Initial weight	g	2.10	2.11	2.13	2.10	2.14
Final weight	g	5.05	5.40	6.08	6.20	5.32
Weight gain	%	140.5	155.9	185.4	195.2	148.6
Feed conversion	1:	2.25	2.10	1.82	1.76	2.05
PER		1.41	1.49	1.70	1.76	1.48

Crustaceans

Replacing all fish meal (47%) protein by silkworm pupae meal (50%) in diets for the Indian shrimp (*Penaeus indicus*) showed inferior results. All performance parameters were considerably lower when compared to fish meal. Silkworm pupae meal as the only protein component in the diet is a poor protein source for the Indian shrimp⁽²⁾, but at low levels it might be useful in shrimp diets^(20, 21).

39.5 Recommended Inclusion Rates

Silkworm pupae meal is a protein feedstuff. It can be used in diets for fish and shrimp at levels of 5.0 to 15.0%. To avoid rancidity, non-de-oiled silkworm pupae meal should be treated with an antioxidant.

39.6 Legal Aspects

The German feedstuff legislation defines silkworm pupae meal as a by-product from the processing of natural silk. It is the dried, de-oiled and ground pupae of the silkworm and free of cocoons. Only de-oiled meal is permitted as a feedstuff⁽²⁹⁾. Legal requirements are:

- Moisture: max. 13.0%
- Fat: max. 0.4%

39.7 References

1. Akiyama, T.; Murai, T.; Hirasawa, Y.; Nose, T. (1984): Supplementation of various meals to fish meal diet for chum salmon fry. *Aquaculture*, 37., 217-222.
2. Ali, S.A. (1992): Evaluation of some animal and plant protein sources in the diet of the shrimp *Penaeus indicus*. *Asian Fisheries Sci.*, 5., 277-289.
3. Bungova, V.G.; Filippovitch, J.B. (1966): Quoted from: Friede, H.J. (1977).
4. Chang, W.Y.B.; Diana, J.S.; Chuapoehtz, W. (1983): Workshop report to agency for international development, 19-29 April (Mimeograph).
5. Friede, H.J. (1977): Seidenraupenpuppenschrot. In: Kling, M.; Wöhlbier, W.: *Handelsfuttermittel*. Verlag Eugen Ulmer, Stuttgart/Germany.
6. Habib, M.A.B.; Hasan, M.R.; Akand, A.M. (1992): Evaluation of silkworm pupae, poultry offal and blood meal as dietary protein sources for *Clarias batrachus*. 3rd Asian Fish. Forum, Singapore, 26-30 October, 104 (Abstr.).
7. Hastings, W.H. (1969): Nutritional Score. In: Neuhaus, O.W.; Halver, J.H. (eds.): *Fish in research*. Academic Press, New York/USA.
8. Hefner, B. (1988): *Nutrition of pond fishes*. Cambridge University Press, Cambridge/England.
9. Hora, S.L.; Pillay, T.V.R. (1962): *Handbook on fish culture in the Indo-Pacific fisheries region*. FAO Fish. Biol. Techn. Paper, No. 14.
10. Hossain, M.A.; Islam, N.M.; Alim, M.A. (1991): Evaluation of silkworm pupae meal as dietary protein source for catfish (*Heteropneustes fossilis* Bloch). *Proc. Fish Nutrition in Practice*, Biarritz/France, 24-27 June, 785-791.
11. Jayaram, M.G.; Shetty, H.R.P. (1980): Influence of different diets on the proximate body composition of *Catla catla*, *Labeo rohita* and *Cyprinus carpio*. *Mysore J. Agric. Sci.*, 14., 381-384.
12. Kim, Y.K. (1974): Determination of true digestibility of dietary proteins in carp with chromic oxide containing diets. *Bull. Jap. Soc. Sci. Fisheries*, 40., 651-653.
13. Koyama, H.; Okubo, H.; Miyajima, T. (1961): Studies of fish food substitute for silkworm pupae as available foods for carp-culturing in farm ponds. II. Experiment about availability of soybean cake, 'Ko' meal and fish meal. *Bull. Freshwater Fish. Res. Lab., Tokyo*, 11., (1), 49-55.
14. Lakshminarayana, T.; Thirumala, T. (1971): Quoted from: Friede, H.J. (1977).
15. Mangold, E.; Stotz, H.; Columbus, A. (1936): Quoted from: Friede, H.J. (1977):
16. Nandeesh, M.C.; Srikanth, G.K.; Varghese, T.J.; Keshavanath, P.; Shetty, H.C.P. (1989): Growth performance of an Indian major carp, *Catla catla* (Ham.) on fish meal-free diets. In: Silva, S.S. de (ed.): *Fish Nutrition Res. in Asia*, Proc. 3rd Asian Fish Nutr. Network Meeting. Asian Fish. Soc. Spec. Publ. 4.
17. Nandeesh, M.C.; Srikanth, G.K.; Varghese, T.J.; Keshavanath, P.; Shetty, H.C.P. (1989): Influence of silkworm pupae based diets on growth, organoleptic quality and biochemical composition of *Catla-Rohu* hybrid. In: Huisman, E.A.; Zonneveld, N.; Bouwmans, A.H.M. (eds.): *Aquaculture research in Asia: Management techniques and nutrition*. Proc. Asian Sem. on Aquaculture, organised by IFS Malang, Indonesia, 14-18 November, 1988. 211-221.
18. Nandeesh, M.C.; Srikanth, G.K.; Varghese, T.J.; Keshavanath, P.; Shetty, H.C.P. (1990): Growth performance of *Cyprinus carpio* var. *communis* fed on diets containing different levels of de-oiled silkworm pupae. In: Hirano, R.; Hanyu, I. (eds.): *Proc. Second Asian Fish. Forum*, Tokyo/Japan, 17-22 April, 1989. 271-274.
19. Nehring, K. (1955): *Lehrbuch der Tierernährung und Futtermittelkunde* (5th edition). Neumann Verlag, Radebeul and Berlin/Germany.

20. *New, M.B.* (1987): Feed and feeding of fish and shrimps - A manual on the preparation and presentation of compound feeds for shrimps and fish in aquaculture. UNDP/FAO/ADCP/REP/87/26, Rome / Italy.
21. *Paulraj, R.* (1995): Aquaculture feed (2nd edition). Marine prod. Export Dev. Authority, Kochi/India (Publ.).
22. *Shyama, S.; Keshavanath, P.* (1991): Growth response of Tor Khudree to silkworm pupa incorporated diets. Proc. Fish Nutrition in Practice, Biarritz/France, 24-27 June, 779-783.
23. *Smirnov, M.T.; Mamedov, R.B.* (1962): Quoted from: *Friede, H.J.* (1977).
24. *Stählin, A.* (1957): Beurteilung der Futtermittel, Vol. XII. Neumann Verlag, Radebeul and Berlin/Germany.
25. *Steger, H.; Piatkowski, B.* (1959): Quoted from: *Friede, H.J.* (1977).
26. *Täufel, A.; Ternes, W.; Tunger, L.; Zobel, M.* (1993): Lebensmittel-Lexikon. Behr's Verlag, Hamburg/Germany.
27. *Tomme, M.E.* (1970): Quoted from: *Friede, H.J.* (1977).
28. *Tsushima, J.; Ina, K.* (1978): Survey of feeding stimulants for carp, *Cyprinus carpio*. J. Agric. Chemistry Soc. Japan, 52., 225-229.
29. *Weinreich, O.; Koch, V.; Knippel, J.* (1994): Futtermittelrechtliche Vorschriften. Buchedition Agrimedia, Hamburg/Germany.
30. *Zaher, M.; Mazid, M.A.* (1993): Aquafeeds and feeding strategies in Bangladesh. In: *New, M.B.; Tacon, A.G.J.; Csavas, I.* (eds.): Farm made aquafeeds. RAP Publication 1993/18, AADCP/PROC/5, Bangkok/Thailand, 75-86.

40. SNAIL MEAL

40.1 Rationale

Snails are slow-moving gastropod molluscs that live on land (lung snails) or in water (gill snails) and have a spiral protective shell or are shellless (Figure 40-01). Some species are hermaphrodites. Snails are human food but are also ectoparasites and predators⁽¹⁴⁾. Major edible snails are the land snails *Helix* spp. and *Achatina* spp.⁽¹⁸⁾.

The African giant snail (*Achatina fulica*) originated from Africa, is now widespread throughout the entire South-east Asia and the Pacific⁽¹⁸⁾. It is a potential human health risk, involved in transmitting meningitis to people when eaten uncooked⁽¹⁷⁾, and a serious pest of rice, banana and other vegetable crops⁽¹⁵⁾. The common field slug (*Agriolimax meticulatus*), a shellless snail, is an intermediate host of the sheep lungworm⁽¹⁷⁾. The golden apple snail (*Pomacea caniculata*) is also a pest of rice fields⁽¹⁵⁾ and *Cerithium tenellum* and *Telescopium telescopium* are pests in milkfish ponds⁽¹⁶⁾.

All these snail species appear in large numbers and are a potential feedstuff for on-farm feed preparation but not for industrial manufacturing of aquaculture feed.

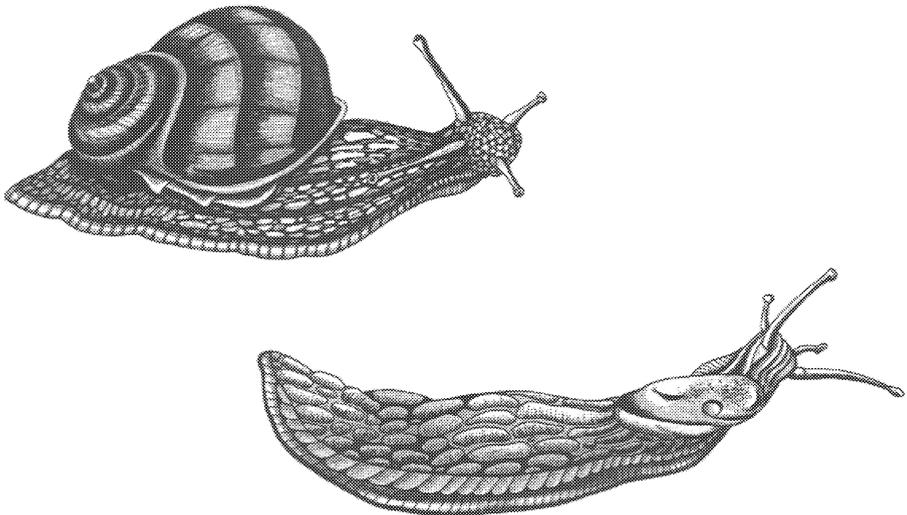


Figure 40-01. Land (lung) snails. Edible snail (*Helix pomatia*) (left) and common field (red) slug (*Agriolimax meticulatus*) (right).

40.2 Processing

Freshly collected snails are boiled in water for 15 to 20 minutes. The flesh is separated from the shell, minced and dried at a temperature of not more than 60°C^(3, 5, 15). The adult *Helix aspersa maxima* has a liveweight of about 40 g. The shell portion amounts to around 15% of the liveweight⁽¹⁸⁾.

40.3 Chemical, Physiological and other Properties

Chemical Properties

The manner of processing influences the chemical composition of snail meal. Whole snail meal (flesh and shells) is low in protein but high in ashes. Meal only from snail flesh is an excellent protein feedstuff (Table 40-01) and is a source of high levels of essential amino acids (Table 40-02). The essential amino acid index (EAAI) of golden apple snail protein is 0.91⁽²⁾.

The fat of the golden apple snail is a good source of the essential fatty acids linoleic acid (18:2n-6), linolenic acid (18:3n-3) and arachidonic acid (20:5n-3)⁽²⁾.

The calcium content of whole snail meal and snail shells is high but the phosphorus content is extremely low (Table 40-01).

Table 40-01: Chemical composition of snail meal (% in dry matter)

	Flesh meal ⁽⁵⁾	Shell meal ⁽⁵⁾	Whole meal ⁽⁵⁾	Whole ¹ meal ⁽¹³⁾	Whole ² meal ⁽⁶⁾
Moisture	-	-	-	4.74	7.0
Crude protein	60.9	2.8	16.1	13.75	52.8
Crude fat	6.1	1.0	2.0	1.68	1.8
Ash	9.6	54.5	46.0	73.84	20.9
Crude fibre	4.5	-	-	0.97	1.9
N-free extract	18.9	-	-	9.76	22.6
Calcium	2.0	36.1	31.1	-	-
Phosphorus	0.84	0.14	0.32	-	-

¹ From *Cerithium* sp.; ² From golden apple snail (*Pomacea caniculata*)

Table 40-02: Essential amino acid profile of snail meal (g/16 g N)^(5, 9)

Arginine	4.88
Histidine	1.43
Isoleucine	2.64
Leucine	4.62
Lysine	4.35
Methionine	0.89
Phenylalanine	2.62
Threonine	2.76
Tryptophan	-
Valine	3.07

Physiological Properties

The gross energy of flesh meal amounts to 5,110 kcal/kg (21.4 MJ/kg) and the metabolisable energy (determined in broilers) is 3,400 kcal/kg (14.2 MJ/kg)⁽⁵⁾.

Snail meal is a source of xanthophylls⁽⁷⁾. When laying hens were fed with snail meal, chicken eggs had a deeper yolk colour⁽⁴⁾. It also may contain UGF (see chapter 44)^(5, 15).

Other Properties

Meal from unboiled snails contain an anti-nutritional factor which is present in the slime of the snail. By washing and/or cooking, the toxic and unpalatable factor can be removed^(5, 8). The addition of methionine also eliminates the effect of the anti-nutritional factor^(4, 15).

40.4 Feeding Value

The feeding value of snail meal has been tested in broilers⁽⁵⁾, laying hens⁽⁴⁾ and pigs⁽¹⁵⁾. A significant improvement of performances were obtained by using 5.0 to 10.0% snail meal.

Satisfactory results were obtained when tiger prawns (*Penaeus monodon*) until the age of four months were fed with golden apple snails alone or in combination with carbohydrates. The mixture of snails and maize gave best results⁽²⁾. Golden snails are a useful protein ingredient in farm-made crustacean feed^(3, 11, 12, 13).

40.5 Recommended Inclusion Rates and Precautions

Recommended Inclusion Rates

In experimental diets for the freshwater prawn *Macrobrachium rosenbergii* snail meal at levels of 15.0% were used⁽¹⁾. For on-farm mixed aquaculture feed appropriate levels are 5.0 to 10% snail meal prepared from boiled snails and flesh only.

Precautions

Snails are high in protein and calcium. However, snail meal is only of value as feed for aquatic animals, if cooked⁽¹⁰⁾.

40.6 References

1. *AQUACOP* (1976): Incorporation of vegetable protein into a diet for the freshwater prawn *Macrobrachium rosenbergii*. *Aquaculture*, 8., 71-80.
2. *Bombero-Tuburan, I.; Fukumoto, S.; Rodriguez, E.* (1994): Use of the golden apple snail, cassava and maize as feeds for tiger shrimp *Penaeus monodon* in ponds. National Seminar-Workshop on Fish Nutrition and Feeds, 1to2 June, Tigbauan, Iloilo/The Philippines (Abstr.).
3. *Basa, S.S.* (1988): Country review (Philippines). Proc. Workshop on Shrimps and Finfish Feeds Development, Johore Bahru/Malaysia, 25-29 October.
4. *Creswell, D.C.; Habibie, A.* (1989): Studies on snail meal as a protein source for chickens. 2. Feeding value for laying hens. *Poultry Sci.*, 60., 8, 1861-1864.

5. *Creswell, D.C.; Kompiang, I.P.* (1989): Studies on snail meal as a protein source for chickens. 1. Chemical composition, metabolisable energy, and feeding value for broilers. *Poultry Sci.*, *60.*, 8, 1854-1860.
6. *Feed Development Section* (1994): Feeds and feeding of milkfish, Nile tilapia, Asian sea bass, and tiger shrimp. SEAFDEC, Aquaculture Dept., Tigbauan, Iloilo, The Philippines.
7. *Fox, D.L.* (1966): Pigmentation in molluscs. In: *Wilbur, K.M.; Yonge, C.M.* (eds.): *Physiology of molluscs*, Vol. II. Academic Press, Inc., New York.
8. *Mead, A.R.* (1961): The giant African snail. A problem in economical malacology. The University of Chicago Press, Chicago/USA.
9. *Mead, A.R.; Kemmerer, R.* (1951): Quoted from: *Creswell and Kompiang* (1981).
10. *New, M.B.* (1987): Feed and feeding of fish and shrimps - A manual on the preparation and presentation of compound feeds for shrimps and fish in aquaculture. UNDP/FAO/ADCP/REP/87/26, Rome/Italy.
11. *New, M.B.; Csavas, I.* (1993): A summary of information on aquafeed production in eleven Asian countries. In: *New, M.B.; Tacon, A.G.J.; Csavas, I.* (eds.): *Farm-made aqua feeds*. RAPA Publication 1993/18 - AADCP/PROC/5, 397-419.
12. *Pascual, F.P.* (1989): Nutrition and feeding of *Penaeus monodon*. Aquaculture Extension Manual No. 3 (3rd ed.) SEAFDEC, Iloilo/The Philippines.
13. *Piedad-Pascual, F.* (1993): Aquafeeds and feeding strategies in the Philippines. In: *New, M.B.; Tacon, A.G.J.; Csavas, I.* (eds.): *Farm-made aqua feeds*. RAPA Publication 1993/18 - AADCP/PROC/5, 317-343.
14. *Quayle, D.B.; Newkirk, G.F.* (1989): Farming bivalve molluscs. Methods for study and development. The World Aquaculture Soc., Baton Rouge, LA/USA.
15. *Sison, J.A.* (1985): Handbook on crisis management on feedmilling and technology for the Philippines. Feedindex (Phils.), Quezon City/The Philippines.
16. *Trinio, A.T.; Bolivar, E.C.; Jerochi, D.D.* (1993): Effect of burning of rice straw on snails and soil in a brackishwater pond. *Intern. J. Tropical Aquaculture*, *11.*, (2), 93-97.
17. *West, G.P.* (1992): Black's veterinary dictionary. A & C Black, London, 17th Edition.
18. *Wilhelmsen, D.* (1988): Snegleproduksjon - en mulig nisje for landbruket? Institutt for husdyrfag, Norges Landbrukshøgskole, Ås/Norway (Mimeograph).

41. SOYA LECITHIN

41.1 Rationale

Almost 150 years ago the French chemist *Maurice Gobley* isolated for the first time lecithin from egg yolk. He found the emulsifying properties of this substance and named it “Lecithin”, from the Greek word - LEKITHOS - for egg yolk.

Scientifically “Lecithin” is the trivial name for one of its components - “Phosphatidylcholine”. But in the colloquial language lecithin is defined as a complex of “polar” and “neutral” lipids with a polar content of at least 60%. Lecithin is synonymous to phospholipids and phosphatides. The generic term for lecithin is “Phospholipids”. Hence, the term phospholipids is commonly used⁽¹⁷⁾.

All products of plant and animal origin contain phospholipids. Soya beans are the main source of natural phospholipids. It contains 0.5 to 1.5% lecithin. Animal sources of phospholipids are egg yolk, brain and molluscs. Other sources of phospholipids are micro-organisms such as bacteria, algae, fungi and yeast⁽⁵⁶⁾. Apart from its use in aquaculture as a feed ingredient, soya lecithin has a wide field of application⁽²⁹⁾.

41.2 Manufacture and Processing

Crude Lecithin

The crude soybean oil is heated to 70°C to 90°C and mixed with 1.0 to 4.0% water. The water swells the lecithin to a jelly-like mass and by high-speed separation it is split from the oil (Figure 41-01). The moisture of the so obtained lecithin sludge is removed in a thin-layer evaporator by reduced pressure and at a temperature as low as possible. The moisture-free material is the crude lecithin which is a plastic viscous, dark-brown, difficult to handle mass. This process is also known as “de-gumming”⁽⁵⁸⁾.

Standardised Lecithin

This is crude lecithin that is refined, and phospholipid content and viscosity are standardised.

Modified Lecithin

By treating crude lecithin biologically or chemically modified lecithin is obtained. There are a number of processes which can be used for modification. The most common is hydroxylation with hydrogen peroxide in the presence of lactic acid and the enzymatical treatment with four different phospholipases. Modified lecithin is still a liquid but has better emulsifying property than all the other lecithin products⁽²⁷⁾.

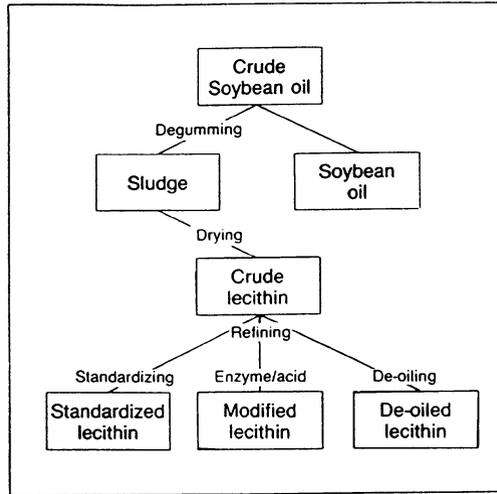


Figure 41-01. Diagram of processing of crude soybean oil to lecithin products used in the feeding of aquatic animals⁽⁷⁹⁾.

De-oiled Lecithin

This quality is also called “pure lecithin”. The adhering soybean oil is removed in several refining stages. It is available in the form of powder or granules.

41.3 Chemical and Physiological Properties

Chemical Properties

Soya lecithin is composed of polar lipids, soybean oil, moisture and impurities (Table 41-01). It is rich in unsaturated fatty acid (Table 41-02) and the phosphorus content is high (Table 41-03). It contains also cholines, serines, ethanolamines, inositols and glycerols (sphingosines).

The phospholipids are the major component of soyalecithin. They are “polar lipids” (Figure 41-02), possessing at least one polar group and are subdivided into phospholipids and glycolipids. The presence of phosphorus is the distinguishing characteristic of phospholipids which can be divided into:

- Glycerophospholipids
- Sphingophospholipids.

Phospholipids are chemically composed of the “head” and the “tail”. The “head” or the hydrophilic portion has various chemical structures which determine the different glycerophospholipid classes⁽⁴⁹⁾. Of major interest in aquaculture feed are:

- Phosphatidylcholine (PC)
- Phosphatidylethanolamine (PE)
- Phosphatidylinositol (PI)

Table 41-01: Composition of soybean oil "sludge" and crude lecithin (%)⁽¹⁹⁾

	Sludge	Crude lecithin
Polar lipids	33	60 to 70
Soybean oil	12	27 to 37
Moisture	53	0.5 to 1.5
Impurities	2	0.5 to 2.0

Table 41-02: Fatty acid content (% of total fatty acids) of soya lecithin⁽⁵⁶⁾

		Crude lecithin	De-oiled lecithin
Palmitic acid	16:0	15.6	20.3
Stearic acid	18:0	4.7	4.6

Saturated fatty acids		20.3	24.9
Oleic acid	18:1	17.9	9.2
Linoleic acid	18:2	54.0	58.9
Linolenic acid	18:3	6.7	7.0

Unsaturated fatty acids		78.6	75.1
Unsaturated:saturated ratio 1:		3.9	3.0

Table 41-03: Macro and trace mineral contents of soya lecithin⁽⁵⁹⁾

			Crude lecithin	De-oiled lecithin
Phosphorus	P	%	2.00	3.00
Potassium	K	%	0.44	0.80
Calcium	Ca	%	0.04	0.07
Magnesium	Mg	%	0.06	0.09
Sodium	Na	%	0.01	0.03
Aluminium	Al	mg/kg	26.0	16.5
Iron	Fe	mg/kg	67.0	52.0
Boron	B	mg/kg	10.0	12.8
Copper	Cu	mg/kg	0.5	2.4
Zinc	Zn	mg/kg	12.2	23.7
Manganese	Mn	mg/kg	1.0	1.5

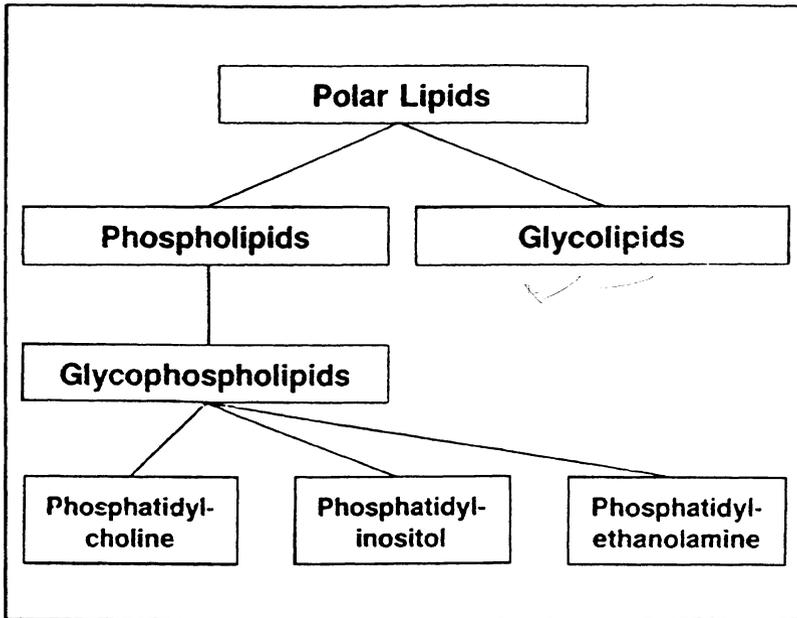


Figure 41-02. Polar lipids and their classification⁽¹⁹⁾.

The phospholipid content of various lecithins are in Table 41-04. Soya lecithin also has antioxidative^(41, 50) as well as chemo-attractant properties⁽¹⁵⁾.

Table 41-04: Mean composition (%) of soya lecithins⁽⁶⁷⁾

	Standard lecithin	Modified lecithin	De-oiled lecithin
Phosphatidylcholine	15.0	12.0	23.0
Phosphatidylinositol	13.0	10.0	19.0
Phosphatidylethanolamine	14.0	9.5	21.0
Other phospholipids, glycolipids, phosphatidic acid	20.0	24.5	35.0

Total phospholipids ¹	62.0	56.0	98.0
Soybean oil and other substances	38.0	44.0	2.0

¹ pure lecithin, incl. glycolipids

Quality criteria for lecithins have been initiated by the “German Association of Lipid Sciences” (Deutsche Gesellschaft für Fettwissenschaft e.V. [DGF]) as well as by the “American Oil Chemists Society” (AOCS). The definition of lecithins by the European Union (EU) and their quality criteria are compiled in Table 41-05⁽¹⁹⁾.

Table 41-05: Definition of Lecithin by the European Union (EU) (E 322)⁽¹⁹⁾

Description:	Lecithins are mixtures or fractions of phosphatides obtained by physical procedures from animal or vegetable foodstuffs; they also include hydrolysed products obtained through the use of harmless and appropriate enzymes. The final product must not show any signs of residual enzyme activity; The lecithins may be slightly bleached in aqueous medium by means of hydrogen-peroxide. This oxidation must not chemically modify the lecithin phosphatides;
Appearance:	Lecithins: brown liquid or semi-liquid or powder; Hydrolyzed lecithins: liquid brown to brown viscous or paste;
Content:	Lecithins: not less than 60% of substance insoluble in acetone; Hydrolysed lecithins: not less than 56% of substances insoluble in acetone;
Volatile matter:	Not more than 2.0% determined by drying at 105°C for one hour;
Substances insoluble in toluene:	Not more than 0.3%;
Acid value:	Lecithins: not more than 35 mg of potassium hydroxide per gram; Hydrolysed lecithin: not more than 45 mg of potassium hydroxide per gram;
Peroxide value:	Equal to or less than 10, expressed as milli-equivalents per kilogram.

Functions of Phospholipids

Phospholipids are the major constituent of most membranes, and are vital to the normal function of every cell and organ. They have regulatory activity inside the cell, within the plasma membrane, as well as outside the cell⁽⁶⁾ and are present in certain body fluids, such as blood plasma of vertebrates in the form of “lipoprotein”.

In aquaculture feed dietary soya lecithin is:

- Necessary in intermediary metabolism, and
- As a bio-surfactant (emulsifier) in the intestine.

Phosphatidylcholine particularly is closely involved in lipid metabolism. Phospholipids are very important in the metabolic transport of fatty acids. Out of the liver they can only be transported in the form of triglyceride within lipoproteins. An essential constituent of these lipoproteins is phosphatidylcholine. Inadequate supply of phosphatidylcholine

prevents transport of triglyceride from the liver causing an accumulation of fat known as “fatty liver syndrome”. Thus, there is an absolute dependence for phosphatidylcholine⁽⁶⁶⁾. Without phospholipids there is no metabolic transport of fatty acids.

While mammals are capable of synthesising phospholipids *de novo* from 1,2-diglycerides and from cytidine-5'-diphosphate choline (CDP-choline), crustaceans have a limited ability to bio-synthesise them and consequently have to be provided with exogenous phospholipids via the feed⁽⁹⁾, but the lobster, *Homarus americanus*, may bio-synthesise phospholipids by the pathways established for vertebrates⁽⁵⁷⁾.

The biosynthesis of phospholipids in fish may be similar to that of mammals^(22, 40, 61). Phospholipids are also involved in the acclimatisation of fish to different environmental temperatures⁽¹⁶⁾, in the migration of fish from freshwater to seawater and vice versa^(8, 16, 45) and are important for the osmoregulatory system of marine fish⁽³⁷⁾.

The bio-surfactant property of soya lecithin enhances the emulsification of dietary lipids in the intestine and consequently fat absorption. Together with the bile and other lipid soluble matter, aggregate into micelles which transport the splitted fat products to the *ville* membranes where absorption occurs⁽³⁹⁾. Similarly phospholipids are needed for the absorption of fat soluble vitamins.

41.4 Feeding Value

Fishes

Early feeding salmonids - rainbow trout (*Oncorhynchus mykiss*, *Salmo gairdneri*) and Atlantic salmon (*Salmo salar*) - clearly survive better and grow faster when the diet is supplemented with soya lecithin^(53, 54, 55, 59) (Figure 41-03).

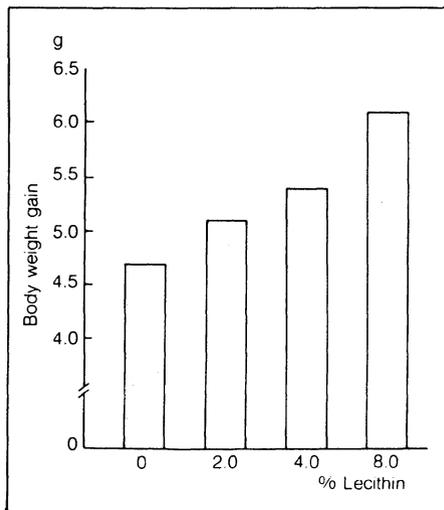


Figure 41-03. Performances of rainbow trout (*Oncorhynchus mykiss*) fed a herring meal basal diet and supplemental soya lecithin⁽⁵³⁾.

Soya lecithin in diets for the larval ayu sweetfish (*Plecoglossus altivelis*) is needed for better growth and survival and for reducing incidences of malformation and twist of jaw^(32, 34). The juvenile white sturgeon (*Acipenser transmontanus*) responded positively to diets fortified with refined soya lecithin^(24, 25). However, it has been also presumed that the beneficial effects may have resulted from the choline moiety of phosphatidylcholine rather than the lecithin *per se*⁽²³⁾. The juvenile striped jack (*Pseudocaranx dentex*) performed better when the diet was fortified with phosphatidylcholine than with phosphatidylethanolamine⁽⁶⁶⁾.

In the larval and juvenile stage of red seabream (*Chrysophrys major*), Japanese flounder (*Paralichthys olivaceus*), greenling (*Hexagrammos otakii*) and gilthead seabream (*Sparus aurata*) the supplementation of soya lecithin at levels of 1.5 to 7.4% improved growth and survival^(30, 33, 38, 48).

Although most of the trials have been done with larval, juvenile and fingerling fish, there is evidence that phospholipids are also effective in larger animals^(1, 18).

In fish, soya lecithin was found superior to chicken egg lecithin. Only bonito egg lecithin was more effective than soya lecithin^(32, 34).

Crustaceans

The juvenile spiny lobster (*Homarus americanus*) grow faster and survival rate is higher when the feed is supplemented with 3.0 to 8.0% crude soya lecithin^(2, 3, 13, 36). But, if crab protein is fed - which has a high phospholipid content - there is no need for dietary lecithin^(3, 13, 31). Weight gain increased with increasing levels of crude soya lecithin in the feed^(36, 64), but survival rate improved only up to a supplementation level of 6.0% crude soya lecithin⁽⁶⁴⁾. In the absence of cholesterol, lecithin hardly had any effect on the survival rate of the juvenile lobster⁽³⁶⁾.

The larval and juvenile kuruma prawn (*Penaeus japonicus*) develop faster when the diet is fortified with soya lecithin^(31, 35, 62, 63) (Figure 41-04). Increasing amounts of soya lecithin in diets for larvae and juvenile kuruma prawn and white leg prawn (*Penaeus vanameii*) improved weight gain and survival rate simultaneously up to an inclusion rate of 3.5% phosphatidylcholine^(12, 35). There is also a synergistic effect between dietary soybean phosphatidylcholine and dietary cholesterol. The best response was obtained with 3.0% phosphatidylcholine and 1.0% cholesterol⁽⁶³⁾.

Soya lecithin in diets for the tiger prawn (*Penaeus monodon*) not only improves growth and survival^(4, 51, 52) but has also a positive effect on maturation and spawning⁽⁴⁷⁾. Weight gain, feed conversion and survival of the red tail prawn (*Penaeus penicillatus*) were likewise improved when diets were supplemented with phosphatidylcholine or cholesterol⁽¹¹⁾.

Apparently freshwater prawns like *Marcrobrachium rosenbergii* do not need dietary soya lecithin^(5, 20).

Like in fish, soya lecithin gives better weight gain and survival than chicken egg lecithin in the Halifax lobster⁽⁶⁴⁾, in the kuruma prawn⁽³⁵⁾ and in the tiger prawn⁽¹⁰⁾. Only bonito egg lecithin has been found superior to soya lecithin⁽³⁵⁾.

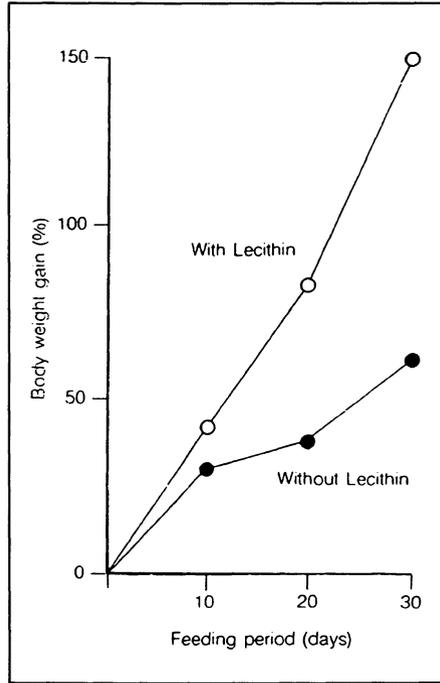


Figure 41-04. Weight gain (%) of kuruma prawns (*Penaeus japonicus*) receiving diets with and without lecithin⁽⁶²⁾.

Soya Lecithin Components of Significance

Choline, inositol and phosphorus are significant components of soya lecithin in the form of phosphatidylcholine, phosphatidylinositol and phosphorus. Each kg of de-oiled soya lecithin contains⁽¹⁹⁾:

- 36 g choline,
- 38 g inositol,
- 31 g phosphorus.

Soya lecithin, therefore, contributes to the requirement of these nutrients in aquaculture diets. Studies in the white sturgeon and Atlantic salmon (Figure 41-05) show that phospholipids can replace choline chloride^(43, 59) and is as well utilised as synthetic choline chloride as found in chicken^(7, 42). In man, lecithin is a more effective source of choline than choline chloride^(21, 26, 65, 66).

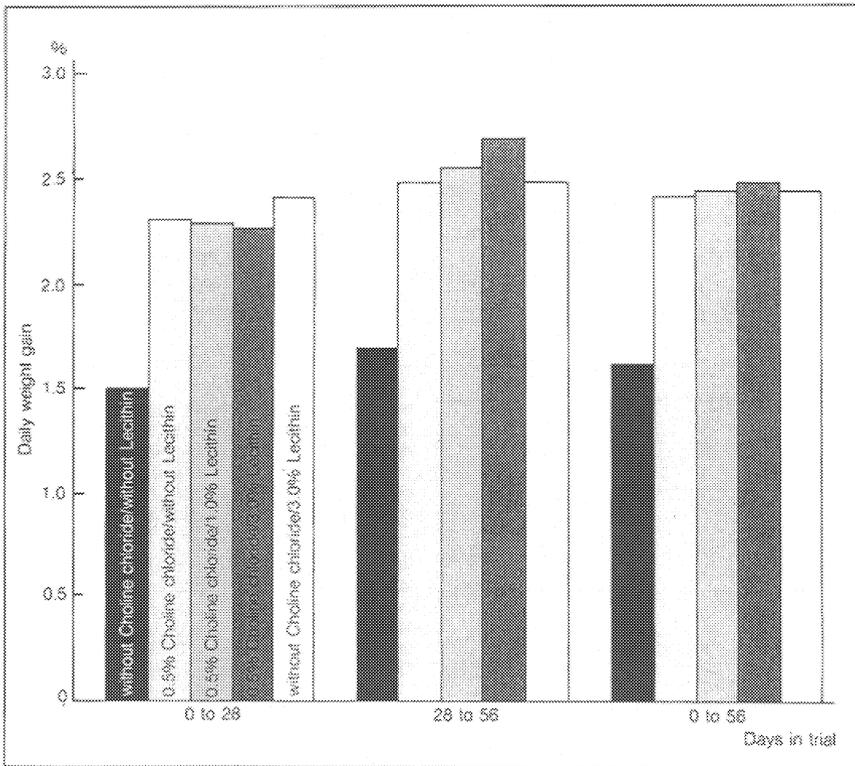


Figure 41-05. Daily growth rates of Atlantic salmon (*Salmo salar*) fingerlings by trial periods after feeding phospholipids (de-oiled lecithin) and choline chloride⁽⁵⁹⁾.

41.5 Recommended Inclusion Rates

The lecithin requirement of fish and shrimp (Table 41-06 and 41-07) comes from about 1/3 of the inherent phospholipid content of the components of the feed and 2/3 of the supplemental soya lecithin in the form of pure phospholipids (de-oiled lecithin)⁽¹⁹⁾.

The phospholipid requirement depends on:

- The total fat content of the feed;
- The age or developmental stage of the aquatic animal;
- The temperature of the water in which the animal is cultured (e.g. coldwater fish need more phospholipids than warmwater fish).

De-oiled lecithin is advantageous for the phospholipid fortification of feed^(14, 35, 46). The use of fluid lecithin (crude lecithin, standardised lecithin, modified lecithin) should be based only on its phospholipid content.

Table 41-06: Recommendations for the phospholipid requirement (% in the feed) of fishes (added lecithin in the form of de-oiled powder and the native phospholipid content of the feed)⁽¹⁹⁾

Total fat content of the feed		Type of feed					
		Starter		Grower		Finisher	
%		Total phospholipid content of the feed (%)					
		Cold ¹	Warm ²	Cold	Warm	Cold	Warm
up to	3.0	2.0	1.5	1.5	1.1	1.0	0.7
3.0 -	5.0	2.5	2.0	2.0	1.6	1.4	1.1
5.0 -	7.0	3.0	2.5	2.5	2.1	1.8	1.5
7.0 -	9.0	4.0	3.5	3.0	2.6	2.2	1.9
9.0 -	11.0	5.0	4.5	3.5	3.1	2.6	2.3
11.0 and more		6.0	5.5	4.0	3.6	3.0	2.7

¹Cold water fish; ²Warm water fish

Table 41-07: Recommendations for the phospholipid requirement (%) of shrimps (added lecithin in the form of de-oiled lecithin and the inherent phospholipid content of the feed)⁽²⁸⁾

Total fat content of the feed		Type of feed		
		Starter	Grower	Finisher
%				
until	3.0	2.0	1.5	1.0
3.0 -	5.0	2.5	2.0	1.4
5.0 -	7.0	3.0	2.5	1.9
7.0 -	9.0	4.0	3.0	2.5
9.0 and more		6.0	4.0	3.0

41.6 Legal Aspects

In the European Union (EU) lecithin is listed in Section L, Annex I, No. E 322 of the EU Regulations on Feed Additives and can be used in feeds for all kinds of productive farm animals without quantitative limitation⁽¹⁹⁾. In U.S.A. lecithin has the GRAS (Generally Recognised As Safe) status with the FDA registration no. 582.1400⁽⁴⁴⁾.

41.7 References

1. *Allwoerden, H.N. von; Hoffmann, D.; Feldheim, W.* (1990): Versuchsbericht des Inst. für Humanernährung und Lebensmittelkunde der Univ. Kiel/Germany.
2. *Boghen, A.; Castell, J.D.* (1980): Considerations of the lecithin and protein requirements of juvenile lobsters (*Homarus americanus*). Proc. 1980 Lobster Nutrition Workshop. University of Maine/Orano, 15 to 16 January.
3. *Bowser, P.R.; Rosemark, R.* (1981): Mortalities of cultured lobster, *Homarus*, associated with a molt death syndrome. *Aquaculture*, 23., 11-18.
4. *Briggs, M.R.P.; Brown, J.H.* (1990): The effect of dietary lipid and phospholipid levels on the growth, survival, feed efficiency and carcass composition of juvenile *Penaeus monodon*. (unpublished data).
5. *Briggs, M.R.P.; Jauncey, K.; Brown, J.H.* (1988): The cholesterol and lecithin requirements of juvenile prawn (*Macrobrachium rosenbergii*) fed semi-purified diets. *Aquaculture*, 70., 121-129.
6. *Bruni, A.; Bellini, F.; Mietto, L.; Boarato, E.; Viola, G.* (1990): Phospholipids absorption and diffusion through membranes. In: *Hanin, I.; Pepeu, G.* (1990): Phospholipids. Plenum Press, New York and London, 59-68.
7. *Budowski, P.; Kafri, I.; Sklan, D.* (1977): Utilization of choline from crude soybean lecithin by chicks. 2. Absorption measurements. *Poultry Sci.*, 56., (3), 754-757.
8. *Castell, J.D.* (1979): Review of lipid requirements of finfish. In: *Finfish nutrition and fish feed technology*. Schriften BFF, Hamburg/Germany, 14./15., (2), 59-84.
9. *Castell, J.D.; Mason, E.C.; Covey, J.F.* (1975): *J. Fish Research Board Canada*, 38., 1431-1435.
10. *Catucatan, M.; Kanazawa, A.* (1985): Quoted from: *Piedad-Pascual* (1986):
11. *Chen, H.Y.; Jenn, J.S.* (1991): Combined effects of dietary phosphatidylcholine and cholesterol on growth, survival and body composition of marine shrimp, *Penaeus penicillatus*. *Aquaculture*, 96., 167-178.
12. *Clark, Ann E.; Lawrence, A.* (w/o year): Lecithin requirement of post larval *Penaeus vannameii*. Shrimp Mariculture Project, Texas Agric. Experim. Station, Port Aransas (Mimeograph).
13. *Conklin, D.E.; D'Abramo, D.E.; Bordner, C.E.; Baum, N.A.* (1980): A successful purified diet for the culture of juvenile lobsters: The effect of lecithin. *Aquaculture*, 21., 243-249.
14. *D'Abramo, L.R.; Bordner, C.F.; Conklin, D.E.* (1982): Relationship between dietary phosphatidylcholine and serum cholesterol in the lobster *Homarus* sp. *Marine Biology*, 67., 231-235.
15. *Harada, K.* (1987): Relationship between structure and feeding attraction activity of certain L-amino acids and lecithin in aquatic animals. *Bull. Jap. Soc. Sci. Fishery*, 53., 2243-2247.
16. *Hepher, B.* (1988): Nutrition of pond fishes. Cambridge University Press, Cambridge/U.K.
17. *Hertrampf, J.W.* (1991): Feeding aquatic animals with phospholipids. I. Crustaceans. Lucas Meyer Publication No. 8.
18. *Hertrampf, J.W.* (1991): Zur Phospholipid-Versorgung von Salmoniden. *Die Mühle + Mischfüttertechnik*. 128., (36), 463-465.
19. *Hertrampf, J.W.* (1992): Feeding aquatic animals with phospholipids, II. Fishes. Lucas Meyer Publication No. 11.
20. *Hilton, J.W.; Harrison, K.E.; Slinger, S.J.* (1984): Semi-purified test diet for *Macrobrachium rosenbergii* and the lack of need for supplemental lecithin. *Aquaculture*, 37., 209-215.
21. *Hirsch, M.J.; Growdon, J.H.; Wurtman, R.J.* (1978): Relations between dietary choline or lecithin intake, serum choline levels and various metabolic indices. *Metabolism*, 27., 953 ff.
22. *Holub, B.J.; Nilsson, K.; Piekarski, J.; Slinger, S.J.* (1975): Bio-synthesis of lecithin by the CDP-choline pathway in liver microsomes in rainbow trout, *Salmo gairdneri*. *J. Fishery Res. Board Canada*, 32, 1633-1637.

23. Hung, S.S.O. (1989): Choline requirement of hatchery-produced juvenile white sturgeon (*Acipenser transmontanus*). *Aquaculture*, 78., 183-194.
24. Hung, S.S.O.; Lutes, P.B. (1988): A preliminary study on the nonessentiality of lecithin for hatchery produced juvenile white sturgeon (*Acipenser transmontanus*). *Aquaculture*, 68., 353-360.
25. Hung, S.S.O.; Moore, B.J.; Bordner, C.E.; Conte, F.S. (1987): Growth of juvenile white sturgeon (*Acipenser transmontanus*) fed different purified diets. *J. Nutrition*, 117., (2), 328-334.
26. Jope, R.S. et al. (1982): Quoted from Kahl, J. (1991).
27. JWH (1993): Modified lecithin for aquaculture feed. *Lecithin Trends* 2/93, August, (Lucas Meyer Newsletter).
28. JWH (1993): Shrimp's lecithin requirement. *Lecithin Trends* 5/93, November, (Lucas Meyer Newsletter).
29. JWH (1994): Unlimited application for soya lecithin. *Lecithin Trends* 14/64, August (Lucas Meyer Newsletter).
30. Kanazawa, A. (1991): Essential phospholipids of larval fish and crustaceans. Paper pres. 4th Symp. on Fish Nutrition and Feeding, 24-27 June, Biarritz/France.
31. Kanazawa, A.; Teshima, S.; Endo M.; Abdel Razem, F.S. (1979): Effects of short-necked clam phospholipids on the growth of prawns. *Bull. Jap. Soc. Sci. Fish.*, 45., 961-965.
32. Kanazawa, A.; Teshima, S.; Inamori, S.; Iwashita, T.; Nagao, A. (1981): Effects of phospholipids on growth, survival and incidence of malformation in the larval ayu. *Mem. Fac. Fish. Kagoshima University*, 30., 301-309.
33. Kanazawa, A.; Teshima, S.; Inamori, S.; Matsubara, H. (1983): Effects of dietary phospholipids on growth of the larval red sea bream and knife jaw. *Mem. Fac. Fish. Kagoshima University*, 32., 109-114.
34. Kanazawa, A.; Teshima, S.; Kobayashi, T.; Iwashita, M.; Vendra, R. (1983): Necessity of dietary phospholipids for growth of the larval ayu. *Mem. Fac. Fish. Kagoshima University*, 32., 109-114.
35. Kanazawa, A.; Teshima, S.; Sakamoto, M. (1985): Effects of dietary lipid fatty acids and phospholipids on growth and survival of prawn (*Penaeus japonicus*) larvae. *Aquaculture*, 50., 39-49.
36. Kean, J.C.; Castell, J.D.; Boghen, A.G.; D'Abramo, L.R.; Conklin, D.E. (1985): A re-evaluation of lecithin and cholesterol requirements of juvenile lobsters (*Homarus americanus*) using crab protein-based diets. *Aquaculture*, 47., 143-149.
37. Kimelberg, H.K.; Papahadjopolus, D. (1972): Phospholipid requirement or (Na⁺ and K)ATPase activity. Head group specificity and fatty acid fluidity. *Biochem. Biophys. Acta*, 282., 277-292.
38. Koven, W.M.; Kolkovski, S.; Tandler, A.; Kissil, G.W.; Sklan, D. (1991): The effect of dietary lecithin and exogenous lipases on fatty acid incorporation in the tissue lipids of *Sparus aurata* larvae. Paper pres. Symp. on Fish Nutrition and Feeding, 24-27 June, Biarritz/France.
39. Lang, K. (1979): *Biochemie der Ernährung*, 2nd Ed., Dr. Dietrich Steinkopff-Verlag, Darmstadt/Germany.
40. Lee, D.J.; Sinnhuber, R.O. (1972): Lipid requirement. In: Halver, J.E.: *Fish Nutrition*. Academic Press, New York, 149-186.
41. Linow, F.; Mieth, G. (1976): Zur fettstabilisierenden Wirkung von Phosphatiden. 3. Mitt. Synergistische Wirkung ausgewählter Phosphatide. *Nahrung*, 20., (1), 19-24.
42. Lipstein, B.; Bornstein, S.; Budowski, P. (1977): Utilization of choline from crude soybean lecithin by chicks. 1. Growth and prevention of perosis. *Poultry Sci.*, 56., 251-252.
43. Lucas, C.C.; Ridout, J.H. (1967): Transmethylation and biosynthesis of the methyl group. In: *Holman: Fatty livers and lipotropic phenomena*. Progress in Chemistry of fats and other lipids, 10., (1), Pergamon Press London.
44. Lusas, E.W.; Riaz, M.N. (1996): Fats in feedstuffs and pet foods. In: Hui, Y.H. (ed.): *Bailey's industrial oil and fat products*, 5th Ed., Vol. 3. John Wiley & Sons, Inc.
45. Meister, R.; Zwingelstein, C.; Jouanneteau, J. (1974): Salinite et composition en acides grasides phosphoglycerides tissulaires chez l'anguille (*Anguilla anguilla*). *Ann. Inst. Michel Pacha*, 1973, (8), 58-71.

46. Meyers, S.P. (1990): Aquaculture diets with lecithin. *Feed International*, 11., (6), 17-20.
47. Millamena, O.M.; Primavera, J.H.; Pudadera, R.A.; Caballero, R.V. (1986): The effect of diet on the reproductive performance of pond-reared *Penaeus monodon* Fabricius broodstock. Proc. 1st Asian Fish. Forum, 539-596 (Asian Fish. Soc., Manila).
48. Oda, T. (1984): Effects of artificial diet supplemented soybean lecithin for fat greenling *Hexagrammos otakii* larvae. Bull. Fish. Exp. Station Okayama Prefecture, 64-68.
49. Paltauf, F.; Hermetter, A. (1990): Phospholipids - Natural, semi-synthetic, synthetic. In: Hanin, I.; Pepeu, G.: Phospholipids, Plenum Press, New York and London, 1-12.
50. Pardun, H. (1982): Progress in production and processing of vegetable lecithins. *Fette, Seifen, Anstrichmittel*, 84., 1-11.
51. Piedad-Pascual, F. (1984): Lecithin requirements of *Penaeus monodon*. In: Taki, Y.; Primavera, J.H.; Llobrera, J.A. (1985): Proc. 1st International Conf. on the Culture of Penaeid prawns/shrimps, 4 to 7 Dec. 1984, Iloilo City/The Philippines.
52. Piedad-Pascual, F. (1986): Effect of supplemental lecithin and lipid sources on the growth and survival of *Penaeus monodon* juveniles. Proc. 1st Asian Fish Forum, 615-618 (Asian Fish. Soc., Manila).
53. Poston, H.A. (1990): Performance of rainbow trout fry fed supplemental soy lecithin and choline. *Prog. Fish. Cult.*, 52., 218-225.
54. Poston, H.A. (1990): Effect of body size on growth, survival and chemical composition of Atlantic salmon fed soy lecithin and choline. *Prog. Fish. Cult.*, 52., 226-230.
55. Rumsey, G.W.; Smith, R. (1990): Lecithin with diatomaceous earth works well in fish feed. *Feedstuffs*, 62. 11-13 (30 June).
56. Schäfer, W.; Wywiol, V. (1986): Lecithin - der unvergleichliche Wirkstoff. Verlag Alfred Strothe, Frankfurt.
57. Shieh, H.S. (1969): The biosynthesis of phospholipids in the lobster, *Homarus americanus*. *Comp. Biochem. Physiol.*, 30., 679.
58. Stansby, M.E. (1990): Fish oils in Nutrition. Van Nostrand Reinhold, New York.
59. Storebakken, T.; Berge, G.; Hung, S.S.O. (1992): Growth effects of dietary phospholipids and choline on Atlantic salmon fingerlings. Trial-Report of 28 Jan.
60. Takeuchi, T.; Arakawa, T.; Sato, S.; Watanabe, T. (1992): Supplemental effect of phospholipids and requirement of eicosapentaenoic acid and docosahexaenoic acid of juvenile striped jack. *Nippon Suisan Gakkaishi*, 58., (4), 707-713.
61. Tarr, H.L.A. (1972): Enzymes and systems of intermediary metabolism. In: Halver, J.E.: Fish Nutrition. Academic Press, New York, 255-326.
62. Teshima, S.; Kanazawa, A. (1986): Nutritive value of sterols for the juvenile prawn. *Bull. Jap. Soc. Sci. Fish.*, 52., (3), 519-524.
63. Teshima, S.; Kanazawa, A.; Sasada, H.; Kawasaki, M. (1982): Requirements of the larval prawn *Penaeus japonicus* for cholesterol and soybean phospholipids. *Mem. Fac. Fish. Kagoshima Univ.*, 31., 193-199.
64. Trider, D.J.; Castell, J.D. (1980): Some current findings of the Halifax lobster nutrition group. Proc. 1980 Lobster Nutrition Workshop. University of Maine/Orono, 15-16 January.
65. Wurtmann, R.J.; Hirsch, W.J.; Growdon, J.H. (1977): quoted from Chan, M.M. (1984).
66. Zeisel, S.H. (1990): Phospholipids and choline deficiency. In: Hanin, I.; Pepeu, G. (1990): Phospholipids. Plenum Press, New York and London, 219-231.
67. Ziegelitz, R. (1990): Personal Communication.

42. SOYA PROTEIN PRODUCTS

42.1 Rationale

Soya protein products are valuable, protein-rich by-products from soybean oil extraction. Soya proteins have a wide range of application in the food industry where they are used for their good nutritional value, but the primary interests are their functional properties⁽¹⁰⁾. Among others they are used as substitutes for animal protein and are particularly good animal protein replacements in aquaculture feeds.

42.2 Manufacture and Processing

All soya proteins are made from de-hulled soya beans and for animal nutrition are subdivided into (Figure 42-01):

- Soybean meal (see chapter 46);
- Soya protein concentrate,
- Soya protein isolate;
- Soya protein hydrolysate.

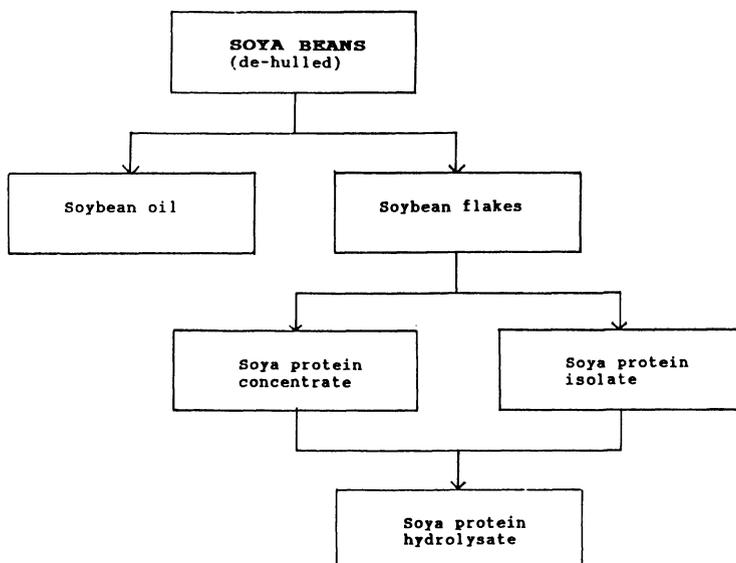


Figure 42-01. Diagram of soya protein products.

Soya Protein Concentrate

The roller milled flakes still contain N-free extracts (carbohydrates, phytic acid, oligosaccharides) which are removed by an additional extraction with 80% aqueous alcohol or isoelectric leaching⁽⁶⁾. However, the alcohol treatment denatures the protein. The product, therefore, has a low protein solubility. In the process of extrusion soya protein concentrate acquires a good texture and remarkably swells⁽⁹⁾.

Soya Protein Isolate

In the production of soya protein isolate, de-fatted and ground soybean meal are dispersed in water. The water soluble carbohydrates are dissolved while the undissolved constituents are separated by centrifuges or filters (e.g. insoluble polysaccharides, cell-wall material). The extract is then acidified to pH 4.5 and the proteins are precipitated. The precipitate is pasty and it is neutralised with caustic soda. Spray-drying the material yields a fine soya protein isolate which is readily soluble in water⁽¹⁰⁾. Soya protein isolate may also be fractionated into its various globulins by a variety of techniques⁽⁸⁾.

Soya Protein Hydrolysate

Soya protein hydrolysate is produced from either soya protein concentrate or soya protein isolate by enzymatic hydrolysis. The insoluble protein is converted into soluble protein (Figure 42-02)⁽³⁾. The Oriental soya sauce is an example of hydrolysed soya protein⁽²¹⁾.

The sludge in the separation process step 2, contains polysaccharides and unconverted protein. It can be hydrolysed for a second time or dried and used as animal feed⁽³⁾. So far there is no information on the nutritive value of dried sludge as an aquaculture feed ingredient.

42.3 Chemical and Physiological Properties*Chemical Properties*

Soya protein products are high in protein, fat content is negligible and crude fibre is at a reasonable level (Table 42-01). Higher crude fibre contents indicate that the respective product is processed from unde-hulled soya beans⁽¹³⁾.

Table 42-01: Chemical composition of soya protein products (%)⁽¹⁸⁾

	Soybean meal (de-oiled)	Soya protein concentrate	Soya protein isolate
Moisture	5.0 - 8.0	5.0 - 8.0	5.0 - 8.0
Crude protein	52.0 - 54.0	67.0 - 72.0	90.0 - 92.0
Crude fat	0.5 - 1.0	0.5 - 1.0	0.1 - 1.0
Crude fibre	3.5 - 4.5	3.5 - 5.0	4.0 - 5.0
N-free extract	34.0 - 35.0	19.0 - 21.0	0.3 - 0.6

Soya protein products have a good amino acid profile, except for lysine and methionine (Table 42-02). The various production processes hardly affect the amino acid composition of the products.

For determining the quality and the nutritional value of soya protein products the following parameters are of interest:

- Protein dispersibility index (PDI). Indicates the heat damage during treatment and the water solubility of the protein;
- Protein efficiency ratio (PER). Indicates the effectiveness of the protein. Tested in rats (weight gain per g of protein consumed) and should be in the range of 2.0 to 2.4;
- Trypsin inhibitor activity;
- Urease activity.

Table 42-02: Essential amino acid content of soya protein products (g/16 g N)⁽⁵⁾

	Soybean meal (de-oiled)	Soya protein concentrate	Soya protein isolate
Leucine	7.0	7.9	7.8
Isoleucine	4.4	4.6	4.5
Lysine	6.3	6.3	6.0
Methionine	1.3	1.3	1.0
Phenylalanine	5.1	5.1	5.2
Threonine	4.0	4.3	3.5
Tryptophan	1.4	1.5	1.2
Valine	4.8	4.8	4.6

Physiological Properties

The true digestibility of soya protein products is high in rats. Hydrolysed soya protein processed from soya protein concentrate is superior to the same made from soya protein isolate. Hydrolysis improved the digestibility by 6.0% and 10.0%, respectively. The “net protein utilisation” differed significantly (Table 42-03)⁽³⁾. The apparent dry matter and protein digestibility of soya protein for the white leg shrimp (*Penaeus vannamei*) is 84.1% and 96.4%⁽⁴⁾.

Table 42-03: Biological evaluation of soya protein products in rats⁽³⁾

	True digestibility	Biological value	Net protein utilisation ¹
Casein (control)	89	80	72
Soya protein concentrate	87	69	60
Soya protein isolate	81	53	43
Hydrolysed soya protein ²⁾	91	49	44
Hydrolysed soya protein ³⁾	93	55	52

¹ (TD x BV) : 100; ² Made from soya protein isolate; ³ Made from soya protein concentrate

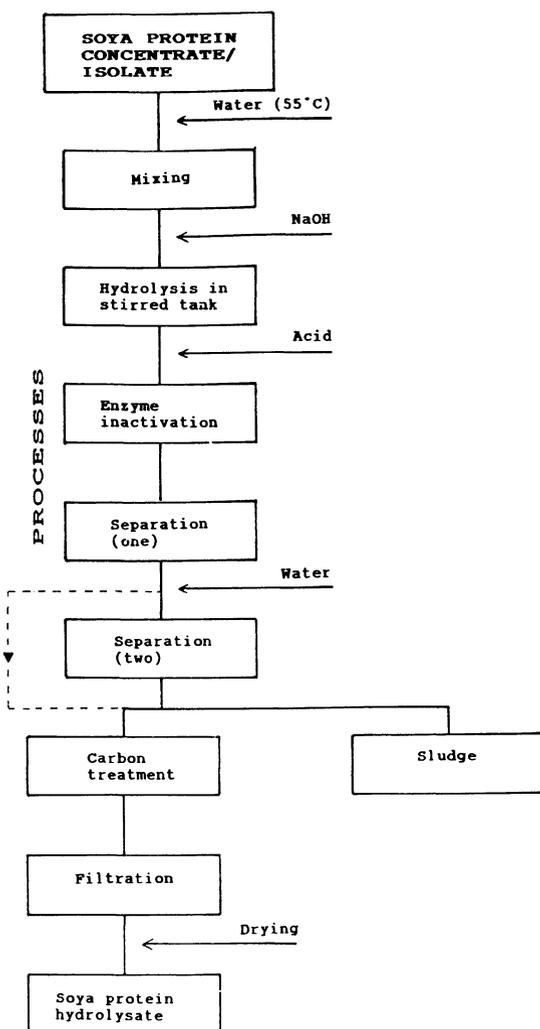


Figure 42-02. Diagram of the production of soya protein hydrolysate^(data from: 3).

The amino acid digestibility of soya protein concentrate and the retention rate is better for the larger fish than for smaller ones as found in yellowtail (*Seriola quinqueradiata*)⁽²⁰⁾.

42.4 Feeding Value

Soya protein products are protein feedstuffs and useful for young terrestrial animals. Soya protein isolate can replace skim milk powder in diets for early weaned piglets⁽¹⁹⁾ and veal calves⁽¹¹⁾. However, supplementation with lactose has to be considered⁽⁷⁾.

Soya Protein Concentrate

High quality fish meal replaced by soya protein concentrate at levels as high as 56% of the total protein in diets for older salmonids (Atlantic salmon [*Salmo salar*], rainbow trout [*Oncorhynchus mykiss*]) had no negative effect on performances of the fish. There was no difference in the efficacy of soya protein concentrate between rearing in seawater and freshwaters^(13, 14, 17). Rainbow trout fingerlings, however, showed depressed growth when fed soya protein concentrate⁽¹²⁾.

In the young yellowtail (*Seriola quinqueradiata*) (100 to 200 g liveweight) brown fish meal can be partially replaced by 20% soya protein concentrate but has to be supplemented with amino acids (Table 42-04)⁽²⁰⁾.

Table 42-04: Response of yellowtail (*Seriola quinqueradiata*) on replacement of brown fish meal by soya protein concentrate⁽²⁰⁾

Brown fish meal	%	65	55	45	35
Soya protein concentr.	%	-	10	20	30
Amino acids ¹	%	-	0.398	0.796	1.194
Crude protein	%	53.9	54.7	53.9	53.0
Energy/protein ²	%	76.8	76.4	76.9	76.5

Initial liveweight	g	128.6	128.6	128.6	128.6
Final liveweight	g	358.6	352.2	354.3	326.1
Daily gain	%	2.25	2.19	2.23	2.06
Feed conversion ³	%	81.2	80.5	79.1	74.9
PER ⁴	1.51	1.48	1.46	1.42	
Survival rate	%	100.0	98.6	100.0	98.6

¹ Essential amino acid blend: 5.0% l-Threonine; 6.0% l-Valine; 55.0% dl-Methionine; 25.0% l-Lysine, 9.0% l-Histidine. ² Metabolisable energy (kcal/kg diet) : crude protein (%).

³ (Liveweight gain x 100) : daily feed intake. ⁴ Protein efficiency ratio: Liveweight gain: protein intake

Soya Protein Isolate

In separate experiments 30% and 35% soya protein isolate replaced all other animal protein in basal diets for the Atlantic salmon and rainbow trout without negative effects^(15, 16).

42.5 Recommended Inclusion Rate

Soya protein products have a high protein content and a good digestibility but the inclusion rate should not exceed 20%. Additional fortification with amino acids (methionine, lysine) has to be considered.

42.6 Legal Aspects

The use of soya protein products in animal feeds is not restricted. They are described and listed by the following national and international bodies:

- “Codex Alimentaire” of the joint FAO/WHO Food Standards Programme⁽⁶⁾;
- European Union, Directive 92/87/EEC of 26 October, 1992⁽²²⁾;
- Feed Ingredient Definitions by AAFCO⁽¹⁾;
- German feedstuff legislation (Table 42-05)⁽²²⁾.

Table 42-05: Minimum quality requirements (% in dry matter) for soya protein products as stipulated by international and national bodies

Soya protein ...	Codex ⁽⁶⁾	EU ⁽²²⁾	U.S.A. ⁽¹⁾	Germany ⁽²²⁾	
	Protein	Protein	Protein	Protein	Lysine
Concentrate	65	N/R ¹	65	63	3.7
Isolate	90	-	90	90	5.0
Hydrolysate	-	-	N/R	-	-

¹ No requirement

42.7 References

1. AAFCO (1995): Official publication 1995. Ass. of American Feed Control Officials (publisher), Sacramento, CA/USA.
2. Adler-Nissen, J. (1976): Enzymatic hydrolysis of proteins for increased solubility. *J. Agric. Food Chemistry*, 24. (6), 1090-1093.
3. Adler-Nissen, J. (1977): Enzymatic hydrolysis of food proteins. *Process Biochemistry*, 12. (6), 18-21.
4. Akiyama, D.M. (1988): Soybean meal utilization by marine shrimp. Proc. AOCS World Congress on Veg. Protein Utilization in Human Food and Animal Feedstuffs, Singapore, 2-7 October.
5. Anonymous (1989): Edelsona. Published by Edelsona GmbH, Hamburg/Germany.
6. Berry, K.E. (1989): Preparation of soy protein concentrate products and their application in food systems. In: Applewhite, T.H. (ed): Proceedings of the World Congress on Vegetable Protein Utilization in Human Foods and Animal Feedstuffs, Singapore, October 1988, 62-65.
7. Coffey, R.D.; Maxwell, C.V.; Clutter, A.C. (1991): The effect of isolated soy protein substitution for milk proteins with and without maintaining constant lactose on performance of early weaned pigs. *Anim. Science Res. Rep.*, MP-134, 307-316. Dept. Anim. Science, Oklahoma State University
8. Gibson, P.W.; Yackel, W.C. (1989): Soy protein fractionation and applications. In: Applewhite, T.H. (ed): Proceedings of the World Congress on Vegetable Protein Utilization in Human Foods and Animal Feedstuffs, Singapore, October 1988, 507-509.
9. Hayakawa, I. (1992): Texturising soya explained in detail. *Extrusion Communiqué*, 5., (1), 5-11.
10. Johnson, D.W.; Kikuchi, S. (1989): Processing for producing soy protein isolates. In: Applewhite, T.H.

- (ed): Proceedings of the World Congress on Vegetable Protein Utilization in Human Foods and Animal Feedstuffs, Singapore, October 1988, 66-77.
11. *Lalles, J.P.; Toullec, R.; Branco Pardal, P.; Sissons, J.W.* (1995): Hydrolyzed soy protein isolate sustains high nutritional performance in veal calves. *J. Dairy Sci.*, *78.*, 194-204.
 12. *Murai, T.; Ogata, H.; Villaneda, A.; Watanabe, T* (1989): Utilization of soy flour by fingerling rainbow trout having different body size. *Nippon Suisan Gakkaishi*, *55.*, 1067-1073.
 13. *Olli, J.J.; Krogdahl, Å.* (1994): Nutritive value of four soybean products as protein sources in diets for rainbow trout (*Oncorhynchus mykiss*, Wahlbaum) reared in fresh water. *Acta Agric. Scand., Sect. A, Animal Sci.*, *44.*, 185-192.
 14. *Olli, J.J.; Krogdahl, Å.; Ingh, T.S.G.A.M. van den; Brattås, L.E.* (1994): Nutritive value of four soybean products in diets for Atlantic salmon (*Salmo salar*, L.). *Acta Agric. Scand., Sect. A, Animal Sci.*, *44.*, 50-60.
 15. *Poston, H.A.* (1990a): Performance of rainbow trout fry fed supplemental soy lecithin and choline. *The Progressive Fish Culturist*, *52.*, 218-225.
 16. *Poston, H.A.* (1990b): Effect of body size on growth, survival and chemical composition of Atlantic salmon fed soy lecithin and choline. *The Progressive Fish Culturist*, *52.*, 226-230.
 17. *Schulz, D.; Goerlich, R.; Hartfiel, W.; Greuel, E.* (1985): Vergleichende Untersuchungen an Regenbogenforellen (*Salmo gairdneri*, R.) über den Futterwert eines herkömmlichen Sojafeynmeles und eines Sojaproduktes ohne Antigenwirkung. *Z. Tierphysiol., Tierernährung, Futtermittelkd.*, *53.*, 199-207.
 18. *Sipos, E.F.* (1990): Edible uses of soybean protein. *ASA Technical Bulletin*, Vol. HN12.
 19. *Sohn, K.S.; Maxwell, C.V.* (1991): Alternative protein sources for milk protein in early weaned pig diets. *Anim. Science Res. Rep.*, MP-134, 359-366. Dept. Anim. Science, Oklahoma State University.
 20. *Takii, K.; Shimeno, S.; Nakamura, M.; Itoh, Y.; Obatake, A.; Kumai, H.; Takeda, M.* (1989): Evaluation of soy protein concentrate as a partial substitute for fish meal protein in practical diet for yellowtail. *Proc. Third Int. Symposium on Feeding and Nutrition in Fish*, 28 August - 1 September, Toba/Japan, 281-288.
 21. *Uchid, K.* (1989): Trends in preparation and uses of fermented and acid-hydrolysed soy sauce. In: *Applewhite, T.H.* (ed): Proceedings of the World Congress on Vegetable Protein Utilization in Human Foods and Animal Feedstuffs, Singapore, October 1988, 78-83.
 22. *Weinreich, O.; Koch, V.; Knippel, J.* (1994): Futtermittelrechtliche Vorschriften. Buchedition Agrimedia, Hamburg/Germany.

43. SQUID MEAL

43.1 Rationale

There are some one thousand species of the class *Cephalopoda*, mainly two families are commercially caught: *Omnastrephidae* and *Loliquinidae*. World-wide about 1.5 million MT are landed per year with Japan on the top with more than 600,000 MT per annum⁽³⁰⁾. Koreans consume more than any other country 8.3 kg squid per capita⁽²⁸⁾.

Squid, also named “cuttlefish” can be found in all oceans. The smallest species of this rapacious aquatic animal is just 10 cm long (*Loligo loligo*) while the largest can be as large as 70 cm⁽³⁰⁾ (Figure 43-01).

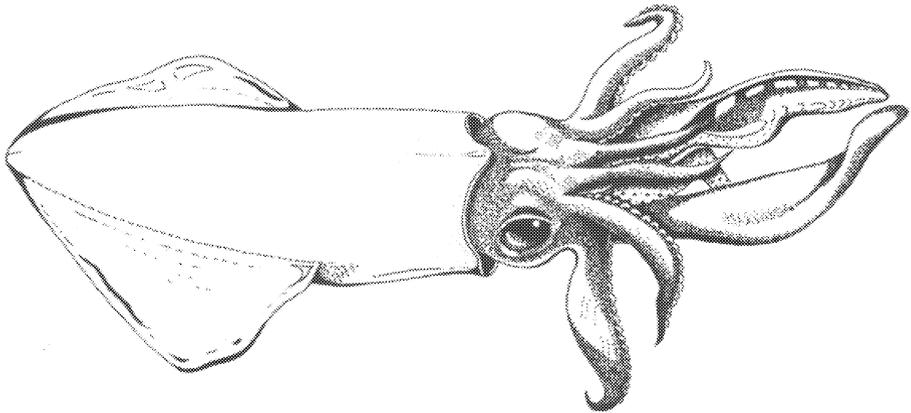


Figure 43-01. The common squid (*Loligo vulgaris*).

The mantle, head and tentacles are used mainly for human consumption. The squid waste which usually includes viscera may also contain head and tentacles, fin, skin and pen amounting to about 52% of the whole weight⁽¹⁴⁾. These wastes are made into a meal. A valuable oil may be extracted from the viscera. By-products of squid processing are important feed ingredients in aquaculture diets, particularly in shrimp diets.

43.2 Manufacture and Processing

Drying is the most common method of processing squid and squid waste. Squid may be dried whole or sliced lengthwise, viscera and head and tentacles removed. The mantle is

either blanched in boiling water or directly dried under the sun or in an oven on screen trays. The dried product is ground into a meal.

Blanching of squid waste for two minutes in a 2.0% salt solution (2.0% sodium chloride and 0.5% alum solution) reduces yield but the product can be dried in a shorter time, colour of the product is improved and grinding is easier⁽¹⁴⁾.

Squid liver meal is of lower quality than squid meal. It usually contains 70% squid meal (viscera included) and 30% potato pulp or other absorbents as carrier⁽²⁶⁾. Apart from the cottage-style, manufacture by the industrial method of processing squid waste into squid meal or squid liver meal follows the described principles but is more sophisticated. Fresh viscera may also be ensiled⁽⁹⁾ (see Chapter 20).

43.3 Chemical, Physiological and Other Properties

Chemical

Squid meal has high protein value ranging from 70% to almost 90% (Table 43-01). The crude protein content of squid liver meal is lower because it is not pure squid.

The amino acid profile is well balanced (Table 43-02). Its essential amino acid index^{''} (EAAI) is high (0.96) and similar to white fish meal (0.96) and shrimp meal (0.98) and is much higher than soybean meal (0.87)⁽²⁵⁾.

The fat content of squid meal is moderate (Table 43-01). The portion of highly unsaturated fatty acids (HUFA) of the total fat is high (Table 43-03). Of the total fat content of the squid *Loligo pealei* and *Illex illecebrosus* 57% are polyunsaturated fatty acids (PUFA), of which 99% are HUFA. Timnodonic acid (eicosapentaenoic) (20:5n-3) and docosahexaenoic (22:6n-3) accounted for almost 50% of the total fat⁽¹⁸⁾.

Ash content is around 6.0% for squid meal and ranges between 5.0 and 10% for squid liver meal (Table 43-01). The calcium content of squid meal is low (0.11%) and the phosphorus content is 0.41%⁽¹⁶⁾. A higher phosphorus content, 1.1%, was obtained in squid viscera from *Dosidicus gigas*⁽⁶⁾.

The amount of cholesterol in squid meal is affected by the squid species and varies widely within species⁽¹⁸⁾:

- Squid (*Loligo pealei*): 171 to 449 mg/100 g raw squid
- Squid (*Illex illecebrosus*): 108 to 336 mg/100 g raw squid

Table 43-01: Chemical composition of squid products (% in dry matter)

	Squid meal <i>(13, 14, 16, 25)</i>	Squid liver meal <i>(2, 15, 26)</i>	Squid viscera (fresh) ⁽⁶⁾	Squid viscera (silage) ⁽⁶⁾
Dry matter	95.3	88.88	17.8	19.9
Crude protein	80.5	50.8	75.3	60.8
Crude fat	4.0	17.2	7.4	7.3
Ash	6.4	7.6	6.8	9.5

Table 43-02: Essential amino acid profile of squid meal and squid liver meal (g/16 g N)^(3, 15, 25)

	Squid meal	Squid liver meal
Arginine	6.08	2.79
Histidine	2.16	-
Isoleucine	4.19	-
Leucine	7.28	-
Lysine	6.30	2.88
Methionine	2.83	1.09
Phenylalanine	3.43	-
Thereonine	3.60	1.95
Tryptophan	0.90	0.55
Valine	4.16	-

Table 43-03: Fatty acids and cholesterol content of squid by-products (% of total fat)^(2, 6, 26)

	Squid viscera, Fresh	Squid liver meal
Crude fat	-	0.3
Free fatty acids	1.9	-
Cholesterol	-	0.35 - 0.40

Octadecadienoic 18:2n-6	3.0	-
Eicosapentaenoic 20:5n-3	15.0	-
Docosahexaenoic 22:6n-3	25.2	-

Physiological Properties

Fresh squid has in the dry matter a gross energy content of about 4,600 kcal/kg (19.2 MJ/kg). The protein of squid contributes 84% to the gross energy (Table 43-02)⁽³⁰⁾.

Squid meal from *Dosidicus gigas* is highly digestible in sheep (organic matter = 83%; crude protein = 94.0% and fat = 96% digestible)⁽¹⁶⁾. The apparent protein and dry matter digestibility of squid meal for tiger prawn is 96.0% and 85.5%, respectively⁽¹⁰⁾.

The apparent amino acid digestibility of squid meal in the experimental diet for white leg prawn is (% of dry matter)⁽¹⁾:

- | | | | |
|-------------|------|-----------------|------|
| • Arginine | 79.4 | • Lysine | 78.6 |
| • Histidine | 73.6 | • Phenylalanine | 74.1 |

• Isoleucine	77.2	• Threonine	79.7
• Leucine	79.4	• Valine	79.3

Other properties

Squid meal and other squid products have chemo-attractant properties (glycine and betaine) which are important activators of the feeding behaviour⁽²⁰⁾. Raw squid contains 619 to 928 mg glycine/betaine per 100 g raw muscle, and in octopus 1,434 mg glycine/betaine per 100 g fresh material⁽¹⁷⁾.

Squid meal appears to have also growth promoting properties⁽²⁴⁾. Biological studies have shown that squid contains some unidentified growth factors which are called “squid factor”⁽¹³⁾. Growth was enhanced in Kuruma prawn (*Penaeus japonicus*) by 30 to 50% when the diet was supplemented with squid meal.

The lipid of squid reduces the serum cholesterol in animals⁽²⁹⁾.

43.4 Feeding Value

Squid meal has been classified as an excellent ingredient for aquaculture feed, and fresh squid is also recommended in moist diets⁽²⁴⁾. Its feeding value is based on growth promotion and chemo-attractant properties⁽¹²⁾.

Fishes

Studies with squid meal or other squid products in fish are scanty. Fresh squid at a level of 46% in moist diets for Atlantic salmon (*Salmo salar*) and rainbow trout (*Salmo gairdneri*) gave greater increases in weight and length, a higher condition factor, no change in carcass percentage and higher dry matter and fat contents in both fish species than with the control diet⁽⁴⁾.

Crustaceans

Highest protein efficiency ratio, weight gain and feed conversion were obtained with squid meal as compared to fresh mussel meat, casein and shrimp meal when fed to 15 mg tiger prawn (*Penaeus monodon*) post-larvae (Table 43-04)⁽¹⁹⁾.

Table 43-04: Squid meal and other protein feedstuff in diets for post-larvae tiger prawn (*Penaeus monodon*)⁽¹⁹⁾

Diet	Portion of the diet %	Weight gain mg	Feed conversion 1:	PER
Squid meal	63.0	16.0	1.9	1.05
Shrimp meal	64.4	13.8	0.9	0.91
Mussel meat ¹	13.7	2.4	0.66	
Casein	55.0	12.5	0.8	0.80

¹Control diet - fresh brown mussel (*Modulus metcalfei*) fed at 20% (dry weight basis) of body weight

Tiger prawns reared in brackishwater ponds and fed diets containing either squid meal, fish meal, or soybean meal as the main ingredient produced after 110 days, more body mass 39% and 117%, respectively, when grown on squid meal diet than on fish meal or soybean meal diets⁽²⁷⁾.

Rice bran was replaced by varying amounts of squid mantel meal in diets for intensive culture of the brown shrimp (*Penaeus aztecus*) and northern white shrimp (*Penaeus setiferus*). Not surprisingly, better results were obtained with diets containing squid meal than with rice bran as the major component of the diet (Figure 43-02)^(11, 12). This was also found when a mixture of squid and soybean meal (60:40) was fed to shrimps⁽⁹⁾.

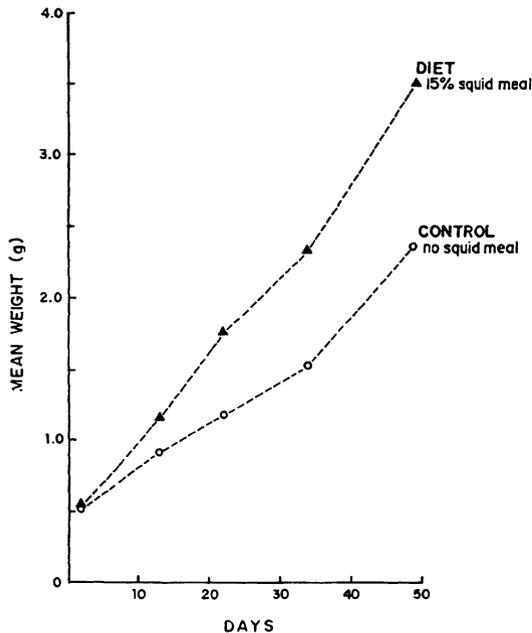


Figure 43-02. Response on liveweight of brown shrimp (*Penaeus aztecus*) juveniles when fed diets containing squid meal^(Data from: 11).

Frozen squid (squid protein fraction) was effective in improving growth rates even at low level of 1.5% in diets for blue shrimp (*Penaeus stylirostris*), white leg shrimp (*Penaeus vannamei*) and tiger prawn though not for Indian white prawn (*Penaeus indicus*)⁽⁷⁾.

Under semi-intensive pond production, squid meal in extruded feed substantially improved performances of juvenile tiger prawn. When fed a diet where fish protein concentrate was replaced by squid mantle. Shrimps were kept in laboratory tanks and in pond pens. Performances under pond conditions were better than in the laboratory test (Table 43-05)⁽⁸⁾.

Table 43-05: Squid meal replaces fish protein concentrate in diets for juvenile tiger prawn (*Penaeus monodon*)(feeding period: 40 days)⁽⁸⁾

Squid mantel meal	%	-	10.0
Fish protein concentrate	%	10.0	-
Crude protein	%	47.6	48.7
Fat	%	7.6	8.5

Final weight	g	7.0	9.2
Weight gain	g	4.9	7.0
Growth rate	%	224.0	323.0
Feed conversion	1:	2.2	1.7
Survival	%	96.6	95.0

Squid viscera meal increases growth rate and survival of various penaeids such as tiger prawn, chinese prawn (*Penaeus orientalis*), kuruma prawn and white leg shrimp. The feed is more palatable and feed conversion is better⁽³¹⁾.

Fresh squid as well as squid meal is used in maturation diets at levels of 30% for tiger prawn broodstock^(21, 22, 23). Fresh squid is also used in moist diets⁽²⁴⁾. In rearing larvae of shrimp 30% squid meal is fed up to day 32⁽⁵⁾.

43.5 Recommended Inclusion Rates

Squid meal and other dry squid products are not only protein feedstuffs but also serve as chemo-attractants for aquaculture feeds. The recommended inclusion rates are:

- Grower and finisher feed
- Broodstock feed
- Larval feed
- 5.0 to 10.0%
- 20.0 to 30.0%
- 20.0 to 30.0%

43.6 Legal Aspects

The use of squid meal, squid viscera and squid liver meal is not prohibited.

A general standard for squid meal has been set by the “National Fishery Inspection” of the Republic of Korea for export and domestic use with these requirements⁽²⁸⁾:

- Moisture: max. 11.0%
- Crude protein: min. 45.0%
- Crude fat: 3.0%

43.7 References

1. *Akiyama, D.M.* (1986): The development of a purified diet and nutritional requirement of lysine in penaeid shrimp. Dr. Thesis, Graduate College, Texas A&M Univ./U.S.A.
2. *Anonymous* (1992): Innovations. Infofish International, (6), 53.
3. *Anonymous* (1994): Chemical and biological value of Danish LT and special A fish meal, Danish soluble meal, Alaskan fish meal in shrimp feed. Ass. Fish Meal and Fish Oil Manufacturers Denmark.
4. *Åsgaard, T.* (1987): Squid as feed for salmonids. *Aquaculture.*, 61., 259-273.
5. *Bautista, M.N.; Millamena, O.M.; Kanazawa, A.* (1989): Use of kappa-carrageenan microbound diet (C-MBD) as feed for *Penaeus monodon* larvae. *Mar. Biol.*, 103., (2), 169-174.
6. *Carver, L.A.; Akiyama, D.M.; Dominy, W.G.* (1989): Processing of wet shrimp heads and squid viscera with soy meal by dry extrusion process. In: *Applewhite, T.H.* (ed.). Ame. Soybean Asso. Technical Bull. 3 AQ:1689-4., 167-170.
7. *Cruz-Ricque, L.E.; Guillame, J.; Cuzon, G.; Aquacop* (1987): Squid protein effect on growth of good penaeid shrimp. *J. World Aquac. Soc.* 18., (4), 209.
8. *Cruz-Suárez, L.E., Ricque, D.; AQUACOP* (1992): Effect of squid meal on growth of *Penaeus monodon* juveniles reared in pond pens and tanks. *Aquaculture*, 106., 293-299.
9. *Dominy, W.G.; Lim, C.* (1991): Evaluation of soybean meal extruded with wet squid viscera as a source of protein in shrimp feeds. Proc. Aquaculture Feed Processing and Nutrition Workshop, Thailand and Indonesia, 20 to 25 September Ame. Soybean Asso., Singapore.
10. *Feed Dev. Section* (1994): Feeds and feeding of milkfish, Nile tilapia, Asian sea bass and tiger shrimp. Aquaculture Extension Manual No. 21, SEAFDEC Aquaculture Department, Tigbauan, Iloilo, Philippines.
11. *Fennuci, J.L.; Zein-Eldin, Z.P.* (1976): Evaluation of squid mantle meal as a protein source in penaeid nutrition. FAO Technical Conference on Aquaculture., Kyoto, Japan, 601.
12. *Fennuci, J.L.; Zein-Eldin, Z.P.; Lawrence, A.L.* (1980): The nutritional response of two penaeid species to various levels of squid meal in prepared feed. *Proc. World Maricult. Soc.*, 11., 403-409.
13. *Guillame, J.; Cruz-Ricque, E.; Cuzon, E.; Wormhoudt, A.V.; Revol, A.* (1990): Growth factors in penaeid shrimp feeding. In: *Advances in Tropical Aquaculture*, Tahiti, 20 February to 4 March 1989. Aquacop Ifremer Actes de Colloque. 327-338.
14. *Joseph, J.; Prabhu, .V.; Madhavan, P.* (1984): Utilization of squid waste as meal. *Fish Technol. Soc.*, Cochin, 24., 41-43.
15. *Kaufmann, T.* (1991): Amino acid content of important feed ingredients in Asia and how to predict it using regression equations. Proc. at First Feed and Food Expo, Victam Asia '91 Feed Conference, Bangkok/Thailand.
16. *Kling, M.; Wöhlbier, W.* (1977): Handels-Futtermittel. Verlag Eugen Ulmer, Stuttgart/Germany.
17. *Konosu; Yamaguchi* (1982): Quoted from: *Meyers, S.P.* (1986).
18. *Kryznowek, J.F.; Entremont, L.D.; Murphy, J.* (1989): Proximate composition and fatty acid and cholesterol content of squid, *Loligo pealei* and *Illex illecebrosus*. *J. Food Science.* 54., 45.
19. *Lim, C.; Suraniranat, P.; Platon, R.* (1979): Evaluation of various protein sources for *Penaeus monodon* post-larvae, Kalikasan Philipp. *J. Biol.* 8., 29-36.
20. *Meyers, S.P.* (1986): Attractants, aquatic diet development examined. *Feedstuffs*, 58., 11-12.
21. *Millamena, O.M.; Pudadera, R.; Catacutan, M.R.* (1985): Variation as tissue lipid content and fatty acid composition during ovarian maturation of unablated and ablated *Penaeus monodon* broodstock. Proc. of the First Intern. Conf. Culture of Penaeid Prawn and Shrimps. Aquaculture Dept., SEAFDEC, Iloilo, Philippines, 166.
22. *Millamena, O.M.; Pudadera, R.A.; Catacutan, M.R.* (1985): Effects of diet on reproductive performance of wild ablated *Penaeus monodon* broodstock. Proc. of the First Intern. Conf. Culture of Penaeid Prawn

- and Shrimps. Aquaculture Dept., SEAFDEC, Iloilo, Philippines, 178.
23. Millamena, O.M.; Primavera, J.H.; Pudadera, R.A.; Caballero, R.V. (1986): The effect of diet on reproductive performance of pond-reared *Penaeus monodon* Fabricius broodstock. The First Asian Fisheries Forum. Manila, Philippines, Asian Fisheries Society, 593-596.
 24. New, M.B. (1987): Feed and feeding of fish and shrimp - A manual on the preparation and presentation of compound feeds for shrimps and fish in aquaculture. UNDP/FAO/ADCP/RLP/87/26. Rome/Italy.
 25. Peñaflores, V.D. (1989): An evaluation of indigenous protein sources as potential component in the diet formulation for tiger prawn, *Penaeus monodon*, using amino acid index (EAAI). Aquaculture, 83., 319-330.
 26. Piedad-Pascual, F.; Hertrampf, J.W. (1992): Squid meal: High nutritive value and an excellent attractant. Advances in Feed Technology, (8), 34-45.
 27. Rajyalakshmi, T.; Pillar, S.M.; Roy, A.K.; Verghese, P.U. (1982): Studies on rearing of *Penaeus monodon* Fabricius in brackishwater ponds using pelleted feeds. J. Inland. Fish. Soc. India, 14., 28-35.
 28. Roh, J.D. (1992): The squid meal industry in Korea. Infofish International, (3), 26-30.
 29. Stansby, M.E. (1990): Nutritional properties of fish oil for human consumption-early development. In: Stansby, M.E. (ed.): Fish oil in nutrition. Van Nostrand Reinhold, New York/USA.
 30. Täufel, A.; Termes, W.; Tunger, L.; Zobel, M. (1993): Lebensmittel-Lexikon. Behr's Verlag. Hamburg/Germany.
 31. Wang, W.C. (1988): Growth rate and fatty acid composition of lipids of grass prawn fed with diets containing squid viscera oil. Feed Quality Control, 2., 13-28.

44. UNIDENTIFIED GROWTH FACTORS

44.1 Rationale

The use of the term “Unidentified Growth Factors” (UGF) dates back to around 1920, but most research work started from 1950 onwards⁽¹⁶⁾. They were identified in fish extract, fish meal, fermentation products and their residues and lucerne (alfalfa) meal. Particularly good sources of UGF are de-hydrated fish solubles (see chapter 21) and distillers’ feeds (see chapter 13)^(4, 5, 6, 12, 14). Squid might also be a source of UGF since there is no explanation for good performances of shrimps when added to the diet⁽⁸⁾.

Much emphasis has been placed on the identification of UGF. Among others it has been suggested that the holocellulose fraction of alfalfa meal extracts contain the growth stimulants⁽¹⁰⁾, whereby the holocellulose is the residue after hot-water extraction, followed by sodium hypo-chlorite bleaching of the plant material⁽³⁾. Phenolic acids, such as caffeic acid have also been reported to be the “growth factor” in fibrous feeds⁽¹⁰⁾. It is also presumed, that the B-vitamins are related to growth factors.

Even today UGF cannot be isolated nor defined. Nevertheless, UGF can be unequivocally characterised by their beneficial effects on certain growth attributes. UGF might be a potential alternative to antibacterial performance promoters^(17, 18).

44.2 Processing

What is notable about UGF is that the product is produced predominantly from by- and re-cycling products of the agro-industry. In the light of the present knowledge, UGF are classified as:

- Lucerne-whey Factor;
- Fermentation Factor;
- Liver residue/Fish soluble factor.

Milk and milk by-products may also contain the whey factor⁽⁶⁾.

Components of UGF are:

- Corn distillers dried grains (containing high levels of the fermentation factor, fish soluble factor and lucerne-whey Factor);
- Dried extracted streptomyces meal (containing the lucerne-whey factor);
- Fermentation solubles (containing the lucerne-whey factor).

These three components are mixed and standardised.

44.3 Chemical and Physiological Properties

A synergistic property is suggested by blending the three individual components⁽¹⁾. The crude protein content of UGF products may reach levels of about 40% (Table 44-01). The calcium-phosphorus ratio is almost 1:1 and the inositol and choline contents are remarkably high (Table 44-02).

Table 44-01: Mean chemical composition and essential amino acids of UGF⁽¹⁾

Macro nutrients (as fed)			Essential amino acid (g/16 g N)	
Dry matter	%	95.0	Arginine	1.37
Crude protein	%	25.0	Histidine	0.63
Crude fat	%	2.8	Isoleucine	1.21
Crude fibre	%	5.0	Leucine	1.90
Metabolisable			Lysine	0.84
energy	kcal/kg	2,750	Methionine	0.42
Net energy	kcal/kg	1,890	Phenylalanine	0.79
			Threonine	0.95
			Tryptophan	0.22
			Valine	1.42

Table 44-02: Mineral and vitamin contents of UGF⁽¹⁾

Macro and trace minerals			Minerals Vitamins (per 1,000 g)		
Calcium	%	0.75	Vitamin E	mg	20.0
Phosphorus	%	0.80	Vitamin B ₁	mg	4.0
Sodium chloride	%	1.00	Vitamin B ₂	mg	23.0
Iron	mg/kg	240	Vitamin B ₆	mg	12.0
Copper	mg/kg	30	Vitamin B ₁₂	mcg	3.0
Manganese	mg/kg	25	Biotin	mg	0.4
Zinc	mg/kg	60	Folic acid	mg	0.5
Cobalt	mcg/kg	50	Pantothenic acid	mg	8.0
Selenium	mcg/kg	200	Nicotinic acid	mg	60.0
Iodine	mcg/kg	10	Choline	g	2.0
			Inositol	g	3.0

UGF may contain residues of antibiotics, if the fermentation mycel is used as a component of a UGF blend. Extraction of pure antibiotics from the fermentation material does not provide residues absolutely free of any antibacterial activity.

44.4 Feeding Value

UGF in the feed stimulates the performances of terrestrial animals (guinea pigs^(11, 19); piglets^(2, 9); broilers^(7, 15, 16); laying hens⁽¹³⁾).

Experiments on the use of UGF in aquaculture feeds are absent. Nevertheless, its use in feeds for shrimps and fishes, particularly in tropical countries, is very common. Field trials have shown positive results although the findings have not been properly documented.

The presence of UGF in squid known as “squid factor” is suspected and should be verified. The mode of action should also be elucidated for better utilisation of UGF in aquaculture feed⁽⁸⁾.

44.5 Recommended Inclusion Rates and Legal Aspects

Recommended Inclusion rates

UGF is suitable for all species of cultured aquatic animals. It is particularly fit for young and rapidly growing animals. Recommended inclusion rates in compound feeds are 0.15% to 0.30%.

Two principles should be observed when UGF is applied to aquaculture feed:

- The younger the animal, the higher the inclusion rate;
- The higher the performances expected from the animals, the more UGF has to be used.

Legal Aspects

As long as the blend of UGF raw materials used are not residues of the fermentation of antibiotics, no legal aspects have to be followed. However, if UGF-blends contain fermentation residues from antibiotic fermentation, national legal regulations for the application of antibiotics as a feed additive have to be observed.

44.6 References

1. *Anonymous* (w/o year): Amofac (UGF), a perfect blend of Unidentified Growth Factors. Helmerpharma, Enschede, (Leaflet).
2. *Bronsch, K.* (1984): Bericht über einen Ferkelaufzuchtversuch mit Octaferm Plus, Trial Report of 15.8.
3. *Cheeke, P.R.* (1987): Rabbit feeding and nutrition. Academic Press, Inc., Orlando.
4. *DFCR* (w/o year): Distillers grains. Distillers Feed Research Council, Des Moines, Iowa/USA.
5. *Fairbanks, B.W.; Krider, J.L.; Carroll, W.E.* (1944): Distillers by-products in swine rations. I. Creep feeding and growing fattening rations. *J. Animal Sci.*, 3., 29-40.
6. *Feltwell, R.; Fox, S.* (1978): Practical poultry feeding. Faber & Faber Ltd., London.
7. *Gropp, J.; Tiews, J.; Schulz, V.* (1971): Untersuchungen über den Einfluß eines UGF-haltigen Produktes auf Wachstum und Futterverwertung von Mastküken. *Z. Tierphysiologie, Tierernährung und Futtermittelkunde*, 28., 102-112.
8. *Guillaume, J.; Cruz-Ricque, E.; Cuzon, G.; Warmhoudt, A. van; Revol, A.* (1989): Growth factors in Penaeid shrimp feeding. *Aquacop Ifremer Actes de Colloque*, 9., 327-338.

9. *Hoppe, P.P.* (1985): Vergleich zwischen Octaferm Plus und Carbadox bei Ferkeln. Trial Report 14/1985 of 18.12.
10. *Huang, H.M.; Johanning, G.L.; O'Dell, B.L.* (1986): Phenolic acid content of food plants and possible nutritional implications. *J. Agric. Food Chem.*, *34*, 48-51.
11. *Knehans, A.W.; Kincaid, R.L.; Regan, W.D.; O'Dell, B.O.* (1979): An unrecognized dietary factor for guinea pigs associated with the fibrious fractions of plant products. *J. Nutrition*, *109*, 418-425.
12. *Lovell, R.T.* (1980): Nutritional value of solid by-products from ethanol production of corn. Auburn Techn Assistance Center, Auburn, AL/USA.
13. *Monson, W.J.* (1976): Borden reports egg output aided with unidentified factors in feed. *Feedstuffs*, 5.1. (reprint).
14. *New, M.B.* (1987): Feed and feeding of fish and shrimp. A manual on the preparation and presentation of compound feeds for shrimp and fish in aquaculture. UNDP/FAO/ADCA/REP/87/26, Rome/Italy.
15. *Scholtyssek, S.* (1983): Einsatz von Wachstumsförderern für die Broilermast. Trial Report of 12.1.
16. *T.D.* (1988): Helmafac, the perfect blend of unidentified growth factors (UGF). Mimeograph.
17. *Thalmann, A.* (1986): Personal communication, 11.9.
18. *Tiews, J.* (1972): Gutachten über das Auftreten einer antibiotischen Aktivität in Octaferm. Expert opinion of 7.2.
19. *Typpo, J.T.; Anderson, H.L.; Krause, G.F.; Yu, D.T.* (1985): The lysine requirement of young growing male guinea pigs. *J. Nutrition*, *115*, 579-587.

45. VEGETABLE OILS

45.1 Rationale

Vegetable oil is a reservoir and nutrient in seeds and fruit-flesh and can be subdivided according to their origin into:

- Flesh oils,
- Seed oils.

Palm oil, olive oil and avocado oil are the most important representatives of fruit-flesh oils while seed oils are further subdivided into⁽¹⁰²⁾:

- Seed fats (solid and semi-solid),
 - Fats rich in lauric and myristic acids (coconut oil, palm kernel oil, babassu oil)
 - Fats rich in palmitic and stearic acid (cocoa butter);
- Seed oils (fluid),
 - Oils rich in palmitic acid (cotton-seed oil, maize-germ oil),
 - Oils poor in palmitic acid but rich in oleic and linoleic acid (sesame oil, sunflower oil, linseed oil),
 - Legume oils (ground-nut oil, soybean oil),
 - Crucifer oils (rape-seed oil, mustard oil).
 - Other seed oils (e.g. castor oil).

Vegetable oils are used in the food, pharmaceutical, cosmetic, detergent, paint, surfactant, rubber processing and many other industries. The oil-chemistry industry distills (split) vegetable oil into their fatty acids.

Many factors may affect the composition and constants of fats and oils hence, individual samples may vary considerably such as: soil, climate, variety, fertilizer, season, when produced⁽⁵⁾.

In terrestrial and aquatic animal feeds vegetable oils are used as an energy source and as a source of essential fatty acids. Vegetable oils are used in combination with marine oils to reduce the cost of the lipid source of energy in fish diets.

45.2 Manufacture and Processing

There are three methods of separating the oil from the seed/flesh⁽³⁴⁾:

- Pressing
- Screw pressing
- Solvent extraction

Flesh Oils

The fruit-bunches (Figure 45-01) of the oil palm (*Elaeis quineensis*) are steamed, and the solid matter (mesocarp, fibre, nuts and shells) is removed by screw pressing.

Screening and clarifying separates the mixture of crude oil and water from the solids for further processing (Figure 45-02). The oil content is removed by solvent extraction. A common solvent is hexane (C_6H_{14}), a liquid hydrocarbon of the paraffin series. Thereafter, the crude palm oil is purified (filtered) and refined⁽⁹⁸⁾. The absorbent capacity of bleaching earth (sodium calcium aluminosilicate - $Al_2S_{14}O_{10}(OH)_2$) is used for the removal of impurities and unwanted matter such as colouring agents (carotenoids), soap, protein and others⁽⁴⁴⁾ (see Chapter 5).



Figure 45-01. Bunches of oil palm (*Elaeis quineensis*) fruits⁽⁴³⁾.

Seed Oils

Solvent extraction is the prevailing method for separating the oil from the seeds. The oil seeds are scoured and ground. The ground material may be pressed prior to solvent extraction or is immediately solvent extracted (Figure 45-02). With hexane or other hydrocarbons.

After complete extraction, the solvent is removed from the crude oil followed by de-gumming, de-acidifying, bleaching and deodorising in a vacuum steam of $190^{\circ}C$ to $260^{\circ}C$ ⁽¹⁰²⁾. Certain variations in the solvent extraction process exist.

General Characteristics of Vegetable Oils

Vegetable oils are made up of carbon, hydrogen and oxygen⁽³⁰⁾. They are esters of glycerol and fatty acids which may be saturated or unsaturated. The latter have a lower melting point are also more unstable than the saturated fatty acids, and may rapidly become rancid. Oxidative rancidity is caused by oxygen uptake of unsaturated fatty

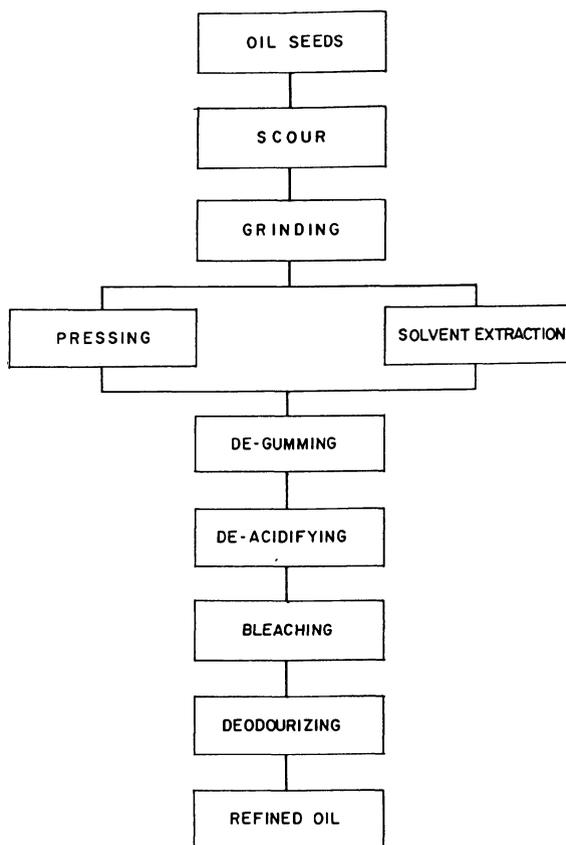


Figure 45-02. Diagram of vegetable oil extraction.

acids. Use of rancid fats can destroy some nutrients such as vitamins. Light and some metals like copper, lead, iron, zinc can also hasten rancidity (see Chapter 2.4).

The gross energy values of vegetable oils are similar and range between 9,249 to 9,297 kcal/kg (38.7 to 38.9 MJ/kg).

Antinutritional Substances

Free fatty acids (FFA) are usually found in oils and vary in different oils⁽⁵⁴⁾. They are not an important criteria for determining whether a vegetable oil is fit for feeding aquatic animals or not. The presence of erucic acid in high amounts in rapeseed oil makes it unsuitable for feed but a low concentration in a new hybrid (canola oil) allows its use. Sterculia acid is also present in cotton-seed oil⁽¹¹⁾.

Table 45-01: Fatty acid profiles of vegetable oils^{4, 5, 8, 28, 42, 58, 62, 64, 65, 68, 86, 102, 110)}

Fatty acid's Systematic name (Common name)	Oil Source													
	Coco- nut	Cotton seed	Ground- nuts	Lin- seed	Maize	Olives	Palm berries	Palm kernel	Rape- seed	Rice bran	Saf- flower	Sesame beans	Soya beans	Sun- flower
Chapter	45.3	45.4	45.5	45.6	45.7	45.8	45.9	45.9	45.10	45.11	45.12	45.13	45.14	45.15
Hexanoic (Caprioc)	0.2	-	-	-	-	-	-	-	-	-	-	-	-	-
Octanoic (Caprilic)	7.9	-	-	-	-	-	1.0	2.7	-	-	-	-	-	-
Decanoic (Capric)	7.3	-	-	-	-	-	0.1	20.0	-	-	-	-	-	-
Dodecanoic (Lauric)	48.4	-	-	-	-	-	-	26.0	-	-	0.6	-	-	-
Tetradecanoic (Myristic)	16.6	1.0	-	0.2	-	1.6	1.0	20.0	-	-	1.6	-	0.1	-
Tetradecenoic (Myristoleic)	-	-	-	-	-	-	-	-	-	-	-	-	0.1	-
Hexadecanoic (Palmitic)	8.3	22.1	7.4	5.4	9.8	14.3	42.4	19.0	2.3	16.4	9.5	0.3	8.8	4.7
Hexadecenoic (Palmitoleic)	1.0	1.3	-	-	-	3.0	0.3	8.0	-	0.2	2.4	-	0.2	-
Octadecanoic (Stearic)	2.9	1.1	3.8	3.4	2.8	2.5	3.8	3.1	1.0	-	2.6	4.5	3.8	3.8
Octadecenoic (Oleic acid)	4.5	24.5	56.0	16.4	34.7	70.3	36.2	35.7	34.3	1.9	17.8	44.3	26.6	26.8
Octadecadienoic (Linoleic)	2.7	48.8	30.2	15.5	51.2	9.0	8.5	6.6	17.0	43.8	67.2	33.2	52.6	57.2
Octadecatrenoic (Linolenic)	-	0.9	-	52.4	0.3	0.8	-	0.2	6.9	1.5	0.5	0.5	6.0	0.3
Octadecatetraenoic (Stearidonic)	-	-	-	-	0.1	-	-	-	-	-	-	-	-	-
Eicosanoic (Arachidic)	-	0.6	3.5	0.6	0.4	0.4	0.2	2.0	-	0.4	-	0.7	0.6	-
Eicosenoic (Gadoleic)	-	-	-	-	-	-	-	-	-	-	3.8	-	-	-
Eicosatetraenoic (Arachidonic)	-	-	-	-	-	1.6	-	-	-	-	2.0	-	-	0.6
Eicosapentaenoic (— — — —) ¹	-	-	-	-	-	1.6	-	-	-	-	1.4	-	-	-
Docosanoic (Behenic)	-	-	1.8	0.1	-	0.2	-	-	0.5	-	-	0.1	-	0.4
Docosenoic (Erucic)	-	-	-	-	-	-	-	-	37.8	-	-	-	-	-
Docosahexaenoic (— — — —) ¹	-	-	-	-	-	1.6	-	-	-	-	1.3	-	-	-
Tetracosanoic (Lignoceric)	-	-	2.5	-	0.2	-	-	-	2.8	-	-	19.1	-	-

¹No common name

45.3 Coconut Oil

45.3.1 Description

Coconut comes from the coconut palm family *Arecaceae*, species *Cocos nucifera*. The palm is most common in the tropics. It bears fruit around six years after planting and the nuts are harvested throughout the year. The meat of mature coconut is dried, and the resulting product, copra, is the source of oil. Coconut oil is used in foods, soapmaking and cosmetics.

World copra production is about 5.5 million MT a year. Almost 75% of the production comes from the Philippines (43%), Indonesia (24%) and India (7.0%)⁽¹⁰²⁾

45.3.2 Chemical and Physiological Properties

Chemical Properties

The oil content of copra is 63 to 68%. Crude methods of drying copra gives a high free fatty acid content in coconut oil as compared to other vegetable oils. Copra should contain not more than 6.0% moisture so that it can be stored without getting mouldy⁽⁸⁾.

Coconut oil contains predominantly saturated fatty acids (91.6%) (Table 45-01). It is a source of medium chain triglycerides, hence, its low melting point (Table 45-02). It is considered an "oil" at tropical room temperature (24 to 27°C) but a "fat" at 19°C to 22°C because its solidification point is at room temperate range and its melting point range is at tropical room temperature⁽⁸⁾.

Table 45-02: Quality characteristics of vegetable oils^(13, 67)

Oil Source	Melting point °C	Solidification point °C	Iodine value
Coconut	26.0	20-24	7.5 - 10.5
Cotton-seed	11.0	30-37	99 - 113
Cotton-seed, hydrogenated	60.0	-	-
Ground-nut	60.0	26-32	-
Linseed	-	19-21	-
Maize	-	14-20	103 - 128
Olive	-	17-26	-
Palm	40.0	40-47	44 - 58
Palm kernel	29.0	20-28	-
Rape-seed	-	11-15	-
Sesame	-	20-25	-
Soybean	-	21-23	120 - 141

Coconut oil is high in lauric acid. It is extremely resistant to oxidative rancidity because it contains mostly saturated fatty acids but is susceptible to hydrolytic rancidity which occurs in the presence of free moisture, catalysed by lipase and is the cause of the flavour attributed to rancid coconut oil. When coconut oil is derived from copra of good quality, it is of relatively light colour, nearly free of phospholipids, gums and other non-glyceride substances⁽⁸⁾.

Physiological Properties

The digestible energy of coconut oil for dogs is 8,960 kcal/kg (37.5 MJ/kg) (Table 45-03)⁽⁵⁸⁾. Digestibility of coconut oil is around 90% as observed for land animals (Table 45-04).

Table 45-03: Energy values of vegetable oils per kg

Species	Gross energy		Metabolisable energy		Digestible energy		Reference
	kcal	MJ	kcal	MJ	kcal	MJ	
<u>Coconut oil</u>	9,250	38.7	-	-	-	-	(58)
Dogs ¹	-	-	-	-	8,960	37.5	(58)
<u>Cotton-seed oil</u>	9,297	38.9	-	-	-	-	(58)
Dogs	-	-	-	-	9,105	38.1	(58)
<u>Ground-nut oil</u>	9,297	38.9	-	-	-	-	(58)
Chicken	-	-	9,010	37.7	8,747	36.6	(28)
<u>Linseed oil</u>	9,297	38.9	-	-	-	-	(58)
Dogs	-	-	-	-	9,010	37.7	(58)
<u>Maize oil</u>	9,295	38.9	-	-	-	-	(58)
Chicken	-	-	8,770	36.7	8,745	36.6	(28)
<u>Olive oil</u>	9,297	38.9	-	-	-	-	(58)
Dogs	-	-	-	-	9,105	38.1	(58)
<u>Rape-seed oil</u>	9,297	38.9	-	-	-	-	(58)
Dogs	-	-	-	-	9,010	37.7	(58)
<u>Safflower oil</u>	-	-	-	-	-	-	
Chicken	-	-	9,010	37.7	8,745	36.6	(28)
<u>Soybean oil</u>	9,249	38.7	-	-	-	-	(58)
Rainbow trout ¹	-	-	-	-	8,007	33.5	(69)
Carp ¹	-	-	-	-	8,007	33.5	(69)
Chicken	-	-	9,010	37.7	8,745	36.6	(28)
<u>Sunflower oil</u>	9,297	38.9	-	-	-	-	(58)
Chicken	-	-	9,010	37.7	8,745	36.6	(28)

¹ Test diet:mixture of soybean oil and cod liver oil (1:1)

Table 45-04: Digestibility (%) of vegetable oils

Oil	Species	Digestibility		Reference
		Fat	Energy	
Coconut	Pigs	86.1	-	(27)
Cotton seed	Dogs	98.0	-	(58)
Ground nut	Dogs	97.0	-	(58)
Linseed	Salmon	-	88.6	(83)
	Common carp	93.4	-	(10)
Maize	Salmon	-	85.9	(10)
	Common carp	95.9	-	(10)
	Channel catfish	97.3	-	(41)
Olives	Rainbow trout	94.2	-	(46)
		95.0	-	(46)
	Rats	94.0	-	(20)
Soyabeans	Rainbow trout	96.2 ¹	-	(99)
	Pigs	86.1	-	(27)
Sunflower	Rainbow trout	-	63.2	(75)
	European eel	99.0	-	(82)

¹ and liver oil (3:1)

45.3.3 Feeding Value

Fishes

The feeding value of coconut oil in diets for fish is low. It can only be used as an energy source rather than for its fatty acid content. The Arctic cohar (*Salvelinus alpinus*) showed the poorest performance when the coconut oil diet was not fortified with polyunsaturated fatty acids⁽⁷⁰⁾. The need for polyunsaturated fatty acids when coconut oil is fed was also demonstrated in milkfish (*Chanos chanos*). The fish performed best on a diet containing equal amounts (5.0% and 5.0%) of coconut oil and cod liver oil⁽²⁾. Coconut oil in diets for the Arctic cohar increased hepatic lipids, sterolesters and moisture content of the muscles while the muscle lipids decreased⁽⁷⁸⁾. After feeding coconut oil the sunshine bass (*Morone chrysops* - female x *Morone saxatilis*- male) exhibited erosion of the caudal fin and skin irritations⁽⁶⁴⁾. When the diet contained 7.0% coconut oil, juvenile red drum (*Sciaenops ocellatus*) grew insufficiently and had little cold tolerance⁽²²⁾. Compared to menhaden oil juvenile sunshine bass showed the lowest weight gain, feed efficiency and PER when fed coconut oil diets⁽⁶⁴⁾.

Crustaceans

Performances of tiger prawn (*Penaeus monodon*) juveniles is inferior when fed coconut oil at increasing inclusion rates (Table 45-05)⁽¹⁷⁾.

Table 45-05: The response of tiger prawns (*Penaeus monodon*) to various levels of coconut oil in the diet for juveniles ⁽¹⁷⁾

Coconut oil	%	0	4.0	8.0	12.0
Weight gain	%	27.5	7.3	5.9	10.1
SGR	%/day	0.86	0.26	0.21	0.34
Survival	%	66.7	72.2	72.2	50.0
Body lipid content	%	0.88	0.82	1.01	-

45.4 Cotton-seed Oil

45.4.1 Description

Cotton-seed is a by-product of cotton production. It belongs to the *Malvaceae* family. The most common species are *Gossypium hirsutum* and *Gossypium barbadense*⁽⁸⁸⁾.

The World produces annually around 17.0 to 18.0 million MT cotton. Major producing countries are P.R. China (23.5% of total production), CIC (formerly USSR) (16.9%), USA (14.2%) and India (9.2%)⁽¹⁰²⁾.

45.4.2 Chemical, Physiological and Other Properties

The oil content of cotton-seed varies from 18.0 to 25.0% and is high in oleic acid (18:1n-9) and linoleic acid (18:2n-6) (Table 45-01). Crude cotton-seed oil is of light brown to dark brown colour while refined cotton-seed oil is of light yellow to reddish colour. The glucoside gossypol and pigments are removed. At a temperature of 10°C solid components called cotton steaming are discarded⁽¹⁰²⁾.

Cotton-seed oil has a digestible energy of 9,105 kcal/kg (38.1 MJ/kg) (dogs) (Table 45-03)⁽⁵⁸⁾. The digestibility is 98% (Table 45-04).

Cotton-seed oil and oil of other species of the family *Malvaceae* contain minor quantities of cyclopropenoic fatty acids. These fatty acids cause extreme liver damage, increased glycogen deposition and elevated saturated fatty acid levels in lipid of rainbow trouts (*Salmo gairdneri*). Furthermore, these rare fatty acids also act synergistically with Aflatoxin B₁ which is a carcinogen^(77, 92).

Gossypol is another toxic substance of cotton-seed oil. It accumulates in the liver of rainbow trout⁽⁷⁶⁾.

45.4.3 Feeding Value

Liquid and hydrogenated cotton-seed oil were compared in diets for sea trout (*Salmo trutta*) and brook trout (*Salvelinus fontinalis*) and no significant differences in performance were found between the liquid and the solid oil^(72, 73).

The addition of 5.0% cotton-seed oil and free fatty acids of cotton-seed, respectively, to the diet of common carp (*Cyprinus carpio*), kept in crowded cages and ponds, improved the growth of the fish by 25 to 50%. The basic diet contained 25% crude protein and 3.0% crude fat⁽¹⁰⁷⁾.

No significant changes in growth rate were observed when feed pellets coated with 4.0 to 8.0% acidulated cotton-seed oil were fed to 100 to 300 g tilapia hybrids (*Sarotherodon aureus* x *Sarotherodon niloticus*). However, fat content of the viscera increased with cotton-seed oil supplementation but fat content of the carcass did not⁽¹⁰⁸⁾.

45.5 Ground-nut Oil

45.5.1 Description

Ground-nut (*Arachis hypogea*) belongs to the same family, *Fabaceae*, as faba beans (*Vicia faba*). The former has been of commercial interest since around 1850 when France began importing them from West Africa for their oil content⁽⁶⁷⁾. Only four countries produce about 70% of the World's total production of 21.5 million MT ground-nuts in shells (India = 29.08%; P.R. China = 27.9%; U.S.A. = 7.8%; and Nigeria = 3.6%).

45.5.2 Chemical and Physiological Properties

Crude ground-nut oil is light yellow with characteristic odour and flavour of peanuts⁽⁸⁾. It will solidify if kept at refrigeration temperature for sometime. Whole nuts generally yield 30% oil while shelled nuts produce 45 to 50% oil⁽⁸⁾.

Total saturated fatty acid is 17.3% while 77.8% comprises total unsaturated fatty acids⁽⁸⁶⁾. Ground-nut oil contains linoleic (18:2n-6) but does not have linolenic acid (18:3n-3) (Table 45-01).

In chicken, metabolisable energy is 9,010 kcal/kg (37.7 MJ/kg) while digestible energy is 8,747 kcal/kg (36.6 MJ/kg)⁽²⁸⁾ (Table 45-03). The fat is 97% digested by dogs (Table 45-04).

45.5.3 Feeding Value

Chinook salmon (*Oncorhynchus tshawytscha*) fingerlings responded better to feed supplemented with ground-nut oil than fat from cattle spleen. No liver and hematopoietic organ damages were observed in the group fed ground-nut oil⁽³²⁾.

Cod (*Gadus morhua*) were fed for eight weeks, diet of which 48% of available energy came from ground-nut oil, cod liver oil and halibut oil. Hepatosomatic index increased from 9.5 to 13% and liver fat from 55.0 to 67.7%. The fatty acid composition of dietary fat affected the composition of liver triglycerides, the main fat depot in cod and also the composition of polar lipid fatty acids in liver and muscle⁽⁵²⁾.

45.6 Linseed Oil

45.6.1 Description

Flax (*Linum usitatissimum*) whose scientific name means “most useful”, is one of the oldest crops used by man. The herbaceous plant belongs to the genus *Linum*, one of the ten genera of the family *Linaceae*. The species *Linum usitatissimum* has two types of cultivars, one grown for seed and the other for fibre⁽¹⁶⁾.

Annual production is rather constant and amounts to about 2.9 million MT of linseed and 0.6 million MT of flax fibre. Major producers of linseeds are Canada (36.8% of world production), Argentina (19.5%), India (17.8%) and CIC (7.9%)⁽¹⁰²⁾.

Linseed oil is a drying oil used in paints. It is also used to waterproof paper and toughen fabrics and paper⁽⁸⁹⁾.

45.6.2 Chemical, Physiological and Other Properties

Linseed contains between 30 and 45% oil, mainly linoleic and linolenic acid (Table 45-01). In aquaculture diets it is used as a source of essential fatty acids, and as an energy source⁽⁶²⁾.

The metabolisable energy amounts to 9,010 kcal/kg (37.7 MJ/kg) in dogs (Table 45-03)⁽⁵⁹⁾. The digestibility of linseed oil for carp (*Cyprinus carpio*) 93.4% is similar to fish oil (Table 45-04)⁽⁸³⁾.

Linseed oil may contain a cyanogenic glycoside found in the germ of the linseed⁽¹⁰²⁾.

45.6.3 Feeding Value

Fishes

Linseed oil in diets of salmonids, in comparison to other fats and oils, showed no differences in growth and other performances of the fish^(3, 36, 62, 73).

Dietary linolenic acid (18:3n-3) found abundantly in linseed oil was not deposited in the body lipids of chinook salmon as such but was apparently converted to docosa-hexaenoic acid (Behenic acid [22:6n-3])⁽⁶³⁾.

No significant differences were found when carp were fed with linseed oil or fish oil. However, increasing the Vitamin E level from 80 mg/kg to 500 mg/kg improved final weight by 26.4% and 29.9%, respectively (Table 45-06)⁽⁸³⁾.

Table 45-06: Effect on growth of carp (*Cyprinus carpio*) fed linseed and fish oils for 133 days⁽⁸⁴⁾

Linseed oil	%	12	-	12.0	-
Fish oil	%	-	12.0	-	12.0
Vitamin E	mg/kg	80	80	500	500

Initial weight	g	220	220	220	220
Final weight	g	685	692	866	899

Channel catfish (*Ictalurus punctatus*) diets with linseed oil and rich in n-3 fatty acids may have an immuno-suppressant effect at temperatures of 25° and 28°C⁽³³⁾.

Linseed oil as a source of essential fatty acid showed in experiments with juvenile red drum (*Sciaenops ocellatus*) and grey mullet (*Mugil cephalus*) that performances of fish increased as the level of n-3 fatty acids increased. Levels of tissue n-6 and n-3 fatty acids were positively correlated with their respective dietary levels.^(7, 53)

Crustaceans

Chinese prawn (*Penaeus chinensis*) fed a diet containing linseed and maize oils had increased egg production compared to those fed the lard diet. However, hatchability was not significantly improved. The n-3-HUFA content of eggs was higher for linseed oil diets (19.5%), than for maize oil and lard⁽¹¹⁴⁾.

45.7 Maize Oil

45.7.1 Description

Maize oil is derived from the germ of the kernel of *Zea mays*, a cereal of the family *Poaceae*. It is a by-product of the maize starch and grain alcohol production. It is used as one of the vegetable oils for human consumption (see Chapter 28).

45.7.2 Chemical, Physiological and Other Properties

Chemical Properties

Maize oil is dark reddish amber and usually darker than other vegetable oils even after refining. It is high in oleic acid and linoleic acid (Table 45-01).

Maize oil contains relatively large amounts of phospholipids and other non-oil substances (2.0% and more). Its free fatty acid content is usually higher (about 1.5%) than other vegetable oils of good quality⁽¹²⁾.

Maize oil may contain per kg:

- Vitamin E: 840 mg
- Carotene: 1.4 mg
- Calcium: 150 mg
- Iron: 13 mg
- Manganese: 10 mg

Traces of Vitamin B₆, nicotinic acid, choline, potassium, sodium and copper are also present in maize oil⁽⁵⁸⁾.

Physiological Properties

The digestible energy for chickens is similar to those of ground-nut oil (Table 45-03)⁽²⁸⁾. Fat digestibility is more than 95% but the energy digestibility is below 90% (Table 45-04).

The digestibility of individual fatty acids of maize oil for the rainbow trout (*Salmo gairdneri*) is between 62.8 to 100%⁽¹⁰⁾, for Atlantic salmon (*Salmo salar*) 52.3 to 97.3%⁽⁹¹⁾ and tiger prawn (*Penaeus monodon*) 87.3 to 97.2%⁽⁵⁷⁾.

Other Properties

Maize oil is used as a vehicle for oral drug administration, of sarafloxacin given to Atlantic salmon held in seawater⁽⁵⁶⁾.

45.7.3 Feeding Value

Fishes

Maize oil is short in linolenic acid (18:3n-3). Retarded performances were observed when rainbow trout (*Salmo gairdneri*) were fed with maize oil as the only lipid source. The addition of fish oil or linolenic acid improved the yield of the fish (Table 45-07)⁽⁵¹⁾. But maize oil at levels of 21 or 29% did not negatively affect growth, feed efficiency and body lipid content of the brown trout (*Salmo trutta*). The higher maize oil level gave significantly higher growth rate (+4.8%), better feed conversion (+12.0%) and higher muscle fat content (+12%)⁽⁹⁾.

Table 45-07: Maize oil as dietary fat source for juvenile rainbow trout (*Salmo gairdneri*) (trial period: 12 weeks)⁽⁵¹⁾

Maize oil	%	10.0	9.0	5.0	-
Salmon oil	%	-	1.0	5.0	-
Linolenic acid	%	-	-	-	1.0

Weight gain	g	4.2	7.9	13.9	8.4
	%	100.0	188.1	331.0	200.0
Feed conversion	1:	1.22	1.02	0.77	0.92
Total losses	%	25.0	6.0	5.0	2.0

Higher temperatures are more beneficial for fecundity than lower temperatures when fish are fed diets containing maize oil. This relationship was found when maize oil was fed to female broodstock of rainbow trout. The gonadosomatic index (weight of ovary/weight of fish), weight of spawn, size and lipid content of the eggs were higher in broodstock reared at 18°C than at 8°C⁽²¹⁾. Maize oil is also a better source of essential fatty acids than cuttlefish liver oil for red sea bream (*Chrysophrys major*) broodstock diets. Substituting cuttlefish liver oil with maize oil in broodstock diets on the verge of spawning markedly reduced the proportion of bouyant eggs⁽¹⁰⁹⁾. Maize oil at a level of 5.0% enhanced the fecundity of Nile tilapia (*Oreochromis niloticus*)^(79, 80).

Channel catfish respond inferiorly to the addition of maize oil, either as single added fat (Table 45-08) or in combination with tallow and fish oil (Figure 45-03)^(25, 26, 71).

On the other hand, Nile tilapia (*Tilapia nilotica*) had best growth and feed conversion when fed a diet containing maize oil compared to pollack liver oil, beef tallow and medium-chain triglycerides⁽¹⁰⁰⁾.

A relationship between maize oil level and Vitamin E fortification of the diet has been reported for the blue tilapia (*Oreochromis aureus*). For every percent maize oil in the diet, 3.0 to 4.0 mg Vitamin E/kg feed is needed⁽⁷⁸⁾.

Table 45-08:Vegetable oils and menhaden oil in diets for the juvenile sunshine bass(*Morone chrysops* x *Morone saxatilis*) (trial period: 8 weeks)⁽⁶⁴⁾

Maize oil	%	5.0	-	-
Menhaden oil	%	-	5.0	-
Safflower oil	%	-	-	5.0

Weight gain	%	285	457	332
Feed efficiency ¹		0.38	0.49	0.38
PER ²		0.95	1.23	0.95
Mortality	%	83.0	0	83.0
Lipids in the carcass:				
- Muscle	%	1.5	3.1	2.6
- Liver	%	24.5	5.8	23.6

¹g weight gain/g dry feed; ²Protein efficiency ratio

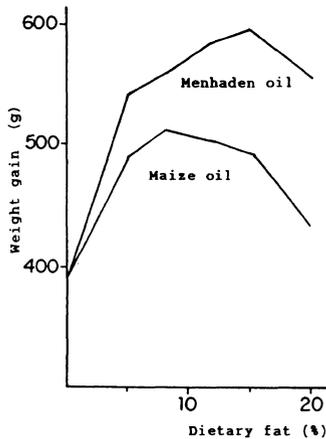


Figure 45-03. Development of channel catfish (*Ictalurus punctatus*) fed on maize oil and menhaden oil^(Data from: 26).

The water temperature does not only affect the fecundity of fish but also the development of growing fish. Ayu (*Plecoglossus altivelis*) fingerlings grew best at a water temperature of 16.5°C when the diet was supplemented with 8.6% maize oil and 10% chlorella compared to the diet without maize oil⁽⁸⁷⁾. And at higher temperature (23° to 24°C) maize oil was more effective in diets for the rock fish (*Sebastes thompsoni*)⁽⁴⁷⁾.

The Japanese eel (*Anguilla japonica*) developed best when the diet was fortified with 12.0% of a blend of maize and cod liver oil (2:1). However, using 20.0% of the oil blend is apparently an energy over-supply⁽⁶⁾.

Essential fatty acid deficiency syndrome and mass mortality (85 to 99%) were recorded when larvae of striped bass (*Morone saxatilis*) and palmetto bass (*Morone saxatilis* x *Morone chrysops*) were fed diets with maize oil but larvae fed the HUFA-diet showed a survival rate of 80%⁽¹⁰⁶⁾.

In general, maize oil as a component of diets for various fish species at various different stages of development is not only a useful energy source but is also an important source of essential fatty acids, foremost of which is linoleic acid (18:2n-6).

Crustaceans

Tiger prawn fed maize oil-containing diets for 28 days had survival rates similar to those fed cod liver oil. Weight gain and SGR were significantly lower for maize oil-fed prawns than for cod liver oil-fed animals⁽¹⁷⁾. But a combination of 1/3 maize oil with 2/3 cod liver oil did not give negative effects when used at increasing levels in diets for juvenile tiger prawn as well as in diets for the juvenile freshwater prawn (*Macrobrachium rosenbergii*)^(84, 85).

Molluscs

A combination of maize oil and menhaden oil (1:1) in a purified diet (25% crude protein) were fed to two abalone species (*Haliotis tuberculata* and *Haliotis discus* Hanai). Growth was better in the control diet (red algae [*Palmaria palmata*])⁽⁵⁵⁾.

45.8 Olive Oil

45.8.1 Description

The olive tree (*Olea europaea*) of the family *Oleaceae* was cultivated in the Mediterranean area even before 6,000 years ago. The olive fruit has a coating which contains the oil hence, olive oil is a flesh oil.

About 800 million olive trees in the World produce 1.8 million MT olive oil. Major producing countries are Spain (32.2% of World production), Italy (28.2%), Greece (18.5%) and Turkey (9.7%)⁽³¹⁾. Greece has the highest olive oil consumption per capita (21.1 liters). Since olive oil is a valuable oil, adulteration with inexpensive oils are not uncommon^(31, 102).

The European olive tree is different from those cultivated in China and Vietnam of the genus *Canarium* (family: *Burseraceae*) which also have fruits rich in oil⁽¹⁰²⁾.

45.8.2 Chemical and Physiological Properties

Chemical Properties

Unlike other vegetable oils, olive oil can be used without refining and is never deodorised although in some instances, poor quality oil may be refined and mixed with a better oil. It has a greenish yellow colour and a characteristic mild pleasant odour. It remains liquid at low temperatures, turns turbid only at 20°C due to its very high oleic acid content⁽⁸⁾.

Olive oil is distinct among vegetable oils for its monounsaturation (73.3%) (Table 45-01). It also contains a high level of squalene, an unsaturated hydrocarbon (C₃₀H₅₀), a precursor of cholesterol.

Traces of potassium and iron have been found in olive oil as well as 1.0 mg sodium per kg. It also contains some carotene (1.2 mg/kg) and Vitamin E (140 mg/kg)⁽⁵⁸⁾.

Physiological Properties

The digestible energy for dogs is given as 9,105 kcal/kg (38.1 MJ/kg) (Table 45-03)⁽⁵⁸⁾. The digestibility of olive oil in rainbow trout (*Salmo gairdneri*) is 94.2% (Table 45-04)⁽⁴⁶⁾.

45.8.3 Feeding Value

Olive oil is a suitable lipid source for fish feed⁽⁹⁴⁾. It can be used as a single component in the food for rainbow trout⁽³⁹⁾. There were no pathological-anatomical changes in the internal and external organs even after a test period of ten weeks. Although olive oil and maize germ oil had lower utilisation values than linseed and sunflower oil, the differences were insignificant. However, olive oil gave the poorest utilisation among the other vegetable oils studied when compared to 10% sunflower oil in the reference diet for rainbow trout⁽⁴⁰⁾.

When European eels (*Anguilla anguilla*) were fed in open and recirculated systems a diet with olive oil and other vegetable oils, differences in growth, feed efficiency and utilisation of these plant oils were found between males and females (phenotypical sex determination)⁽⁸¹⁾.

Juvenile sunshine bass (*Morone chrysops* - female x *Morone saxatilis* - male) female fed semi-purified diets containing 5.0% olive oil or menhaden fish oil were reared for eight weeks in a closed fresh well water recirculating system. Olive oil significantly reduced weight gain of fish compared to those fed the menhaden fish oil⁽⁶⁴⁾. Erosion of the caudal fin and skin irritation were also observed.

45.9 Palm Oil and Palm Kernel Oil

45.9.1 Description

The oil palm (*Elaeis guineensis*) of the family *Arecaceae* originated from the west coast of Africa. It supplies two different oils:

- Palm oil, a fruit flesh oil;
- Palm kernel oil, a seed oil.

World production amounts to about 9.5 million MT palm oil and 3.0 million MT palm kernel oil with Malaysia and Indonesia, producing more than 70% of the World production.

45.9.2 Chemical, Physiological and Other Properties

Chemical Properties

Palm Oil: Palm berries contain around 60% oil. Palm oil is rich in palmitic and oleic acid. It has around 50% saturated and 50% mono- and poly-unsaturated fatty acids (Table 45-01).

The crude palm oil is of reddish colour caused by the rather high content of α - and β -carotene (544 ppm) in a ratio of 1:2 (α : β)⁽¹⁰¹⁾. By refining the crude oil with bleaching earth, the carotenoids and other impurities are removed, and the oil is of white to yellowish colour⁽⁴⁶⁾.

Palm oil is also rich in Vitamin E. It is, therefore, very stable toward oxidation^(8, 46).

Palm Kernel Oil: The portion of the nuts is around 20% of that of the palm berries. The kernels have a fat content of 40 to 52%. Palm kernel oil has a very high level of saturated fatty acids (88%) (Table 45-01) and its composition is similar to coconut oil⁽¹⁰²⁾. The specifications of palm oil and palm kernel oil by the "Palm Oil Refiners Association of Malaysia" are in Table 45-09.

Table 45-09: Specification of crude palm oil and crude palm kernel oil by the "Palm Oil Refiners Association of Malaysia"

		Palm oil	Palm kernel oil
FFA	max. %	0.25 ¹	5.0 ²
Moisture and impurities	max. %	0.1	0.5
Iodine value	max.	55	19
Slip point	max.	39	-

¹As palmitic acid; ²As lauric acid

Physiological Properties

The energy content of palm oil and palm kernel oil is similar to that of other vegetable oils. However, the digestibility is affected by the high level of saturated fatty acids. Tiger prawns (*Penaeus monodon*) utilise unsaturated fatty acids of palm oil better (e.g. linoleic acid = 90.7%) than saturated fatty acids (e.g. palmitic acid = 62.7%)⁽⁵⁷⁾.

45.9.3 Feeding Value

Information on the feeding value of palm oil and palm kernel oil are lacking. Growth rate of larvae of an African catfish (*Heterobranchus longifilis*) was improved when the fish received diets supplemented with palm oil or a mixture of palm and cod liver oils as compared to larvae fed either zooplankton (*Moina notata*) or a compound diet based on yeast powder and beef liver⁽⁵⁰⁾.

45.10 Rape-seed Oil

45.10.1 Description

Rape-seed (*Brassica napus*, family *Brassicaceae*) is an oil seed. More than 80% of the World production of almost 20 million MT are produced in six countries: P.R. China (29.9%), Canada (19.8%), India (13.4%), Germany (7.1%), Poland (6.6%) and France (5.3%).

Rape seed oil is also called “oil of colza”. It is used as a technical oil and for human consumption, particularly in the manufacture of margarine⁽⁹⁰⁾.

45.10.2 Chemical, Physiological and Other Properties

Rape-seed contains 40 to 50% oil⁽¹⁰²⁾. It is rich in mono-unsaturated fatty acid such as oleic acid (Table 45-01), but contains a high level (20% to 50%) of the undesirable erucic acid.

In dogs the digestible energy was determined to be 9,010 kcal/kg (37.7 MJ/kg) (Table 45-03)⁽⁵⁸⁾. The fat digestibility of rape-seed oil is in the same range as of other vegetable oils due to its high level of unsaturated fatty acids (Table 45-04).

The presence of glucosinolates was the major factor limiting the use of rape-seed oil as animal feed but by genetic selection of new cultivars the glucosinolates and erucic acid have been reduced, the former to about 15%⁽¹⁰⁴⁾. Rape-seed oils low in glucosinolates and erucic acid are also known as “canola oil” which should not have less than 5.0% erucic acid⁽¹⁰²⁾.

In land animals, erucic acid is responsible for retarded growth and myocarditis⁽³⁸⁾.

45.10.3 Feeding Value

Feeding low erucic acid rape-seed oil to Atlantic salmon, juvenile Chinook salmon (*Oncorhynchus tshawytscha*), rainbow trout, hybrid tilapia (*Oreochromis mossambicus* x *Oreochromis aureus*) and goldfish (*Carassius auratus*) did not negatively affect growth, feed conversion and survival rate^(24, 36, 38, 45, 112). There was also hardly any difference in performances between low and high erucic acid levels in the diet as observed in Atlantic salmon and rainbow trout.

Contrary to land animals, erucic acid does not damage the myocardium of rainbow trout. After feeding rape-seed oil containing more than 50% and 3.7% erucic acid, respectively, there was no pathological difference between both rape-seed oil diets⁽³⁸⁾. In Atlantic salmon, the erucic acid content of the diet did not affect the fatty acid composition of both heart and muscle lipids as well as the colour of the fish muscle (Table 45-10). The typical “salmon odour” and “salmon taste” was significantly fainter when diets contained erucic acid⁽¹⁰⁵⁾.

Rape-seed oil has an adequate content of the essential linoleic acid and is, therefore, a useful ingredient in diets for cultured aquatic animals.

Table 45-10: Colour strength in muscle of Atlantic salmon (*Salmo salar*) after feeding different dietary oils ⁽¹⁰⁵⁾

Dietary oil	Score ¹
Rape-seed oil with low erucic acid content	5.03
Rape-seed oil with high erucic acid content	3.99
Soybean oil	4.91
Capelin oil	5.29

¹The higher the value, the stronger the colour of the fish

45.11 Rice Bran Oil

45.11.1 Description

Rice bran oil is a by-product of rice milling (see chapter 37) and solvent extracted from the bran. It contains about 12 to 15% oil. The oil is for human consumption, and is also a raw material for the cosmetic industry.

45.11.2 Properties and Feeding Value

Rice bran oil is rich in unsaturated fatty acids, particularly the essential linoleic acid (Table 45-01). It is, therefore, prone to autoxidation.

The deterioration process is initiated immediately upon removal of the bran from the rice kernel. This results in a break-up of the rice bran oil into free fatty acids by the activity of the enzyme lipase which is a component of the crude oil and already active in the bran before solvent extraction. This is a rapid process causing about 3.0 to 5.0% of the oil to be converted into free fatty acids each day^(102, 113). Lipase is removed by refining the oil. Refined rice bran oil is of light yellowish colour⁽¹⁰²⁾.

The feeding value of rice bran oil for aquatic animals has not been established. Occasionally, it is used as a partial replacement for fish oil.

45.12 Safflower Oil

45.12.1 Description

Safflower (*Carthamus tinctorius*) of the aster family, *Asteracea*, is cultivated for its edible oil. It is also used as a dyestuff, spice, medicament and in the paint industry.

The World production is about 700,000 MT a year and the major suppliers are India (48.6% of World production), Mexico (27.2%) and USA (12.1%)⁽¹⁰²⁾.

45.12.2 Chemical and Physiological Properties

The seeds contain 49% oil. The oil is rich in unsaturated fatty acids, particularly in linoleic acid (Table 45-01).

Safflower oil has 9,010 kcal/kg (37.7 MJ/kg) metabolisable energy and 8,747 kcal/kg (36.6 MJ/kg) digestible energy (poultry) (Table 45-03)⁽²⁸⁾. Fat digestibility might be in the range of 95% due to the high level of poly-unsaturated fatty acids.

45.12.3 Feeding Value

Sunshine bass (*Morone chrysops* x *Morone saxatilis*) responded with significantly reduced weight gain when fed a diet containing 5.0% safflower oil instead of 5.0% menhaden oil. Mortality rate of safflower fed fish was also higher compared to the menhaden fed fish. The lipid content of the liver was much higher in fish fed safflower oil (Table 45-08)⁽⁶⁴⁾.

Better results were obtained when safflower oil in comparison to squid liver oil was fed to the nibbler (*Girella punctata*). Growth of the fish fed safflower oil was superior to the squid liver oil fed group. Safflower oil-fed fish had a higher carcass fat content compared to the squid liver animals⁽⁶³⁾.

45.13 Sesame Oil

45.13.1 Description

Sesame (*Sesamum indicum*) is an annual, herbaceous oil seed crop of the family *Pedaliaceae*. The seeds yield an edible oil and are used for its flavour in bread and rolls and other foods⁽⁸⁾.

The crop is cultivated in Africa, Asia, Central and South America⁽¹⁰²⁾. The World sesame seed production amounts to about 2.45 million MT. Two thirds of the production is harvested in four countries (P.R. China = 26.1%; India = 18.6%; Sudan = 12.6%; Burma (Myanmar) = 11.3%).

45.13.2 Properties

Sesame seeds have an oil content of about 50%. The content of unsaturated fatty acids is very high. Dominating fatty acids are oleic acid and linoleic acid (Table 45-01).

Sesame oil contains unsaponifiable substances such as sterols which are not removed by refining. Sesamin and sesamoline are substances of sesame oil that give distinct colour reactions hence, is readily detected even in small amounts and even after hydrogenation. The oil is unusually stable, perhaps due to the presence of these substances that have antioxidant effect⁽¹⁰²⁾.

The feeding value of sesame oil in aquaculture diets has not been elucidated. The nutritional value of sesame oil in poultry feeding is considered to be the same as that of maize oil, soybean oil and sunflower oil⁽³⁰⁾.

45.14 Soybean Oil

45.14.1 Description

The soya bean (*Glycine max*), of the family *Fabaceae* has an oil content of about 19%. World production of more than 100 million MT soya beans a year, means an annual availability of around 20 million MT of crude soybean oil⁽¹⁰²⁾. It is one of the most important vegetable oils for human consumption (see Chapter 42).

45.14.2 Chemical and Physiological Properties

Chemical Properties

Soybean oil is rich in linoleic acid. Next to linseed oil it has the highest linolenic acid content of all vegetable oils (Table 45-01).

A good quality crude soybean oil is light amber and upon alkali refining, the colour is reduced to light yellow. Like other vegetable oils, high temperature steam deodorisation makes the oil odorless and flavourless.

Physiological Properties

The digestible energy of a mixture of soybean and cod liver oil at a ratio of 1:1 for rainbow trout and carp is 8,007 kcal/kg (33.5 MJ/kg) (Table 45-03)⁽⁶⁹⁾.

The digestibility of a blend of soybean and cod liver oil at a 3:2-ratio is 96.2% for rainbow trout. The addition of phospholipids may improve the lipid digestibility further^(97, 99). The digestibility of linoleic and linolenic acids for rainbow trout is high⁽¹⁰⁾.

The apparent digestibility of fatty acids of soybean oil in tiger prawn follows:

- Palmitic acid (16:0) 87.8%
- Palmitoleic acid (16:1n-7) 78.9%
- Stearic acid (18:0) 88.1%
- Oleic acid (18:1n-9) 95.4%
- Linoleic acid (18:2n-6) 95.6%
- Linolenic acid (18:3n-3) 96.6%

45.14.3 Feeding Value

Fishes

Soybean oil replacing herring oil partially in diets for Atlantic salmon, reared in marine net-pens for 23 weeks did not affect growth or composition of the fillets. Fatty acid composition of the fillets reflected the fatty acid composition of the diets⁽³⁷⁾. When diets containing varying soybean oil levels spread on low-fat dry pellets were given to Atlantic salmon for 18 weeks no differences were observed in weight gain or mortality. Substituting 68% of capelin oil with soybean oil did not give any negative effect on growth but, the ratio of n-3:n-6 fatty acids decreased in fish given the soybean oil (Table 45-11)⁽¹⁰⁵⁾.

Table 45-11: Ratio of n-3:n-6 fatty acids in heart phospho-lipids and some HUFAs of muscles' total lipids of Atlantic salmon (*Salmo salar*)⁽¹⁰⁵⁾

		Ratio n-3:n-6 fatty acids		Fatty acids	
		Soybean oil	Capelin oil	Soybean oil	Capelin oil
Heart phospholipids	1:	2.04	8.83	-	-
Muscle lipids					
- Eicosapentaenoic acid ¹	%	-	-	1.5	4.4
- Docosahexaenoic acid ²	%	-	-	5.4	9.3

¹ 20:5n-3; ² 22:6n-3

The best weight gain and feed efficiency were obtained in Nile tilapia (*Tilapia nilotica*) receiving diets containing soybean oil or maize oil and some other fat sources⁽¹⁰⁰⁾. Nile tilapia broodstock fed soybean oil at a 5.0% level gave the highest number of fish that spawned and spawning frequency. Fish fed the cod liver oil diet had the highest weight gain, but had the poorest reproductive performance. The ratio of total n-6:n-3 fatty acid in the liver, ovaries and testes was influenced by the supplemental lipid source. It was highest in fish fed soybean oil and lowest in fish fed the control diet (no lipid supplement or the cod liver oil diet)⁽⁷⁹⁾.

Milkfish fingerlings fed diets containing a combination of equal amounts of soybean oil and other fats showed highest performances with soybean oil and cod liver oil combination (Table 45-12)^(2, 14, 29). The combination of soybean oil and cod liver oil was also the best when fed to sea bass (*Lates calcarifer*) (Table 45-13)⁽¹⁵⁾.

Table 45-12: Growth response of milkfish (*Chanos chanos*) fingerlings fed with various oils and fats (weight: 1.0 g; trial period: 8 weeks)⁽²⁾

Soybean oil	%	- ¹	5.0	5.0	5.0
Cod liver oil	%	-	5.0	-	-
Beef tallow	%	-	-	5.0	-
Pork lard	%	-	-	-	5.0

Weight gain	%	213	346	306	298
Feed conversion	1:	3.48	2.35	2.91	2.61
Survival rate	%	90	100	98	98

¹Control

Table 45-13: Effect of soybean oil on growth parameters of sea bass (*Lates calcarifer*) fry⁽¹⁵⁾

Soybean oil	%	- ¹	9.0	-	4.5
Cod liver oil	%	-	-	9.0	4.5

Weight gain	%	152.7	364.6	460.9	530.2
SGR	%/day	4.6	7.7	8.6	9.2
Survival rate	%	72	89	82	89

¹Control

Poor results were obtained when a 10% soybean oil diet was fed to hybrid striped bass (*Morone saxatilis* x *Morone chrysops*). Fishes did not grow as well as those fed fish oil. Analysis of the fish body also showed significantly less fat, more protein, and greater moisture content than those fed fish oil. There were no differences in survival⁽³⁵⁾.

Crustaceans

Feeding juvenile tiger prawns with increasing levels of soybean oil gave best results at the 8.0% soybean oil level (Table 45-14). The fatty acid composition of the prawns reflected that of the dietary lipids. HUFAS were incorporated more into the polar lipid fraction. A negative effect was observed when linoleic acid exceeded the 5.0% level in the feed⁽¹⁷⁾. For high stocking densities, practical grow-out diets may contain 2.5% soybean oil and 2.5% cod liver oil⁽⁶⁰⁾.

Table 45-14: Responses of tiger prawn (*Penaeus monodon*) to various levels of soybean oil⁽¹⁷⁾

Soybean oil	%	0	4.0	8.0	12.0
Initial weight	mg	0.54	0.58	0.70	0.54
Weight gain	mg	27.5	19.1	37.1	36.9
SGR	%/day	0.86	0.60	1.10	0.93
Survival rate	%	66.7	77.8	83.3	72.2
Lipid content of prawns	%	0.89	1.00	1.13	1.20

The dietary value of soybean oil is inferior to marine lipids for kuruma prawn (*Penaeus japonicus*) because the oil is high in linolenic fatty acid (18:3n-3) but not in eicosapentaenoic acid (20:5n-3) and docosahexaenoic acid (22:6n-3)⁽⁴⁹⁾. However, a mixture of 6.0% soybean and pollack liver oil (1:3 or 1:1) is a good lipid source for kuruma prawn⁽²³⁾.

Crude degummed soybean oil was superior to purified soybean oil in diets that were isonitrogenous and isocaloric fed for eight weeks to tiger prawn juveniles. Survival rates were significantly higher in shrimps fed diets containing crude degummed soybean oil. Around 4.0% crude degummed soybean oil was best⁽⁷⁴⁾.

Growth of the Indian shrimp (*Penaeus indicus*) fed for 35 days diets containing either 5.0% soybean, sunflower, linseed, or ground-nut oil were not significantly different in growth⁽¹⁹⁾.

45.15 Sunflower Oil

45.15.1 Description

Sunflowers (*Helianthus annuus*), family *Asteraceae*, are cultivated for oil and meal. Both oil and meal are used as food for man and feedstuff for animals. The second most important vegetable oil is sunflower oil⁽¹⁰²⁾. About 21 million MT sunflower seeds are produced per annum (CIC = 25.5% of World production); Argentina = 20.2%; France = 8.9%; P.R. China = 8.2%).

45.15.2 Chemical and Physiological Properties

Unde-hulled sunflower kernel contains 22 to 35% oil and de-hulled seeds 42 to 63%. Sunflower oil is high in polyunsaturated fatty acids but has very little, if any of linolenic acid (Table 45-01).

The digestible energy content of sunflower oil is 8,745 kcal/kg (36.6 MJ/kg) (chicken) (Table 45-03). The European eel digested sunflower oil almost completely⁽⁸²⁾ but had a low energy utilisation with rainbow trout 63% (Table 45-04)⁽⁷⁵⁾.

45.15.3 Feeding Value

Sunflower oil has a high feeding value. In diets for rainbow trout, sunflower oil is the most effective one when compared to other vegetable oils or marine oils (Table 45-15) (Figure 45-04). Protein utilisation is improved, indicating the protein sparing effect of dietary oils. On the other hand, the dietary fat increased the fat content of the rainbow trout^(94, 95, 103).

Sunflower oil in diets for carp showed similar response to those obtained in rainbow trout. Weight increased by up to 22% but fat content of the fish carcass and its fatty acid composition was heavily affected^(48, 96).

The European eel (*Anguilla anguilla*) doubled its initial weight of about 175 g when fed a diet supplemented with sunflower oil⁽⁸²⁾.

Table 45-15: Effect of increasing dietary fat levels on performances of rainbow trout (*Salmo gairdneri*)⁽⁹⁵⁾

Sunflower oil	%	-	5.0	-	-
Cod liver oil	%	-	-	5.0	-
Fish oil	%	-	-	-	5.0
Total dietary fat	%	4.7	9.0	8.9	8.2
Crude protein	%	40.1	38.2	38.3	38.6

Weight gain	%	262	382	324	313
Feed conversion	1:	1.98	1.28	1.46	1.57
Protein efficiency ratio		1.26	2.04	1.79	1.65
Productive protein value		22.4	34.5	29.5	28.2

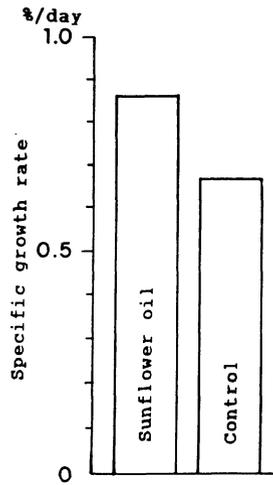


Figure 45-04. Specific growth rate (SGR) of rainbow trout (*Oncorhynchus mykiss*) fed sunflower oil compared with fish oil^(Data from: 103).

45.16 Recommended Inclusion Rates

Crude vegetable oils are predominantly used for energy supplementation in aquaculture feed. They contain impurities. Most of the oils have high levels of unsaturated fatty acids, thus are prone to autoxidation. To prevent oxidation an antioxidant should be added, preferably during processing at the oil mill.

The use of vegetable oils in practical feed formulations have some technical limitations. Inclusion rates of vegetable oils in feeding trials may result in poor pellet quality. The oil level suggested for a common pelletising machine is 4.0 to 5.0%. Higher inclusion rates such as 20% or more are possible, if the feed is extruded or expanded.

45.17 Legal Aspects

Vegetable oils are permitted as a component for animal feeds according to EU Regulations⁽¹¹¹⁾. According to U.S.A-Regulation vegetable oil must contain, and be guaranteed for, not less than 90% fatty acids, not more than 2.0% unsaponifiable matter and not more than 1.0% insoluble impurities. Maximum free fatty acids and moisture must also be guaranteed. The use of an antioxidant has to be declared⁽¹⁾.

The German feedstuff legislation requirements are listed in Table 45-16. Castor oil from *Ricinus communis* and mustard oil from *Brassica nigra* are not permitted under German feedstuff law⁽¹¹¹⁾.

Brominated vegetable oils (BVO) used in softdrinks are not recommended by the World Health Organisation (WHO) of the United Nations. Brominated fat is badly metabolised and accumulate in the heart and other tissues. England and the Netherlands have banned the use of brominated vegetable oil⁽⁶¹⁾.

Table 45-16: Quality requirements by the German feedstuff legislation for feed grade vegetable oils (%)⁽¹¹¹⁾

		Refined oil	Crude oil
Moisture	max.	0.2	1.0
Impurities	max.	0.2	1.5
Unsaponifiable	max.	3.0	3.0
Acid value	max.	-	50

45.18 References

1. AAFCO (1995): Official publication 1995. Asso. of American Feed Control Officials (publisher), Sacramento, CA/USA.
2. Alava, V.R. (1986): Combinations of dietary fat sources in dry diets for *Chanos chanos* fingerlings. Proc. the First Asian Fish. Forum, Asian Fish. Soc., Manila/Philippines.
3. Alexis, M.N.; Papapaskeva Papoutsoglou, E.; Eheochari, V. (1985): Formulation of practical diets for rainbow trout (*Salmo gairdneri*) made by partial or complete substitution of fish meal by poultry by-products and certain plant by-products. Aquaculture, 50., 61-73.
4. Anonymous (1975): Average fatty acid composition and constants of fats and oils. Akzochemie U.K. Ltd. 12/14 St. Ann's Crescent Wandsworth, London/Great Britain.
5. Anonymous (1975): Typical fatty acid composition of common fats and oils (by GLC analysis). Emery Industries, Inc. (1300 Carew Tower, Cincinnati, Ohio/USA.
6. Arai, S.; Nose, T.; Hashimoto, Y. (1971): A purified test diet for the eel (*Anguilla japonica*). Bull. Freshwater. Fish. Res. Lab., 21., 161-178.
7. Argyropoulou, V.; Kalogeropoulos, N.; Alexis, M.N. (1992): Effect of dietary lipids on growth and tissue fatty acid composition of grey mullet (*Mugil cephalus*). Comp. Biochem. Physiol., 101A., 129-135.
8. Arroyo, P.T. (1974): The Science of Philippine Foods.. Abaniko Enterprises, Araneta Center, Quezon City/The Philippines. (1st ed.).
9. Arzel, J.; Cardinal, M.; Cornet, J.; Metailler, R.; Guillaume, J.C. (1993): Nutrition of brown trout (*Salmo trutta*) reared in seawater, effect of dietary lipid on growth performances, body composition and fillet quality. From Discovery to Commercialization. Europ. Aquacult. Soc. No.19. (Oostande/Belgium)
10. Austreng, E.; Skrede, A.; Eldegard, A. (1979): Effects of dietary fat source on the digestibility of fat and fatty acids in rainbow trout and mink. Acta Agric. Scand. 29., 119-126.
11. Austreng, E.; Gjefsen, T. (1981): Fish oils with different contents of free fatty acids in diets for rainbow trout fingerlings and salmon par. Aquaculture, 25., 173-178.
12. Bailey, A.E. (1945): Quoted from: Arroyo, P.T. (1974).

13. *Bimbo, A.P.* (1990): Processing of fish oils. In: *Stansby, M.E.* (ed.): Fish oils in nutrition. Van Nostrand Reinhold, New York/USA. 181-225.
14. *Boonyaratpalin, M.; Unprasert, N.; Buranapanidgit, J.* (1990): Optimal supplementary Vitamin C level in sea bass fingerling diet. The Current Status of Fish Nutrition in Aquaculture. Proc. Third Inter. Symp. on Feeding and Nutr. in Fish. Toba/Japan. 20 Aug. to 1 Sept. 1989. 149-157.
15. *Borlongan, I.G.; Parazo, M.M.* (1991): Effect of dietary lipid sources on growth, survival and fatty acid composition of sea bass (*Lates calcarifer* Bloch) fry. *Bamidgeh*, 43., 95-102.
16. *Bowland, J.P.* (1990): Linseed meal. In: *Thacker, P.A.; Kirkwood, R.M.* (eds.): Nontraditional feed sources for use in swine production. Butterworth Publisher, Stoneham, MA/USA.
17. *Catacutan, M.R.* (1991): Growth and fatty acid composition of *Penaeus monodon* juveniles fed various lipids. *Bamidgeh*, 43., 47-56.
18. *Cheeke, P.R.* (1987): Rabbit feeding and nutrition. Academic Press, Inc.. Orlando/U.S.A.
19. *Colvin, P.M.* (1976): The effect of selected seed oils on the fatty acid composition and growth of *Penaeus indicus*. *Aquaculture*, 8., 81-89.
20. *Cook, R.P.; Thomson, R.O.* (1951). Quoted from: *Cheeke, P.R.* (1987).
21. *Corraze, G.; Larroquet, L.; Maisse, G.; Blanc, D.; Kaushik, S.* (1993): Effect of temperature and of dietary lipid source on female broodstock performance and fatty acid composition of the eggs of rainbow trout. *Fish Nutrition in Practice*. Inst. National Recherche Agronomique (Paris/France). 61., 61-66.
22. *Craig, S.R.; Gatlin, D.M. III; Neill, W.M.* (1992): Effects of kinds and levels of dietary lipid on growth and cold tolerance of juvenile red drum (*Sciaenops ocellatus*). *Aquaculture'92: Growing Toward The 21st Century*. 21 to 25 May, 71-72. (Orlando, Florida/USA)
23. *Deshimaru, O.; Kuroki, K.; Yone, Y.* (1979): The composition and level of dietary lipid appropriate for growth of prawn. *Bull. Jap., Soc. Sci. Fish.*, 45., 519-594.
24. *Dosanjh B.S.; Higgs, D.A.; Plotnikoff, M.D.; Markert, J.R.; Duckley, J.T.* (1988): Preliminary evaluation of canola oil, pork lard and marine lipid singly and in combination as supplemental dietary lipid sources for juvenile fall chinook salmon (*Oncorhynchus tshawytscha*). *Aquaculture*, 68., 325-343.
25. *Dupree, H.K.; Sneed, K.E.* (1966): Response of channel catfish fingerlings to different levels of major nutrients in purified diets. *Techn. Papers U.S. Bureau of Sports, Fishes and Wildlife*, 9., 1-21.
26. *Dupree, H.K.; Gauglitz, E.J.; Hall, A.S.; Houle, C.R.* (1979): Effects of dietary lipids on the growth and acceptability (flavor) of channel catfish (*Ictalurus punctatus*). *Proc. World Symp. on Finfish Nutr. and Fishfeed Techn.*, Hamburg/Germany, Vol. I, 20 to 23 June 1978.
27. *Eusebio, J.H.; Hays, V.W.; Speer, V.C.; McGall, U.T.* (1965): Utilisation of fat by young pigs. *Anim. Sci.*, 24., 1001-1007.
28. *Evans, M.* (1985): Nutrient composition of feedstuffs for pigs and poultry. Queensland Dept. of Primary Industries Information, Series Q185001 (Brisbane/Australia).
29. *Feed Develop. Section* (1994): Feeds and feeding milkfish, Nile tilapia, Asian sea bass, and tiger shrimp. SEAFDEC Aquaculture Department. (Tigbauan, Iloilo/The Philippines).
30. *Feltwell, R.; Fox, S.* (1978): The practical poultry feeding. Faber and Faber, London and Boston.
31. *Fiebig, H.-J.; Wessels, H.* (1994): Olivenöl - Speiseöl seit - Jahrtausenden. *Forschungsreport*, (9), 3-5.
32. *Fowler, L.G.; Wood, E.M.* (1966): Effect of type of supplemental dietary fat on chinook salmon fingerlings. *Progr. Fish-Culturist*, 28., 123-127.
33. *Fracalossi, D.M.; Lovell, R.T.; Craid-Schmidt, M.* (1993): Production of leukotriene B₄ by head kidney leukocytes of channel catfish fed different lipid sources. *From Discovery to Commercialization*. Europ. Aquacult. Soc. no. 19. Oostende/Belgium.
34. *Friesecke, H.* (1984): *Hanbuch der praktischen Fütterung von Rind, Schaf., Pferd, Schwein, Geflügel und*

Süßwasserfischen. BLV Verlagsges, München/Germany

35. Frinsko, M.O.; Robinette, H.R.; Robinson, E.H. (1994): Evaluation of lipid sources for phase II hybrid striped bass (*Morone saxatilis* x *Morone chrysops*). Aquaculture towards the 21st Century. Proc. Infotech - Aquatech '94, Int'l. Conference on Aquaculture, Colombo/Sri Lanka. 97-98.
36. Greene, D.M.S.; Selivonchick, D.P. (1990): Effects of dietary vegetable, animal and marine lipids on muscle lipid and hematology of rainbow trout (*Oncorhynchus mykiss*). Aquaculture, 89., 165-182.
37. Hardy, R.W.; Scott, T.M.; Harrell, L.W. (1987): Replacement of herring oil with menhaden oil, soybean oil, or tallow in the diets of Atlantic salmon raised in marine net-pens. Aquaculture, 65., 267-277.
38. Hartfiel, W.; Schulz, D.; Greuel, E. (1981): Investigations on the conversion of fats of the rainbow trout (*Salmo gairdneri*). 2. The use of two different raw rape-oils in a synthetic food mixture. Fischwirt, 31., 63-64.
39. Hartfiel, W.; Schulz, D.; Greuel, E. (1982): Investigations of fat utilisation of the rainbow trout (*Salmo gairdneri* R.) 3. Use of linseed oil, maize germ oil, olive oil, lard and tallow in comparison to sunflower oil in purified food mixture. Fette, Seifen, Anstrichm., 84., 31-33.
40. Hartfiel, W.; Schulz, D.; Greuel, E. (1984): Investigations about fat utilisation of the rainbow trout (*Salmo gairdneri* R.) 4. comparative use of 18 different feeding fats in a purified diet. Fette, Seifen, Anstrichm., 86., 449-453.
41. Hefner, B. (1988): Nutrition of pond fishes. Cambridge Univ. Press, Cambridge, U.K.
42. Herrtrampf, J.W. (1987): Vitamin E in fats and feeds. Animal Nutrition News 64/87 (Nov.). BASF A.G. Ludwigshafen/Germany.
43. Herrtrampf, J.W. (1989): Zur Bedeutung unkonventioneller Futterstoffe in der Tierernährung. Mühlen- und Mischfutter-Jahrbuch, 100., 134-166, Verlag Moritz Schäfer, Detmold/Germany.
44. Herrtrampf, J.W. (1994). Futtermittel von tropischen und subtropischen Standorten. Paper pres. at Colloquium Inst. für angewandte Botanik, University of Hamburg/Germany. 29 August.
45. Higgs, D.A.; Dosanjh, B.S.; Little, M.; Roy, R.J.J.; McBride, J.R. (1989): Potential for including canola products (meal and oil) in diets for *Oreochromis mossambicus* x *O. aureus* hybrids. The current status of fish nutrition in aquaculture. Proc. 3rd International Symp. Feeding and Nutrition in Fish. 1 August to 3 September. 301-314.
46. Higuera, M. de la; Murillo, A.; Varela, G.; Zamora, S. (1977): Quoted from: Steffen, W (1985).
47. Ikehara, K.; Nagahara, M. (1978): Fundamental studies for establishing rockfish culture techniques. 4. On the favourable contents of protein and lipid in compound food for a young rockfish (*Sebastes thompsoni* Jordan et Hubbs). Bull. Jap. Sea Reg. Fish. Res. Lab., 29., 103-110.
48. Jirasek, J.; Ingr, I.; Spurny, P. (1980): Condition and production of energy reserves in carp fry as influenced by fat feed additives. Zivocisna-Vyroba, 25., 801-808.
49. Kanazawa, A.; Teshima, S.; Tokiwa, S. (1977): Nutritional requirements of prawn. VII. Effect of dietary lipids on growth. Bull. Jap. Soc. Sci. Fish., 43., 849-856.
50. Kerduen, N. (1992): Artificial feeding of an African fish (*Heterobranchus longifilis*) (Teleostei:Claridae): Effect of feeding regime and first estimation of nutritional requirements. Trav. Doc. Midroed. Orstrom. Paris, France Orstrom No. 88, 181.
51. Lee, D.J.; Roehm, J.N.; Yu, T.C.; Sinnhuber, R.O. (1967): Effect of 13 fatty acids on the growth rate of rainbow trout (*Salmo gairdneri*). J. Nutrition, 92., 93-98.
52. Lie, O.; Lied, E.; Lambertsen, G. (1986): Liver retention of fat and of fatty acids in cod (*Gadus morhua*) fed different oils. Aquaculture, 59., 187-196.
53. Lochmann, R.T.; Gatlin, D.M. III. (1993): Evaluation of different types and levels of triglycerides, singly and in combination with different levels of n-3 highly unsaturated fatty acid ethylesters in diets of juvenile

- red drum (*Sciaenops ocellatus*). Aquaculture, 114., 113-130.
54. Lowe, B. (1943): Experimental cookery from the chemical and physical standpoint. John Wiley & Sons, Inc. New York.
 55. Mai, K.; Mercer, J.P.; Donlon, J. (1995): Comparative studies on the nutrition of two species of abalone, *Haliotis tuberculata* L and *Haliotis discus hannai* Ino. III. Response of abalone to various levels of dietary lipid. Aquaculture., 134., 65-80.
 56. Martinsen, B.; Horsber, T.E.; Sohlberg, S.; Burke, M. (1993): Single dose kinetic study of sarafloxacin after intravenous and oral administration of different formulations to Atlantic salmon (*Salmo salar*) held in seawater at 8.5°C. Aquaculture, 118., 37-47.
 57. Merican, Z.O.; Shim, K.F. (1994): Lipid and fatty acid utilization in adult *Penaeus monodon* fed diets supplemented with various oils. Aquaculture, 123., 335-347.
 58. Meyer, H.; Heckötter, E. (1986): Futterwertabelle für Hunde und Katzen. Schlütersche Verlagsanstalt, Hannover/Germany.
 59. Meyer, H. (1990): Ernährung des Hundes. Verlag Eugen Ulmer, Stuttgart/Germany.
 60. Millamena, O.; Triño, A.T. (1994): Evaluation of fish protein concentrate and lactic yeast as protein sources for shrimp *Penaeus monodon*. Proc. Third Asian Fisheries Forum, Asian Fish. Soc. (Singapore). 675-677.
 61. Miller-Jones, J. (1992): Food safety. Eagan Press, Mim./U.S.A.
 62. Mugrdichian, D.R.; Hardy, R.W.; Iwaoka, W.T. (1981): Linseed oil and animal fat as alternative lipid sources in dry diets for Chinook salmon (*Oncorhynchus tshawytscha*). Aquaculture, 25., 161-172.
 63. Nakazoe, J.; Kimura, S.; Yokoyama, M.; Iida, H. (1986): Effects of the supplementation of algae or lipids to the diets on the growth and body composition of nibbler (*Girella punctata*) Gray. Bull. Tokai Reg. Fish. Res. Lab. Tokaisuikenho, 120., 43-51.
 64. Nematipour, G.R.; Gatlin, III, D.M. (1993): Effects of different kinds of dietary lipid on growth and fatty acid composition of juvenile sunshine bass, *Morone chrysops* female x *Morone saxatilis* male. Aquaculture, 114., 141-154.
 65. New, M.B. (1987): Feed and feeding of fish and shrimps. A manual on the preparation and presentation of compound feeds for shrimp and fish in aquaculture. UNDP/FAO/ADCP/REP/87/26, Rome/Italy.
 66. Newton, G.L.; Hale, O.M.; Haydon, K.D. (1960): Peanut kernels. In: Thacker, P.A.; Kirkwood, R.M. (eds.): Nontraditional feed sources for use in swine production. Butterworth Publisher, Stoneham, MA/USA.
 67. NRA (1993): Pocket information manual - a buyer's guide to rendered products. National Renderer's Asso., Inc. Alexandria, Virg./USA. (Leaflet).
 68. NRC (1993): Nutrient requirements of fishes. National Research Council. National Academy Press. Washington D.C./U.S.A.
 69. Ogino, C.; Chen, M.; Takeuchi, T. (1976): Protein nutrition in fish. VI. Effects of dietary energy sources on the utilisation of protein by rainbow trout and carp. Bull. Jap. Soc. Sci. Fisheries, 42., 213-218.
 70. Olsen, R.E.; Henderson, R.J.; Ringoe, E. (1991): Lipids of arctic cohar (*Salvelinus alpinus* L.). 1. Dietary induced changes in lipid class and fatty acid composition. Fish. Physiol. Biochem., 9., 151-164.
 71. Page, J.W.; Andrews, J.W. (1973): Interaction of dietary levels of protein and energy on channel catfish (*Ictalurus punctatus*). J. Nutrition., 103., 1339.
 72. Philipps, A.M.; Livingston, D.L.; Poston, A.H. (1965): Quoted from: Steffens, W. (1985).
 73. Philipps, A.M.; Livingston, D.L.; Poston, A.H. (1967): Quoted from: Steffens, W. (1985).
 74. Piedad-Pascual, F. (1986): Effect of supplemental lecithin and lipid sources on the growth and survival of *Penaeus monodon* juveniles. Proc. the First Asian Fish. Forum, Asian Fish. Soc. (Manila/The Philippines). 615-618.

75. Pieper, A.; Pfeffer, E. (1980): The studies on the comparative efficiency of utilisation of gross energy from some carbohydrates, proteins and fats by rainbow trout (*Salmo gairdneri* R). *Aquaculture*, 30., 323-332.
76. Roehm, J.N.; Lee, D.J.; Sinnhuber, R.O. (1967): Accumulation and elimination of dietary gossypol in the organs of rainbow trout. *J. Nutrition*, 92., 425-428.
77. Roehm, J.N.; Wales, J.H.; Sinnhuber, R.O. (1970): The effect of dietary steroculic acid on the hepatic lipid of rainbow trout. *Lipids*, 5., 80-84.
78. Roehm, A.J.; Kohler, C.C.; Stickney, R.R. (1990): Vitamin E requirements of the blue tilapia (*Oreochromis aureus* Steindachner), in relation to dietary lipid level. *Aquaculture*, 87., 155-164.
79. Santiago, C.B.; Reyes, O.S. (1993): Effects of dietary lipids source on reproductive performance and tissue of lipid levels of Nile tilapia (*Oreochromis niloticus* Linnaeus) broodstock. *J. Appl. Ichthyol.*, 9., 33-40.
80. Santiago, C.B.; Aldaba, M.B.; Abuan, E.F.; Laron, M.A. (1985): Effects of artificial diets on fry production and growth of *Oreochromis niloticus* breeders. *Aquaculture*, 47., 193-203.
81. Schilling, H.U. (1980): Different fat components in the diet for eels (*Anguilla anguilla* L.) reared under intensive conditions. Feeding behaviour, weight and fatty acids. Rheinische Friedrich-Wilhelm University Inaugural Diss. Bonn/Germany.
82. Schmitz, O.; Greuel, E.; Pfeffer, E. (1982): Studies of digestion and utilisation of organic nutrients by growing eels. *Z. Tierphysiol., Tierernähr., Futtermittelkd.*, 48., 138-142.
83. Schwarz, F.J.; Kirchgessner, M.; Steinhart, H.; Runge G. (1988): Influence of different fats with varying additions of alpha-tocopheryl acetate on growth and body composition of carp (*Cyprinus carpio* L.). *Aquaculture*, 69., 57-67.
84. Sheen, S.S.; D'Abramo, L.R. (1991): Response of juvenile freshwater prawn, *Macrobrachium rosenbergii*, to different levels of a cod liver oil/maize oil mixture in a semi-purified diet. *Aquaculture*, 93., 121-134.
85. Sheen, S.S.; Chen, S.J. (1994): Optimum dietary lipid requirement level of the tiger prawns, *Penaeus monodon*. *Aquaculture Towards the 21st Century. Proc. Infotech - Aquatech '94, Int'l. Conference on Aquaculture, Colombo/Sri Lanka.* 203.
86. Shepherd, A.J.; Iverson, J.L.; Weihrauch, J.L. (1978): Composition of selected dietary fats, oils, margarines and butter. In: Kuksis, A. (ed.): *Fatty acids and glycerides.* Oxford Plenum Press, 341-379.
87. Shimm, Y.; Shima, H.; Ikeda, K. (1980): Effects of supplemental oils to single cell protein feeds on the growth and fatty acid composition of ayu, *Plecoglossus altivelis*. *Bull. Nat'l. Res. Inst. Aquacult., Japan*, 1., 47-60.
88. Shores, L. (1974): *Collier's Encyclopedia.* Macmillan Educational Corp. (USA). 7., 382.
89. Shores, L. (1974): *Collier's Encyclopedia.* Macmillan Educational Corp., 14., 674.
90. Shores, L. (1974): *Collier's Encyclopedia.* Macmillan Educational Corp. 20., 330-331.
91. Sigurgisladdottir, S., Lall, S.P.; Parrish, C.C.; Ackman, R.G. (1992): Cholestane as a digestibility marker in the absorption of polyunsaturated fatty acid ethyl esters in Atlantic salmon. *Lipids*, 27., 418-424.
92. Sinnhuber, R.O.; Lee, D.J.; Wales, J.H.; Ayres, J.L. (1968): Dietary factors and hepatoma in rainbow trout (*Salmo gairdneri*). II. Co-carcinogenes by cyclopropanoid fatty acids and the effects of gossypol and altered lipids in aflatoxin-induced liver cancer. *J. Nat. Cancer Inst.*, 41., 1293-1301.
93. Steffens, W. (1985): *Grundlagen der Fischernahrung.* VEB Gustav Fischer Verlag, Jena/Germany.
94. Steffens, W.; Albrecht, M.-L. (1973): Proteineinsparung durch Erhöhung des Fettanteiles im Futter für Regenbogenforellen (*Salmo gairdneri*). *Arch. Tierernährung*, 23., 711-717.
95. Steffens, W.; Albrecht, M.-L. (1975): Der Einfluß des Zusatzes unterschiedlicher Fette zum Trockenmischfutter auf Wachstum und Futtermittelverwertung von Regenbogenforellen. *Arch. Tierernährung*, 25., 717-723.

96. Steffens, W.; Wirth, M.; Rennert, B. (1993): Effects of adding various oils to the diet on growth, feed conversion and chemical composition of carp (*Cyprinus carpio*). From Discovery to Commercialization, European Aquaculture Soc. Special Publ. No. 19. Oostende/Belgium.
97. Strelcova, S.V.; Olsanskaja, L.J. (1974): Quoted from: Steffens, W. (1985).
98. Sutanto, J. (1981): Solvent extraction process to achieve zero-effluent and to produce quality animal feed from mill sludge. Proc. National Workshop on Oil Palm By-Products Utilisation, 14 to 15 Dec., Kuala Lumpur/Malaysia, 85-99.
99. Takeuchi, T.; Watanabe, T.; Ogino, C. (1978): Supplementary effect of lipids in a high protein diet of rainbow trout. Bull. Jap. Soc. Sci. Fish., 44., 677-681.
100. Takeuchi, T.; Satoh, S.; Watanabe, T. (1983): Dietary lipids suitable for the practical feed of tilapia nilotica (*Oreochromis niloticus*). Bull. Jap. Soc. Sci. Fish., 49., 1361-1365.
101. Tan, B.; Ng, J. (1987): Elucidation of palm oil carotenoids. Proc. 8th International Carotenoid Symp., Boston/USA (Abstr.).
102. Täufel, A.; Ternes, W.; Tunger, L. Zobel, M. (1993): Lebensmittel-Lexikon. Behr's Verlag, Hamburg/Germany.
103. Teskeredzic, A.; Teskeredzic, E.; Tomec, M. (1989): The influence of four different kinds of oil upon the growth of rainbow trout (*Oncorhynchus mykiss*). Proc. Third International Symposium on Feeding and Nutrition in Fish. Toba/Japan, 28 Aug. to 1 Sept. 1989, 245-250.
104. Thacker, P.A. (1990): In: Thacker, P.A.; Kirkwood, R.M. (eds.): Canola meal. In: Nontraditional feed sources for use in swine production. Butterworth Publisher, Stoneham, MA/USA.
105. Thomassen, M.S.; Roesjoe, C. (1989): Different fats in feed for salmon: Influence on sensory parameters, growth rate and fatty acids in muscle and heart. Aquaculture, 79., 129-135.
106. Tuncer, H.; Harrell, R.M. (1992): Essential fatty acid nutrition of larval striped bass (*Morone saxatilis*) and palmetto bass (*M. saxatilis* x *M. chrysops*). Aquaculture, 101., 105-121.
107. Viola, S.; Rappaport, U. (1978): Experiments in nutrition of carp in cages and ponds. III. Increasing energy density of pellets by oil. Bamidgeh, 32., 67-69.
108. Viola, S.; Arieli, Y. (1983): Nutrition studies with tilapia hybrids. 2. The effects of oil supplements to practical diets for intensive aquaculture. Bamidgeh, 35., 44-52.
109. Watanabe, T.; Itoh, A.; Murakami, A.; Tsukashima, Y.; Kitajima, C. (1984): Effect of nutritional quality of diets given to broodstock on the verge of spawning on reproduction of red sea bream. Bull. Jap. Soc. Sci. Fish. Nissuishi., 50., 1023-1028.
110. Watt, B.K.; Merrill, A.L. (1963): Composition of foods. Agriculture Handbook No. 8. Consumer and Food Economics Res. Division Agricultural research Service, United States Dept. Agriculture. (Washington D.C./USA).
111. Weinreich, O.; Koch, V.; Knippel, J. (1994): Futtermittelrechtliche Vorschriften. Buchedition Agrimedia. Hamburg/Germany.
112. Wiegand, M.D. (1993): Study on the use of canola oil in the feed of larval goldfish (*Carassius auratus* L.). Broodstock Management and Egg and Larval Quality, 24., 223-220.
113. Williams, M.A. (1989): Extrusion of rice bran. Proc. World Congr. Vegetable Protein Utilisation in Human Foods and Animal Feedstuffs, Singapore, October 1988, 100-102.
114. Xu, X.L.; Ji, W.J.; Castell, J.D.; O'Dor, R.K. (1993): Effect of dietary lipids on fecundity, hatchability and egg fatty acid composition of Chinese prawn (*Penaeus chinensis*). From Discovery to Commercialization, Europ. Aquaculture Soc., Special Publ. No. 19, Oostende/Belgium.

46. VEGETABLE OIL MEALS

46.1 Rationale

Vegetable oil meals are by-products after the removal of oil from oil-bearing seeds. They are produced by annual plants and perennial trees. The latter includes oil palm and coconut palm trees. Most important annual plants belong to the botanical families of legumes and crucifers (see Chapter 45.1).

Meals from vegetable oil processing are protein feedstuffs whose protein content ranges between 20 to 50%⁽¹⁶³⁾. In the past, vegetable oil producing plants were cultivated primarily for their oil for human consumption and industrial applications. The increasing demand for protein for animal production, and aquaculture, made the by-products of greater importance than the oil. An example is soya bean meal, which is the most important protein source for feeding farm animals, but originally was a by-product of little value. The use of full fat oil seed, as a feedstuff is a consequent development of this situation⁽⁴⁰⁾.

However, “not all is gold that glitters.” Vegetable oil meals contain undesirable constituents such as high crude fibre, ash and anti-nutritional factors.

The high crude fibre content is caused by the protective cover of the seed’s germ and nutrients in the form of hulls and shells. The external coating of seeds or corticated seeds can be partially or completely removed mechanically and the process is called decortication thus, the oil meals are classified as:

- Corticated vegetable oil meals (coating not removed, with hulls);
- Decorticated vegetable oil meal (coating removed prior to oil extraction, de-hulled, without hulls).

The crude fibre content of vegetable oil meals is an indicator of whether the meal is corticated or decorticated. A high crude fibre content means that the meal is corticated.

The method used in the removal of oil from the seeds also determines the feeding value of vegetable oil meals (see Chapter 45.2.2). Products obtained from oil removal are:

- Oil meals (oil removed by solvent extraction);
- Oil cake/oil expeller (oil removed by hydraulic or screw pressing).

The term “meal” always refers to a solvent (chemically) extracted product while “cake” or “expeller” means a product obtained by mechanical pressing. Names such as “solvent extracted oil meal” or “screw pressed oil meal” are not only misleading but also redundant. The content of residual fat is the best indicator for the process used in fat extraction. Levels of more than 5.0% refer to an oil cake or oil expeller. Likewise there is no need to use the term “unde-hulled oil meal” but there is a demand to describe a product as “de-hulled oil meal.” The proper terms for vegetable oil meals without any risk of misinterpretation are e.g.:

- Soybean meal
- De-hulled soybean meal,

- Soybean cake (expeller),
- De-hulled soybean cake (expeller),
- Full-fat soybean meal,
- De-hulled full-fat soybean meal.

46.2 Manufacture and Processing

The processes for the removal of oil from oil seeds are described in Chapter 45.2. In addition, each oil seed may require a specific treatment for obtaining the oil. When the oil seeds such as copra, ground-nuts, linseed, rape-seed and sunflower seeds contain more than 35% oil, pre-pressing prior to solvent extraction is more economical than applying only the solvent extraction process⁽⁴⁰⁾. Specific procedures are described in the individual section for each vegetable oil meal.

The amount of vegetable oil meals obtained can be between 38% to 82% from corticated and from 13% to 75% from decorticated seeds. The hull portion varies between 7.0% and 45%⁽⁴⁰⁾.

Full-fat oil seeds have to undergo heat treatment to destroy the heat-labile anti-nutrients. Commercial processes used for treatment of soya beans are:

- Dry roasting,
- Jet-sploding,
- Micronisation,
- Extrusion.

Dry roasting is the most common treatment in which the material is exposed directly to a flame. The more careful treatment which minimises losses of nutrients is jet-sploding whereby the seeds are only indirectly exposed to the heat source⁽¹⁵²⁾.

46.3 Coconut Meal

46.3.1 Description

The by-product of the mature nut (fruit) of the coconut tree (*Cocos nucifera*) is coconut meal. The nut is a hard shell, covered by a fibrous outer coat and contains the edible kernels in the centre. The dry kernel, still containing the oil, is called copra and the residue after the removal of the oil by solvent extraction or screw pressing is named coconut meal and coconut cake (expeller), respectively⁽⁴⁶⁾. A coconut is 13.0% meal, 62% oil, and 25% shells⁽⁴⁰⁾.

46.3.2 Chemical, Physiological and Other Properties

Chemical Properties

Coconut meal is a protein feedstuff, and its crude protein content is just above 20% (Table 46-01). The limiting amino acids are lysine and methionine (Table 46-02)⁽⁷⁵⁾. The content of sulphur amino acids amounts to only 0.36% in the dry matter⁽³¹⁾.

Table 46-01: Chemical composition of vegetable oil meals and expellers (% as fed)

	Dry matter	Crude protein	Crude fat	Ash	Crude fibre	N-free extract	Reference
Coconut meal	90.2	21.9	2.2	6.9	14.1	45.1	(31, 46, 54, 119, 163)
Coconut expeller	91.0	20.6	8.9	5.7	12.4	43.3	(46, 49, 119, 120, 163, 171)
Cotton-seed meal,							
- corticated	90.0	32.9	1.7	6.0	21.8	27.6	(54)
- decorticated	90.8	44.2	1.2	6.8	9.7	28.9	(46, 49, 54, 110, 163)
Cotton-seed expeller							
- corticated	89.7	22.9	5.6	5.4	23.4	32.4	(54, 119, 163)
- decorticated	92.1	41.1	6.2	6.0	11.2	27.6	(54, 125, 163)
Ground-nut meal							
- corticated	91.1	32.0	2.6	5.1	25.0	26.4	(54, 125, 163)
- decorticated	90.2	46.5	1.0	5.4	8.2	29.1	(31, 49, 54, 120, 122, 125, 163)
Ground-nut expeller							
- corticated	91.1	34.1	10.3	6.4	18.1	22.2	(54, 120, 125, 163)
- decorticated	91.1	46.5	7.0	5.1	6.1	26.4	(46, 54, 120, 125, 163)
Linseed meal	90.0	35.0	2.0	6.2	9.2	37.6	(26, 31, 54, 110, 163)
Linseed expeller	90.1	33.4	5.7	6.4	9.2	35.4	(26, 46, 54, 163)
Mustard meal	89.9	42.4	1.8	6.3	9.1	30.3	(24, 62, 71)
Mustard expeller	89.2	28.2	8.9	10.2	8.2	33.7	(62, 71, 119, 132, 163, 188)
Olive meal	92.4	13.3	3.6	8.2	22.8	44.5	(23, 31, 163)
Olive expeller	88.1	5.6	12.7	3.1	35.2	31.5	(23, 31, 163)
Palm-kernel meal	89.8	16.3	1.4	3.9	17.8	50.4	(54, 119, 163, 187)
Palm-kernel expeller	89.9	16.6	7.6	4.0	17.5	44.2	(23, 54, 163)
Rape-seed meal							
- solvent extracted	91.0	37.3	1.9	7.2	11.4	33.2	(163)
- pre-press solvent extracted	93.0	38.0	3.8	6.8	11.1	33.3	(125)
Rape-seed expeller	91.2	34.5	7.2	6.7	12.1	30.7	(119, 163)
Safflower meal							
- corticated	91.3	23.0	1.4	4.7	31.4	30.8	(46, 54, 163)
- decorticated ¹	91.2	43.1	1.6	7.1	11.5	28.0	(46, 49, 54, 163)
- decorticated, debittered	91.1	63.0	0.8	7.4	4.4	15.5	(189)
Safflower expeller							
- corticated	91.0	21.1	5.6	4.8	31.2	28.3	(54, 163)
- decorticated ¹	90.7	45.2	6.9	7.3	10.4	20.9	(54, 163)
Sesame meal	92.4	45.0	4.8	13.0	6.7	24.2	(23, 31, 46, 49, 120, 138)
Sesame expeller	90.6	37.0	13.3	11.1	7.8	21.4	(23, 46, 120)
Soybean meal							
- corticated	90.6	45.9	1.0	6.3	6.3	31.1	(4, 31, 46, 48, 49, 153)
- decorticated	89.5	49.8	0.8	5.6	3.2	30.1	(4, 22, 46)
- full-fat	90.2	37.4	18.9	5.5	5.4	23.0	(110, 153)

Table 46-01: Continued

	Dry matter	Crude protein	Crude fat	Ash	Crude fibre	N-free extract	Reference
Soybean expeller	88.6	43.5	5.6	6.2	5.4	27.9	(22, 48, 153)
Sunflower seeds	93.0	18.9	36.2	3.6	18.7	15.6	(23, 46, 181)
Sunflower meal							
- corticated	90.3	30.8	1.5	6.3	24.8	26.9	(23, 43)
- decorticated	92.6	43.5	3.2	6.6	11.1	28.2	(43, 49, 120)
Sunflower expeller							
- corticated	92.7	35.1	8.2	6.5	17.3	25.6	(23, 46, 120)
- decorticated	92.2	37.1	9.3	6.3	12.3	27.2	(163)

¹Partially decorticated

Table 46-02: Essential amino acid profile of coconut meal and coconut expeller (g/16g N)^(46, 163)

	Coconut meal	Coconut expeller
Arginine	2.37	2.89
Histidine	0.38	0.44
Isoleucine	0.82	0.78
Leucine	1.45	1.33
Lysine	0.56	0.70
Methionine	0.32	0.32
Phenylalanine	0.93	0.94
Threonine	0.71	0.67
Tryptophan	0.18	0.27
Valine	1.14	1.11

Compared to the whole chicken egg protein, coconut cake contains only 37% of lysine and 34% of methionine + cystine⁽¹²¹⁾.

Coconut cake has a higher fat content than solvent extracted meal hence, the former is more prone to spoilage by rancidity than the meal^(46, 49, 120). The crude fibre content is disadvantageous for aquatic feed (Table 46-01).

Coconut meal and expeller have relatively high phosphorus content and are low in calcium. The choline content is high (Table 46-03).

Physiological Properties

The digestible energy of coconut meal in fish is less than 3,000 kcal/kg (Table 46-04). It increases with the fat content of the product (Table 46-05).

Table 46-03: Mineral and vitamin contents of coconut meal and coconut expeller

Minerals ^(31, 46, 49, 54, 120, 163)				Vitamins (per 1,000 g) ^(46, 49, 162, 169)			
		Expeller	Meal			Expeller	Meal
Calcium	%	0.17	0.18	Vitamin A	IU	300	400
Phosphorus	%	0.58	0.59	Vitamin E	mg	4.0	-
Sodium	%	0.09	0.09	Vitamin B ₁	mg	0.4	0.9
Potassium	%	1.87	1.49	Vitamin B ₂	mg	2.8	6.4
Magnesium	%	0.34	0.34	Vitamin B ₆	mg	1.4	2.1
Chlorine	%	-	0.03	Biotin	mg	0.23	-
Sulphur	%	-	0.34	Folic acid	mg	0.14	0.80
Manganese	mg/kg	45.4	60.0	Nicotinic acid	mg	25.1	28.1
Iron	mg/kg	180.0	683.0	Pantothenic acid	mg	8.8	6.3
Zinc	mg/kg	54.2	-	Choline	g	1.1	1.1
Copper	mg/kg	28.2	9.0				

Table 46-04: Energy values of coconut meal and coconut expellers (per kg)

Species	Metabolisable energy		Digestible energy		Reference
	kcal	MJ	kcal	MJ	
Fish ¹	-	-	2,899	12.1 ²	(120)
Poultry	1,635	6.8	3,220	13.5 ²	(46, 54)
	1,493	6.2	3,120	13.1	(46, 49, 54)
Rabbits	-	-	3,180	13.3	(31)

¹Species not specified; ²Coconut expeller

Table 46-05: Relationship between the residual oil content and the digestible energy value of coconut by-products with pigs⁽¹⁷⁾

Type of product	Residual oil Content %	Digestible energy	
		kcal/kg	MJ/kg
Meal	0.4	3,020	12.6
Expeller	9.1	3,700	15.5
Expeller	16.1	4,340	18.2
Expeller	22.0	4,540	19.0
Expeller	33.3	4,690	19.6
Copra (unpressed)	66.2	7,060	29.5

Other Properties

High levels of coconut meal and expeller increases the butterfat content in the milk of dairy cows and hardens the butter^(40, 54). Whether coconut meal or expeller in diets for aquatic animals affect the consistency of carcass fat is unknown.

Coconut expeller improves the press capacity of the pelletising machine due to its fat content but gives a low pellet quality and is highly abrasive^(55, 66).

46.3.3 Feeding Value

Coconut meal and expeller are a good source of protein and energy, particularly for ruminants⁽⁴⁰⁾. The suitability for aquaculture feeds is limited and only a few investigations on the feeding value are available. Higher dietary levels than 12% have been found to give poor growth, even when in combination with fish meal and other plant protein sources^(148, 149).

46.3.4 Recommended Inclusion Rates

Coconut meal and expeller are useful sources of protein for aquatic animals in tropical and subtropical areas. The limiting factor is the high crude fibre content. It is, therefore, not a good ingredient for starter feed. Meal and cake are more suitable for herbivorous/omnivorous than for carnivorous aquatic animals.

The recommended inclusion rates are:

- Herbivorous/omnivorous fish: 5.0 to 15.0%
- Carnivorous fish: 5.0 to 10.0%

An additional amino acid fortification (lysine and methionine) of the feed might be necessary when coconut meal and/or cake is used.

46.4 Cotton-Seed Meal

46.4.1 Description

Cotton (*Gossypium hirsutum*) is grown for its fibre in the manufacture of textiles. The by-product is cotton-seed. For every 100 kg of cotton fibre produced, the cotton plant also yields about 160 kg cotton-seed. Cotton-seed oil is obtained by screw pressing, pre-press solvent extraction, and solvent extraction.

The residues after oil removal is a useful feedstuff (see also chapter 45.4). Cotton-seed is composed of⁽¹⁶⁸⁾:

- Meal: 50.0%
- Hulls: 22.0%
- Oil: 16.0%
- Linters: 7.0%
- Processing losses: 5.0%

Table 46-06: Digestibility (%) of coconut meal and coconut expeller

Species	Dry matter	Crude protein	Fat	Crude fibre	Carbo-hydrates	Energy	Refer-ence
Tropical catfish	86.0	90.0	-	-	-	89.0	(83)
Red tilapia	80.6	99.1	100.0	-	56.0	81.7	(81)
Poultry	69.0	-	-	-	-	-	(54)
	81.0 ¹	-	-	-	-	-	(54)

¹Coconut expeller

46.4.2 Chemical, Physiological and Other Properties

Chemical Properties

Cotton-seed meal has a relatively high crude protein content. It is higher for decorticated meal than for expeller (Table 46-01). Cotton-seed meal is low in lysine and methionine (Table 46-07)⁽⁴⁰⁾. Processing conditions may also have a negative effect on the amino acid content⁽¹⁶⁸⁾.

The fat content of cotton-seed expeller is about 4.0% higher than of cotton-seed meal. Crude fibre is a limiting factor in the use of cotton-seed meal as feed. It is around 10% in decorticated meals and expellers while its content in corticated meal can exceed 20% (Table 46-07).

Table 46-07: Essential amino acid profile of decorticated cotton-seed products (g/16g N)^(125, 163, 168)

	Cotton-seed meal	Cotton-seed expeller
Arginine	4.47	4.51
Histidine	1.04	1.07
Isoleucine	1.28	1.39
Leucine	2.23	2.35
Lysine	1.81	1.64
Methionine	0.52	0.57
Phenylalanine	2.21	2.18
Threonine	1.23	1.36
Tryptophan	0.47	0.53
Valine	1.82	1.97

Phosphorus, potassium and iron content of cotton-seed meal is high, and B-vitamins compare favorably with soybean meal (Table 46-08).

Table 46-08: Mineral and vitamin contents of decorticated cotton-seed meal and cotton-seed expeller

Minerals ^(46, 110, 125)				Vitamins (per 1,000 g) ^(46, 110, 125, 162 168)			
		Cotton-seed meal	Cotton-seed expeller			Cotton-seed meal	Cotton-seed expeller
Calcium	%	0.21	0.20	Vitamin A	IU	330	-
Phosphorus	%	1.41	1.16	Vitamin E	mg	16.1	13.3
Potassium	%	1.34	1.64	Vitamin B ₁	mg	6.3	7.2
Chlorine	%	0.04	-	Vitamin B ₂	mg	4.6	4.3
Magnesium	%	0.48	0.72	Vitamin B ₆	mg	4.7	5.0
Sodium	%	0.03	0.02	Biotin	mg	0.56	0.64
Sulphur	%	0.30	4.75	Folic acid	mg	2.5	1.7
Copper	mg/kg	18.03	13.90	Nicotinic acid	mg	37.3	41.0
Iron	mg/kg	326.33	116.00	Pantothenic acid	mg	10.4	12.3
Manganese	mg/kg	21.67	22.90	Choline	g	2.7	2.8
Selenium	mg/kg	0.06	0.18				
Zinc	mg/kg	60.50	64.30				
Iodine	mg/kg	50.00	-				

Physiological properties

The digestible energy of cotton-seed meal is relatively low due to the high crude fibre content (Table 46-09). Fat is best digested while carbohydrates have the lowest digestibility in common carp (*Cyprinus carpio*) (Table 46-10)⁽⁶⁴⁾. Even in ruminants the digestibility of corticated cotton-seed meal and expeller is only 61%⁽⁵⁴⁾.

Table 46-09:Energy values of cotton-seed meal per kg

Species	Gross energy		Metabolisable energy		Digestible energy		Reference
	kcal	MJ	kcal	MJ	kcal	MJ	
	4,419	18.5	-	-	-	-	(97, 110, 160)
Rainbow trout	-	-	2,365	9.9	2,711	11.3	(12, 160)
Common carp	-	-	2,603	11.1	-	-	(173, 179)
Channel catfish	-	-	-	-	2,894	12.1	(12, 97)
Chicken	-	-	2,137	8.9	3,125	13.1	(46, 49)

Table 46-10: Digestibility (%) of cotton-seed meal⁽⁶⁴⁾

Species	Dry matter	Crude protein	Fat	Crude fibre	Carbo-hydrates	Energy
Channel catfish	-	-	81.0	-	-	56.0
Common carp	46.0	77.0	87.0	67.0	39.4	-

The amino acid availability of cotton-seed meal for channel catfish (*Ictalurus punctatus*) ranges between 71.2 and 90.6% for the true digestibility and 46.5% to 87.3% for the apparent digestibility for common carp. For both species, it is high for arginine but low for lysine. The low availability of lysine can be a result of the solvent extraction process of the oil and the presence of gossypol because it binds lysine⁽¹⁶³⁾. In glandless cotton-seed meal, the lysine availability is better⁽¹⁸⁵⁾.

Deleterious Substances

Gossypol is a highly reactive polyphenolic dinaphthaldehyde compound present in the oil gland of cotton-seed. It is either bound or free^(46, 168). The bound form is non-toxic and is of little significance since it is unavailable and passes through the gastro-intestinal tract unabsorbed⁽⁴⁶⁾. But free gossypol is highly toxic.⁽¹⁰¹⁾ It can be accumulated in the liver of rainbow trout (*Salmo gairdneri*)⁽¹⁴⁵⁾.

The free gossypol content in cotton-seed meal may range from 0.04% to 0.40%⁽¹⁶⁸⁾. Tolerance levels for cultured aquatic animals have not been established. They are for:

- Laying hens: 50 ppm⁽⁴⁹⁾
- Broilers: 200 ppm⁽⁴⁶⁾
- Pigs: 100 ppm⁽¹⁶⁸⁾

However, gossypol can be de-toxified by iron salts (most effective is ferrous sulfate [FeSO₄·7H₂O]) by blocking the toxic effects of gossypol. It can be completely eliminated by including iron on a 1:1 weight ratio of iron to free gossypol when its level is above 100 ppm⁽¹⁶⁸⁾.

Cyclopropenoids (malvalic and sterculic acids) in cotton-seed meal are also undesirable⁽⁴⁶⁾. In rainbow trout, these cause depressed growth and increase glycogen deposition in the liver. The rare fatty acids together with aflatoxin B₁ are liver carcinogens^(146, 157).

46.4.3 Feeding Value

Fishes

The use of cotton-seed meal in fish feeds is limited to certain species. Chinook salmon (*Oncorhynchus tshawytscha*) and coho salmon (*Oncorhynchus kisutch*) can tolerate diets with up to 34% and 22% dietary cotton-seed meal, respectively⁽⁵²⁾.

Up to 15% of cotton-seed meal could replace soybean meal and, if supplemented with lysine up to 30% cotton-seed meal could be used in the diets for channel catfish^(140, 141, 142, 143). The chemical composition and dressing-out percentages of the channel catfish filets (wet-tissue basis) did not significantly differ (Table 46-11)⁽¹⁴¹⁾.

Glanded cotton-seed meal depressed performance of channel catfish compared to fish given glandless meal⁽¹⁴⁴⁾ and with more than 17.4% glanded cotton-seed meal or 900 ppm free gossypol, growth was poor⁽⁴⁴⁾.

Corticated and decorticated cotton-seed meal with and without lysine supplementation (30% crude protein) were fed to Nile tilapia (*Oreochromis niloticus*) with a fish meal as control diet for 130 days. Performance of the fish meal group was superior to the cotton-seed fed group. Decorticated cotton-seed meal was superior to corticated cotton-seed meal in growth and feed conversion while PER was not significantly different⁽⁴⁵⁾.

Nile tilapia fed for 56 days a cotton-seed cake diet (32.4% protein) gained only 31% while the fish meal group (31.5% protein) attained an 81% weight gain⁽¹²⁷⁾.

Table 46-11: The replacement of soybean meal by cotton-seed meal in diets for channel catfish and the effect on carcass composition (*Ictalurus punctatus*)⁽¹⁴²⁾

Soybean meal	%	42	16.5	16.5	-	-
Cotton-seed meal	%	-	30.0	30.0	51.25	51.25
Lysine	%	-	0.32	-	0.65	-

Carcass Composition:						
Moisture	%	75.6	75.1	76.0	76.5	75.2
Protein	%	17.3	16.6	17.3	16.7	17.6
Fat	%	5.5	5.4	5.2	5.2	5.8
Ash	%	1.1	1.2	1.2	1.2	1.2
Dressing-out	%	61.1	61.3	61.5	60.3	60.1
Visceral fat	%	4.1	3.8	3.5	3.7	3.8

Crustaceans

Two levels of glandless cotton-seed meal in relation to the shrimp size were tested for three-weeks in northern white shrimp (*Penaeus setiferus*) and white leg shrimp (*Penaeus vannamei*). Growth declined with increasing level of cotton-seed meal and decreasing animal protein: vegetable protein ratio and was more pronounced in northern white shrimp than in white leg shrimps. Larger shrimps entred to tolerate cotton-seed meal better than the smaller animals (Table 46-12)⁽³²⁾.

Table 46-12: Effect of cotton-seed meal in diets for northern white shrimp (*Penaeus setiferus*) and white leg shrimp (*Penaeus vannamei*) of different sizes⁽³²⁾

		S ¹	V ²	S	V	S	V
Cotton-seed meal	%	-	-	4.5	4.5	9.0	9.0
Crude protein	%	28.0	28.0	29.5	29.5	28.3	28.3
Animal protein:plant							
Protein ratio	1:	1.5	1.5	0.9	0.9	0.6	0.6

Daily growth rate:							
Large shrimp	g	0.006	0.072	0.005	0.064	0.001	0.021
Medium shrimp	g	0.023	0.120	0.011	0.077	0.005	0.068
Small shrimp	g	0.011	0.030	0.004	0.013	0.003	0.010
Feed conversion:							
Large shrimp		-	5.6	-	4.8	-	-
Medium shrimp		6.0	2.8	6.4	2.5	20.8	4.1
Small shrimp		3.0	2.1	3.0	2.3	6.2	4.8
Survival rate:							
Large shrimp	%	80	100	70	100	70	80
Medium shrimp	%	95	86	100	100	95	79
Small shrimp	%	100	100	93	97	83	87

¹ Northern white shrimp; ² White leg shrimp

Four cotton-seed meal levels at two protein levels gave more favorable results. Survival ranged from 91 to 100% for northern white shrimp, 84 to 95% for blue shrimp (*Penaeus stylirostris*) and 98 to 100% for white leg shrimp. Up to 10% cotton-seed meal of 20% protein content did not give any negative effect on growth. It appears that the tolerable cotton-seed meal level in diets for penaeid shrimps depends not only on the dietary protein level but also on the shrimp species⁽⁵⁰⁾.

Crayfish (*Procambarus clarkii* and *Procambarus zonangulus*) can utilise whole cotton-seeds. The crayfish strip away the lint, chew open the seed coat and eat the inner cotton-seed⁽⁷⁴⁾.

46.4.4 Recommended Inclusion Rates

Only decorticated cotton-seed meal and expeller are suitable feedstuffs for aquatic animals. Glandless cotton-seed meal should be chosen whenever available. For practical conditions the following inclusion rates are recommended:

- Fishes: 5.0 to 15.0%
- Crustaceans: 5.0 to 10.0%

Lysine deficiencies, due to the lysine-binding capacity of free gossypol, can be avoided, if the amino acid is added to the feed. As a preventive measure 0.05% iron (0.25% ferrous sulphate) should be incorporated in all diets containing cotton-seed meal, to block the toxic effects of gossypol in the organism.

46.5 Ground-Nut Meal

46.5.1 Description

Ground-nut meal is the residue remaining after extraction of the oil from the ground-nut (*Arachis hypogaea*) (see Chapter 45.5). Ground-nuts are also known as peanuts, earthnuts, arachis nuts, monkey nuts, Manilla nuts, Chinese nuts, pindar and goober peas^(46, 49).

Ground-nut meal and ground-nut expeller are obtained from ground-nuts in shells (corticated ground-nuts) or without shells (decorticated ground-nuts). About 30% of the ground-nut are the shell (pod) portion while the meal is 34% and the oil is 36%⁽⁴⁰⁾. The ground-nut kernels contain 4.1% testa or skins^(40, 122).

46.5.2 Chemical, Physiological and Other Properties

Chemical Properties

Ground-nut meal may contain less than 40% crude protein, but can reach 50% or more when the nuts are decorticated (Table 46-01). Lysine, methionine, threonine and tryptophan are low, compared to soybean meal but arginine is high (Table 46-13)^(40, 93, 100). Ground-nut meal contains only 1.06% of sulphur amino acids⁽³¹⁾.

The residual oil of ground-nut meal and expeller is high in unsaturated fatty acids. The crude fibre content of corticated ground-nut meal is the highest of the vegetable oil meals (Table 46-01).

Table 46-13: Essential amino acid profile, and true amino acid availability (%) and the chemical score of ground-nut meal for channel catfish (*Ictalurus punctatus*)

	Amino acid profile (g/16g N)		True amino acid availability (%) (185)	'Scores' ⁽¹²⁰⁾
	Ground-nut meal (49, 110, 125, 163)	Ground-nut expeller (46, 125, 163)		
Arginine	5.28	5.01	97.7	164
Histidine	1.26	1.05	89.4	92
Isoleucine	1.80	1.58	93.3	43
Leucine	3.18	3.03	95.1	72
Lysine	1.29	1.46	94.1	53
Methionine	0.51	0.43	91.2	24
Phenylalanine	2.37	2.32	96.0	91
Threonine	1.40	1.27	-	51
Tryptophan	0.48	0.37	93.3	-
Valine	2.08	2.06	94.5	45

¹Scores based on comparison with amino acids of whole egg protein

Ground-nut meal contains appreciable levels of minerals, it is particularly low in sodium. There are considerable amounts of water soluble vitamins in ground-nut meal (Table 46-14).

Table 46-14: Mineral and vitamin contents of ground-nut products

Minerals ^(46, 49 110, 125)				Vitamins (per 1,000 g) ^(49, 112, 127, 168)			
		Ground-nut meal	Ground-nut expeller			Ground-nut meal	Ground-nut expeller
Calcium	%	0.29	0.14	Vitamin A	I.U.	-	300
Phosphorus	%	0.96	0.71	Vitamin E	mg	2.9	3.0
Sodium	%	0.06	0.02	Vitamin B ₁	mg	4.9	7.6
Potassium	%	1.18	1.13	Vitamin B ₂	mg	7.9	6.6
Magnesium	%	0.31	0.36	Vitamin B ₆	mg	4.7	6.6
Chlorine	%	0.03	0.03	Biotin	mg	0.32	0.39
Sulphur	%	0.31	0.28	Folic acid	mg	0.70	0.36
Manganese	mg/kg	36.2	54.0	Nicotinic acid	mg	171.5	175.0
Iron	mg/kg	366.0	278.0	Pantothenic acid	mg	36.5	49.8
Zinc	mg/kg	40.0	60.7	Choline	g	2.0	2.2
Copper	mg/kg	14.0	22.5				
Iodine	mg/kg	5.0	-				

Physiological Properties

The digestible energy is higher for ground-nut expeller, due to the higher fat content, than for meal (Table 46-15). There is a big gap between the metabolisable and digestible energy for poultry ⁽⁴⁶⁾.

Table 46-15: Energy value of ground-nut meal per kg

Species	Gross energy		Metabolisable energy		Digestible energy		Reference
	kcal	MJ	kcal	MJ	kcal	MJ	
	4,230	17.7	-	-	-	-	(110)
Fish ¹	-	-	-	-	2,155	9.0	(120)
	-	-	-	-	3,172	13.3 ²	(120)
Chicken	-	-	2,460	10.3	3,480	14.6 ²	(46, 49, 54)

¹Species not specified; ²Ground-nut expeller

The digestibility of ground-nut meal is high in the common carp (*Cyprinus carpio*) for protein and fat but insufficient for other nutrients. This is in contrast to the very low protein digestibility reported for pigs (Table 46-16).

Table 46-16: Digestibility (%) of ground-nut meal

Species	Dry matter	Crude protein	Fat	Crude fibre	Carbo-hydrates	Reference
Common carp	62.4	92.1	90.5	57.2	69.5	(64, 151)
Pigs	87.0 ¹	46.1	-	-	-	(54)

¹Organic matter

The true amino acid availability of ground-nut meal for channel catfish (*Ictalurus punctatus*) appears to be satisfactory⁽¹⁸⁵⁾. However, this could be deceiving because of the fact that in ground-nut meal most of the amino acids are deficient when compared to the amino acid profile of whole chicken egg (Table 46-13)⁽¹²⁰⁾.

Grass carp (*Ctenopharyngodon idellus*) can utilise phosphorus and magnesium of ground-nut meal effectively but calcium and iron is only scarcely absorbed⁽⁷³⁾.

Deleterious Substances

The testa or skins of ground-nuts contain 16 to 19% tannins, which are known for their toxicity. Ground-nut skins added to pig diets reduced significantly the dry matter and protein digestibility as well as feed efficiency⁽⁵⁷⁾. In addition, ground-nut skins react strongly with copper⁽¹³⁷⁾. However, the tannin content of ground-nut meal appears to be of little practical consequences in feeding of aquatic animals. This is also true for the

trypsin inhibitor, which can be found in ground-nut kernels⁽¹²²⁾ and the small amount of the toxic oxalic acid ($[\text{COOH}]_2$) (0.16% in dry matter)⁽⁴⁰⁾.

Ground-nut meal is prone to fungal growth that produces aflatoxin, a carcinogen^(46, 49, 122).

46.5.3 Feeding Value

Although ground-nut meal and ground-nut expeller are protein feedstuffs, their use in aquaculture feeds is limited.

Fishes

The feeding value of ground-nut by-products has been poorly investigated in fish. Ground-nut meal has been used at different levels together with other protein sources in diets e.g. for the Indian major carp (*Catla catla*)^(116, 117, 118), tilapia (*Tilapia discolor*)⁽¹²⁶⁾, and mudfish (*Claris anguillaris*)^(103, 104). From the result of these experiments the feeding value of ground-nut meal cannot be interpreted due to lack of comparable parameters.

In diets for tilapia (*Sarotherodon mossambicus*) ground-nut meal can replace 25% of the fish meal⁽⁷⁷⁾.

Ground-nut meal is extensively used in diets for carp⁽¹²³⁾. In Thailand it is used in diets for carp and catfish at levels of around 25%⁽¹⁷²⁾. The inclusion rates of ground-nut meal and expeller in experimental and practical diets for aquatic animals are in the range of 5.0 to 61.0%^(3, 33, 78, 82, 103, 104, 121, 126, 165, 179).

The residual oil of ground-nut meal and particularly ground-nut cake may cause soft fish carcass because of the high level of unsaturated fatty acids as observed in pork.

Crustaceans

Substitution of menhaden fish meal by 30% of ground-nut meal in diets for red swamp crayfish decreased the consumption of feed and fish meal and shrimps were poorly digested⁽²⁸⁾.

Ground-nut meal, providing 30% of the diet's crude protein fed to juvenile red swamp crayfish (*Procambarus clarkii*) is an inferior protein source for the crustacea compared to the diet containing soybean meal and shrimp meal. (Table 46-17)⁽⁹⁶⁾.

Table 46-17: The effect of ground-nut meal in diets for red swamp crayfish (*Procambarus clarkii*) (Trial period: 6 weeks)⁽⁹⁶⁾

Ground-nut meal	%	-	25.0
Soybean meal	%	35.0	15.0
Crude protein	%	28.9	29.7
Crude fat	%	10.3	10.4

Weight gain	%	1,493	630
Survival rate	%	86	86

46.5.4 Recommended Inclusion Rates

Ground-nut meal is a protein feedstuff for aquaculture feed in countries where it is easily available. Only decorticated ground-nut meal, free of any aflatoxin contamination, should be used in diets for aquatic animals.

The following inclusion rates are recommended:

- Herbivorous/omnivorous fish: 10.0 to 15.0%
- Carnivorous fish: 5.0 to 10.0%
- Crustaceans: 5.0 to 8.0%

When feeding ground-nut meal, supplementation with essential amino acids (methionine, lysine and threonine) has to be considered; otherwise protein synthesis might be limited.

46.6 Linseed Meal

46.6.1 Description

Linseed meal is the by-product of the extraction of linseed oil from flax (*Linum usitatissimum*) seed (see Chapter 45.6). Linseed production is associated with linseed chaff amounting to about 200 kg per 100 kg linseed. Approximately 70% meal and 30% oil are obtained from linseed⁽⁴⁰⁾.

Most linseed meal is used in ruminant and horse feeding. Only very little is used in diets for other monogastric animals. The insignificance of linseed meal for aquaculture diets is demonstrated by the fact that the feedstuff is not included in the feedstuff composition tables in the "Nutrient Requirements of Fish"⁽¹²⁴⁾.

46.6.2 Chemical, Physiological and Other Properties

Chemical Properties

The crude protein content of this protein feedstuff averaging 36% is intermediate in comparison to other vegetable oil meals (Table 46-01). The protein quality of linseed meal is low due to the low lysine content⁽³¹⁾ which amounts to only 55% of that of soybean meal⁽²⁶⁾ (Table 46-18). Linseed has a total of 1.41% sulphur amino acids⁽³¹⁾.

The residual oil of linseed meal and expeller is highly unsaturated and has a low melting point (18°C). The difference in the residual oil content between linseed meal and expeller is about 3.0 to 4.0% (Table 46-01).

The crude fibre content is relatively high but not as high as in some other vegetable meals. The phosphorus content is about double the calcium level (Table 46-19). Selenium is particularly high with a wide variation from 0.65% to 1.51%⁽¹⁷⁾. The selenium level depends on the geographic location, soil composition and other factors but linseed meal contains a protective factor against selenium-toxicity as found in chickens⁽⁷⁹⁾, pigs⁽¹⁸¹⁾, and rats⁽⁵⁸⁾. The vitamin levels of linseed meal and expeller are similar to those of other vegetable oil meals (Table 46-19).

Table 46-18: Essential amino acid profile and apparent and true amino acid digestibility (%) of linseed meal for carp

	Amino acid profile (g/16g N) ^(26, 31, 46, 120, 163)		Apparent digestibility (71)	True digestibility (71)
	Linseed meal	Linseed expeller		
Arginine	3.06	3.10	84.5	90.2
Histidine	0.75	0.74	87.1	-
Isoleucine	1.68	1.65	85.6	87.6
Leucine	2.19	2.04	85.8	88.4
Lysine	1.22	1.20	83.7	87.8
Methionine	0.57	0.63	85.0	95.1
Phenylalanine	1.60	1.55	85.5	87.4
Threonine	1.30	1.26	85.5	88.3
Valine	1.79	1.73	85.9	89.6

Table 46-19: Mineral and vitamin contents of linseed meal and linseed expeller

Minerals ^(26, 31, 46, 49 54, 110, 120, 163)				Vitamins (per 1,000 g) ^(26, 46, 110)			
		Linseed meal	Linseed expeller			Linseed meal	Linseed expeller
Calcium	%	0.38	0.38	Vitamin A	I.U.	300	100
Phosphorus	%	0.85	0.81	Vitamin E	mg	7.7	6.3
Sodium	%	0.10	0.11	Vitamin B ₁	mg	3.8	6.9
Potassium	%	1.00	1.09	Vitamin B ₂	mg	3.8	3.0
Magnesium	%	0.55	0.53	Vitamin B ₆	mg	7.8	7.5
Sulphur	%	0.39	0.43	Biotin	mg	0.4	-
Chlorine	%	0.04	0.04	Folic acid	mg	38.6	35.4
Manganese	mg/kg	38.6	41.0	Nicotinic acid	mg	3.0	2.1
Iron	mg/kg	185.0	246.7	Pantothenic acid	mg	11.0	15.8
Zinc	mg/kg	60.5	55.8	Choline	g	2.2	1.6
Copper	mg/kg	24.4	22.3				
Selenium	mg/kg	0.78	0.91				
Iodine	mg/kg	-	0.95				

Physiological Properties

The differences between the digestible energy of linseed meal and linseed expeller are minimal and the digestible energy values for fish and land animals are within the same

range. Surprisingly, the metabolisable energy in salmonids is much higher than reported for chicken (Table 46-20)^(25, 46, 54).

Carp digests protein of linseed meal better than salmonids but there are no differences in the energy digestibility (Table 46-21). The mean true digestibility of the amino acids is 4.1% better than the apparent digestibility (Table 46-18).

Monogastric animals can hardly digest the carbohydrates of linseed meal due to its content of 3.0 to 10.0% of mucilage, a thick, sticky water-dispersible carbohydrate. This substance absorbs large amounts of water and may cover the gut wall that delays and prevents, the absorption of nutrients^(40, 169).

Table 46-20: Energy values of linseed meal per kg^(31, 46, 112, 54, 123, 125)

Species	Gross energy		Metabolisable energy		Digestible energy		Reference
	kcal	MJ	kcal	MJ	kcal	MJ	
	4,111	17.2	-	-	-	-	(110)
Fish ¹	-	-	-	-	2,971	12.4	(120)
	-	-	-	-	2,983	12.5 ²	(120)
Rainbow trout	-	-	3,128	13.1	3,268	13.7	(123)
Chicken	-	-	1,685	7.1	3,220	13.5	(46, 54)
	-	-	1,520	6.4	3,390	14.2 ²	(46)
Rabbits	-	-	-	-	3,370	14.1	(31)

¹Unspecified species; ²Linseed expeller

Table 46-21: Digestibility (%) of linseed meal

Species	Dry matter	Crude protein	Fat	Crude fibre	Carbo-hydrates	Energy	Reference
Salmonids	-	76.8	-	-	-	71.1	(64)
Common carp	-	85.8 ¹	-	-	-	72.1	(71)
	-	89.9 ²	-	-	-	-	(71)
Pigs	-	-	-	-	84.0	-	(54)
	-	-	-	-	78.0 ³	-	(54)

¹Apparent digestibility; ²True digestibility; ³Linseed expeller

Deleterious Constituents

Immature linseed contains lina-marin, a cyanogenic glucoside which in the presence of linase, produces hydrogen cyanide (prussic acid) on hydrolysis. Prussic acid is very toxic. Unprocessed whole seeds and linseed meal processed under low temperature can be toxic to animals especially if moistened before being fed^(56, 62, 109). However, normal processing involving high temperature treatment and the use of solvents such as trichlorethylene or carbon tetrachloride destroys linase and most of the linamarin so that the meal is no longer toxic^(26, 46, 120).

An estrogenic factor, anti-vitamin B₁ (thiamine) factor, and Vitamin B₆ (pyridoxine) antagonist have been identified in linseed expeller. The antagonist is a dipeptide called linatine^(26, 120, 163).

46.6.3 Feeding Value

The nutritional value of linseed expeller was evaluated at two levels of partial substitution for fish meal in the diet of the common carp (*Cyprinus carpio*)⁽⁷²⁾. Although the lower inclusion level of linseed cake performed better than the higher inclusion rate. Both linseed groups were inferior to the fish meal group (Table 46-22). Since the linseed cake diets contained hydrocyanic and phytic acids, the growth depression of carp fed these diets may not only be due to the deficiency in lysine, methionine and threonine but also due to the presence of these anti-nutritional factors.

Table 46-22: Growth and feed utilisation of linseed meal by common carp (*Cyprinus carpio*) fry (Trial period: 8 weeks)⁽⁷²⁾

Linseed meal	%	-	29.8	59.3
Fish meal	%	52.5	39.3	16.3
Crude protein	%	40.6	40.3	39.8
Hydrocyanic acid	mg/g	-	0.13	0.26
Phytic acid	%	-	0.28	1.56

Weight gain	mg	6.94	5.13	3.00
Weight gain	%	643	466	278
SGR	%/day	3.58	3.09	2.37
Mortality	%	-	-	-
Feed conversion ratio	1:	2.09	2.39	3.16
PER		1.17	1.04	0.79

Linseed cake, 40% of the 35% total protein, partially substituted fish meal in diets for catfish (*Clarias batrachus*) fry. After seven weeks the fish showed hardly any differences on the recorded parameters (Figure 46-01)⁽⁶¹⁾.

In the diet of Indian major carp (*Labeo rohita*) linseed cake substituted 20 or 40% of the fish meal protein. No significant differences were observed with increasing levels of the linseed expeller in the diet although growth was best in the fish meal group. There were some abnormalities in the liver tissue of fish fed linseed expeller⁽⁶²⁾.

Residual, unsaturated oil of linseed meal and expeller in diets for pigs could produce soft pork^(26, 46). Similar experiences from cultured aquatic animals are not available.

46.6.4 Recommended Inclusion Rates

Only linseed meal processed under high temperature should be used for aquaculture feeds. Thus, this statement excludes the use of linseed expeller.

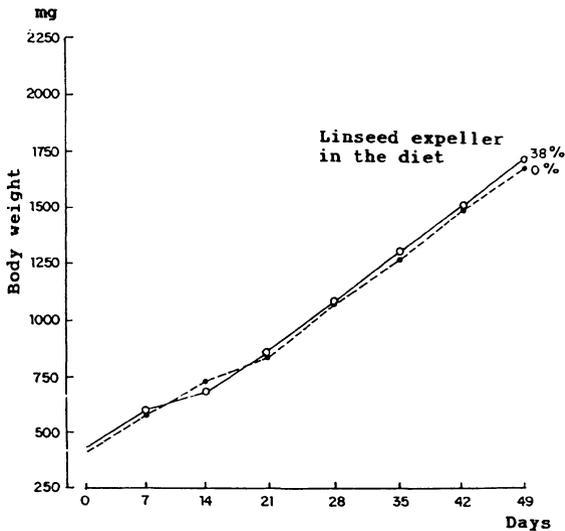


Figure 46-01. Growth responses of catfish (*Clarias batrachus*) fry to a combination of linseed expeller (38%) and fish meal (26%) compared with fish meal only⁽⁶¹⁾.

Although, under experimental condition levels between 30% and 40% have been successfully used, for practical conditions the levels should be much lower. Using the pattern from recommendations for monogastric land animals^(26, 46, 49), linseed meal should be used in diets for aquatic animals at the following rates:

- Herbivorous/omnivorous species: 3.0 to 7.0%
- Carnivorous species: 2.0 to 5.0%

Fortification with lysine has to be considered.

46.7 MUSTARD MEAL

46.7.1 Description

Mustard is an oil-seed crop that grows well in temperate and high altitude, sub-tropical areas. Seeds are used for making table mustard as well as for its oil which is used in the food industry but particularly for industrial applications. Mustard belongs to the family *Brassicaceae* and is closely related to rape-seed. Most important mustard species cultivated are^(24, 169):

- Black mustard - (*Brassica nigra*)
(synonym: French, red or brown)
- Indian mustard - (*Brassica juncea*, var. *integrifolia*)
(synonym: Russian or oriental)
- Abyssinia mustard - (*Brassica carinata*)
- Yellow mustard - (*Brassica hirta*)
- Sarepta mustard - (*Brassica juncea juncea*)

Mustard meal for human consumption is made from unde-oiled or de-oiled seeds. De-oiled mustard meal is more spicy⁽¹⁷⁵⁾. The non-oil portion of mustard seed is about 65 to 70%.

46.7.2 Chemical, Physiological and Other Properties

Chemical Properties

The chemical composition of mustard meal and mustard cake is similar to that of rape-seed meal and rape-seed expeller. The protein content of mustard meal is around 40% but that of mustard expeller is just above 30% (Table 46-01). The amino acid profile indicates that methionine is the limiting amino acid (Table 46-23).

Phosphorus content of mustard meal is double that of the calcium content: 0.50 and 0.85 for calcium and 1.00 and 1.62 for phosphorus^(62, 72).

Physiological Properties

Mustard expeller has a gross energy content of 4,978 kcal/kg (20.8 MJ/kg)⁽¹⁸⁸⁾. The digestible energy amounts to 3,395 kcal/kg (14.2 MJ/kg) in pigs⁽²⁴⁾.

Both apparent and true amino acid digestibility of mustard cake for the common carp (*Cyprinus carpio*) is relatively high (Table 46-23)⁽⁷¹⁾.

Table 46-23: Essential amino acid profile of mustard meal and apparent and true amino acid digestibilities of mustard expeller for common carp (*Cyprinus carpio*)

	Amino acid profile (g/16g N) ^(24, 71, 163)	Apparent digestibility ⁽⁷²⁾ %	True digestibility ⁽⁷²⁾ %
Protein		85.3	89.3
Arginine	2.44	84.6	90.1
Histidine	1.14	86.6	-
Isoleucine	1.78	86.1	89.0
Leucine	2.62	85.9	88.2
Lysine	2.16	84.8	87.7
Methionine	0.77	84.9	96.4
Cystine	-	85.6	88.0
Phenylalanine	1.64	86.0	88.4
Tyrosine	-	85.5	88.3
Threonine	1.38	85.9	88.9
Tryptophan	0.50	85.9	89.8
Valine	1.66	89.9	89.8

Deleterious Substances

The pungent aroma and hot taste of table mustard is the characteristic of all *Brassica* species. Both are caused by glucosinolates. After the cells are destroyed by treatment of

the seeds, the glucosinolate is converted into isothiocyanate and together with sinigrine allylisothiocyanate and sinalbine, p-hydroxybenzylisothiocyanate are formed^(24, 169).

More than 50 different glucosinolates are known (Table 46-24)⁽¹⁶⁹⁾. They are potentially toxic to man and animals because they can affect production of thyroxine by the thyroid gland. Eliminating the glucosinolates from meal by chemical treatment is not economical. In humans, a high intake of vegetables from the genus *Brassicaceae* with an inadequate intake of iodine could precipitate goiter⁽¹¹¹⁾. In fish, glucosinolates induce histological changes in the liver, depressed growth, feed utilisation and thyroid hypertrophy⁽⁶⁷⁾.

Table 46-24: Glucosinolate content of mustard products ^(24, 71, 169)

Mustard product	Glucosinolate	Content
Mustard meal ¹	Allylisothiocyanate	90 micromole/g
Brown mustard meal	Allylisothiocyanate	100 micromole/g
Indian mustard meal	Allyl-glucosinolate	25 micromole/g
Indian mustard meal	Butenyl-glucosinolate	95 micromole/g
Yellow mustard meal	p-Hydroxybenzyl-glucosinolate	300 micromole/g
Mustard cake	Allylisothiocyanate	0.54 %
Mustard cake ²	Glucosinolate	1.6 mg/g
Mustard cake ³	Glucosinolate	3.3 mg/g

¹Oil free; ²25% mustard cake in the diet; ³50% mustard cake in the diet

After feeding diets containing 25 and 50% mustard expeller to common carp (*Cyprinus carpio*), thyroid follicles had variable shapes and was especially pronounced in fish fed the diet with 50% mustard expeller compared to fish meal-fed fish⁽⁷²⁾. The diet contained 1.6 and 3.3 mg/g glucosinolates, respectively, which is much higher than the 0.3 mg/g glucosinolate suggested for chinook salmon (*Oncorhynchus tshawytscha*)⁽⁶⁸⁾. Abnormalities in the liver, congestion and cytoplasmolysis were found in the Indian major carp (*Labeo rohita*) fry after feeding 20 and 30% mustard cake⁽⁶²⁾.

In addition, mustard meal and mustard expeller contain up to 1.8% tannins⁽⁷²⁾. Protease inhibitor and thiaminase (anti-Vitamin B₁ factor) are also present in these feedstuffs⁽¹⁶³⁾. They may also be contaminated with aflatoxin.

46.7.3 Feeding Value

Fishes

Mustard expeller was tested at two levels and compared to a diet with fish meal as the sole source of protein in common carp fry reared in a recirculatory system⁽⁷²⁾. Weight gain decreased with increase in mustard expeller caused by the high content of glucosinolates from the mustard expeller (Table 46-25).

Mustard cake is an inferior protein source compared to fish meal as sole source of protein when used at 20 and 40% levels, respectively in 40% protein diets for Indian major carp fry⁽⁶²⁾.

Table 46-25: Response of common carp (*Cyprinus carpio*) fry fed mustard expeller (Trial period: 8 weeks)⁽⁷²⁾

Mustard cake	%	100	75	50
Fish meal	%	0	25	50
Crude protein	%	40.6	40.0	40.3
Fat	%	9.5	9.6	10.3
Crude fibre	%	8.2	7.8	7.7

Weight gain	%	643	454	286
SGR	%/day	3.6	3.1	2.4
Mortality	%	-	-	-
Feed conversion	1:	2.1	2.5	3.1
ANPU ¹	%	17.8	15.1	11.4

¹Apparent net protein utilisation

Crustacean

Pond trials with giant freshwater prawn (*Macrobrachium rosenbergii*) were conducted using mustard expeller and rice bran (1:1) as supplementary food. Survival rates ranged from 32 to 58% with yields of 172 to 215 kg/ha⁽⁵⁹⁾. A subsequent trial using 30% mustard expeller, 30% fish meal, 20% rice bran and 20% wheat bran plus fertilisation gave a survival of 47 to 58% after six months feeding. Yields ranged from 370, 542 and 790 kg/ha for ponds stocked at 10,000, 15,000 and 20,000/ha, respectively, indicating the usefulness of mustard expeller for semi-intensive culture of the herbivorous freshwater prawn.

Tubificid Worms

Tubifex is a genus of small, freshwater oligochaete worms found predominantly in polluted water. It is not only an ornamental fish feed but also a natural larval food for cultured freshwater species such as rainbow trout (*Salmo gairdneri*), white sturgeon (*Acipenser transmontanus*), catfish (*Clarias batrachus*) and African catfish (*Clarias gariepinus*). Tubificid worms can be produced in 60 days in a culvert system under running water in a medium containing 20% mustard expeller, 35% wheat bran, 25% cow manure and 20% fine sand⁽⁵⁾.

46.7.4 Recommended Inclusion Rate

Mustard meal and mustard expeller, are not very suitable as protein sources. Inclusion rates of 5.0 to 10.0%, should not be exceeded.

The use of mustard meal requires checking of the amino acid content. Supplementation of the diet with iodine may be considered if higher levels of mustard meal are used.

46.8 OLIVE BY-PRODUCTS

46.8.1 Description

The refuses from removal of the oil from olives (*Olea europea*) are of different nature, depending on the extraction process (see Chapter 45.9).

Olive cake is the residue of pressing and centrifugation of olives⁽⁴¹⁾. From 100 kg olives about 40 kg of olive cake bagasse is obtained (Figure 46-02). Usually, the cake is then solvent extracted and about 25 kg olive meal from 100 kg olives is gained⁽⁴⁰⁾. The olive pulp from the stone removed prior to oil extraction is around 12 kg. The stone portion is about 14 to 16% of the olives⁽¹⁶⁹⁾.

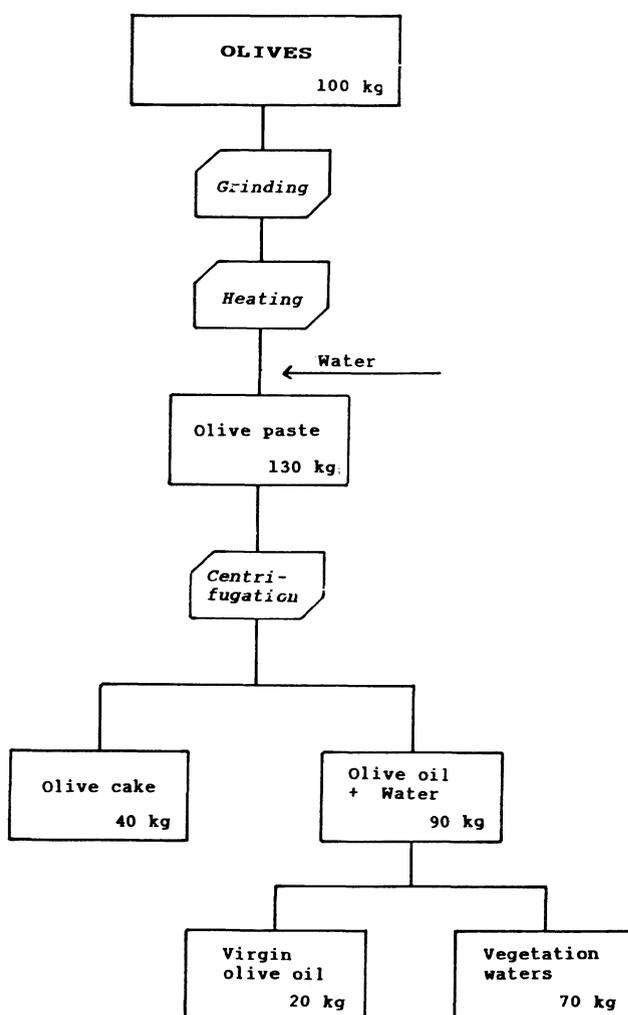


Figure 46-02. Diagram of olive oil processing^(Data from: 40).

45.8.2 Chemical and Physiological Properties

By-products of olive processing are very low in crude protein, but high in crude fibre. In unprocessed olives the crude protein content is only 13.6% (Table 46-01). Olive meal contains about 55% stones and 26% pulp. This product has a crude fibre content of more than 30%.

The metabolisable and digestible energy of olive pulp is very low as established in rabbits (Table 46-26)⁽¹⁰⁶⁾. The total digestible nutrients (TDN) are about 40%.

Table 46-26: Energy values of olive pulp per kg with rabbits

	Gross energy		Metabolisable energy		Digestible energy		Reference
	kcal	MJ	kcal	MJ	kcal	MJ	
Olives	2,460	10.4	-	-	-	-	(169)
Olive meal	-	-	450	1.9	-	-	(106)
Olive meal	-	-	-	-	400	1.8	(31)
Olive pulp	-	-	-	-	800	3.3	(31)

46.8.3 Feeding Value

The availability of olive by-products only in the Mediterranean and the unfavourable nutrient content have limited the use of olive by-products in feeding trials for aquatic animals.

In rainbow trout (*Salmo gairdneri*), olive cake has been fed at a level of 11%. No differences in weight gain, fish size, chemical composition of the carcass and the palatability of the feed were observed between the trial and the control group⁽¹⁵⁰⁾.

The use of 11% olive cake (bagasse) in a commercial diet did not influence the apolar lipids and fatty acid composition of rainbow trout muscle⁽⁴¹⁾.

46.8.4 Recommended Inclusion Rates

The high crude fibre content of olive by-products is the limiting factor for their use in aquaculture diets. Products, which contain stones, have to be considered as unsuitable for aquaculture feed formulations. In practice, the inclusion rate of olive pulp should not exceed 10%.

46.9 Palm-Kernel Meal

46.9.1 Description

Palm-kernel is a by-product of processing the fruit bunches of the African oil palm (*Elaeis guineensis*) (see Chapter 45.9). From 100 kg crude palm-kernels only about 18.4 kg

palm-kernel meal are obtained (Figure 46-03)^(40, 65). Palm-kernel meal is both a protein as well as an energy source.

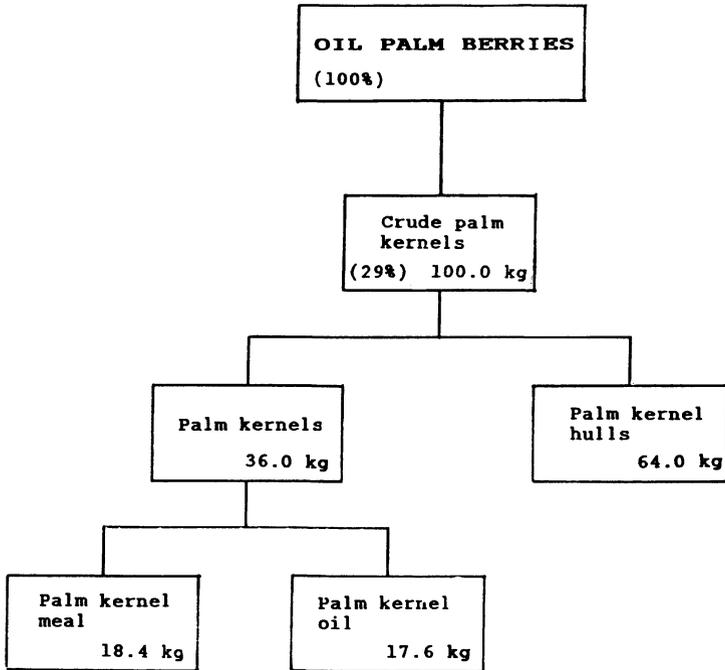


Figure 46-03. Products obtained from the processing of crude palm-kernels^(Data from: 40).

46.9.2 Chemical, Physiological and Other Properties

Chemical Properties

The crude protein content of palm-kernel meal is about 15.0 to 18.0% with hardly any differences between palm-kernel meal and palm-kernel expeller (Table 46-01). However, the palm-kernel meal of Nigerian origin has a higher crude protein content (20 to 25%)⁽¹³¹⁾. Palm-kernel meal is deficient in lysine and methionine (Table 46-27).

The crude fibre content of palm-kernel meal and cake is very high (Table 46-01). The Ca:P-ratio is 1:2.4 (Table 46-28) and palm-kernel is a good source of manganese.

Physiological Properties

The metabolisable and digestible energy value differ substantially for meal and expeller caused by the higher fat content of the latter (Table 46-29). Digestibility data for aquatic animals are unknown. Pigs digest palm-kernel meal better than poultry (Table 46-30)^(18, 54, 187).

Table 46-27: Essential amino acid profile of palm-kernel meal and palm-kernel expeller (g/16g N)^(163, 187)

	Palm-kernel meal	Palm-kernel expeller
Arginine	2.36	2.18
Histidine	0.32	0.29
Isoleucine	0.64	0.62
Leucine	1.19	2.22
Lysine	0.54	0.59
Methionine	0.33	0.30
Phenylalanine	0.79	0.73
Threonine	0.61	0.55
Tryptophan	0.20	0.17
Valine	0.82	0.93

Table 46-28: Macro and trace mineral contents of palm-kernel meal and palm-kernel expeller^(42, 120, 131)

		Palm-kernel meal	Palm-kernel expeller
Calcium	%	0.32	0.26
Phosphorus	%	0.73	0.63
Magnesium	%	0.16	0.27
Manganese	mg/kg	-	225.0
Iron	mg/kg	-	4.1
Zinc	mg/kg	-	77.0
Copper	mg/kg	-	28.5

Table 46-29: Energy values of palm-kernel meal and palm-kernel expeller per kg

	Gross energy		Metabolisable energy		Digestible energy		Reference
	kcal	MJ	kcal	MJ	kcal	MJ	
	4,135	17.3	-	-	-	-	(42)
Fish ¹	-	-	-	-	3,177	13.3 ²	(120)
	-	-	-	-	2,664	11.1	(120)
Chicken	-	-	1,760	7.4 ²	-	-	(187)
	-	-	1,470	6.2	-	-	(187)

¹Species not specified; ²Palm-kernel expeller

Table 46-30: Digestibility (%) of palm-kernel meal and palm-kernel expeller^(18, 54, 130, 194)

Species	Dry matter	Crude protein	Fat	Crude fibre	Organic matter	Energy	Reference
Chicken ¹	53.0	59.8	-	24.4	-	78.9	(128, 187)
Pigs	-	76.1	71.8	70.4	71.0	-	(18)
	-	-	-	-	74.0 ²	-	(54)

¹40% palm-kernel meal in the diet; ²Palm-kernel expeller

Other Properties

The press capacity for palm-kernel expeller is better than for palm-kernel meal due to the higher fat content of the former. The pellet quality as well as the abrasiveness is medium⁽⁵⁵⁾.

46.9.3 Feeding Value

The suitability of palm-kernel meal for monogastric animals has been comprehensively tested^(15, 18, 75, 187). Similar results from experiments in aquatic animals are lacking, except for a trial in Nile tilapia (*Oreochromis niloticus*)⁽¹³¹⁾.

With increasing levels of palm-kernel meal in the diet, the performances of fish declined due to the increasing crude fibre content. Best results were obtained with 15% palm-kernel meal which was even better than the control group, although not comparable due to lack of isonitrogenicity (Table 46-31).

Table 46-31: Growth and feed utilisation of Nile tilapia (*Oreochromis niloticus*) fed diets with palm-kernel meal (Trial period: 12 weeks)⁽¹³¹⁾

Palm-kernel meal	%	15.0	20.0	25.0	30.0	0
Fish meal	%	25.0	20.0	15.0	10.0	40
Crude protein	%	28.0	28.0	28.0	28.0	57.9
Crude fibre	%	13.5	15.8	15.8	19.0	4.3

Weight gain	%	130.31	107.34	108.53	100.38	121.13
Specific growth rate	%/day	0.74	0.52	0.43	0.39	0.67
Feed conversion ratio	1:	0.86	1.23	1.49	1.65	0.97
PER		0.58	0.38	0.34	0.31	0.34

46.9.4 Recommended Inclusion Rates

Palm-kernel meal as well as palm-kernel expeller are of low feeding value for aquaculture diets due to their high crude fibre content and the rather low crude protein level.

They are more suitable for extensive farming systems and where the feedstuff is abundantly available. It is more suitable for herbivorous/ omnivorous species than for carnivorous animals, and should not be used in diets for young aquatic animals. Recommended inclusion rates are:

- Herbivorous/omnivorous fish: - 5.0 to 10.0%
- Carnivorous fish: - 3.0 to 8.0%

The supplementation of diets with lysine and methionine has to be considered.

46.10 Rape-Seed Meal

46.10.1 Description

Rape-seed meal also known as rape, colza and raps is a by-product of oil production from rape-seed (*Brassica* spp.). It is a protein feedstuff. The non-oil containing portion of rape-seed is about 65% of which 44% is meal and 16% is hulls⁽⁴⁰⁾ (see Chapter 45.10).

In the past, the nutritional value of rape-seed meal and expeller was limited because of the high content of deleterious substances like erucic acid and glucosinolates. Two types mainly cultivated are: Argentine rape-seed (*Brassica napus*) and Polish rape-seed (*Brassica campestris*). The Argentine cultivars mature later but are higher yielding than the Polish varieties⁽¹⁷⁰⁾.

Rape-seed cultivars low in deleterious substances are called “Canola meal” or named “O rape-seed meal” or “OO rape-seed meal”. The latter means that the cultivar is “double low”, not in erucic acid but also in glucosinolates^(40, 95).

Rape-seed expeller may be available only in countries which do not have facilities for solvent extraction of the oil.

46.10.2 Chemical, Physiological and Other Properties

Chemical Properties

The crude protein content of rape-seed meal varies between 35 and 39%, depending on the cultivar and the location from which the meal is produced (Table 46-01). Limiting amino acids are lysine and the sulphur containing ones (Table 46-32). The processing method can greatly affect the availability of amino acids. The least destructive process is the “pre-press solvent extraction” which uses low temperatures⁽⁴⁶⁾.

The fat content of rape-seed expeller is in the range of 4.0 to 8.0% while the fat level of the meal should be less than 2.0%. Higher fat levels are possible, if the gums from oil refining are added to the solvent-extracted meal⁽¹⁷⁰⁾.

A limitation in the use of rape-seed meal is its high crude fibre content, caused by the high proportion of hulls in relation to the size of the seeds (Table 46-01). Genetical selection aims for seeds with a lower crude fibre portion (triple zero cultivars)⁽⁴⁰⁾.

Rape-seed meal is a rich source of minerals, particularly phosphorus and potassium but due to its high phytic acid and crude fibre content, the availability of phosphorus is reduced^(40, 170). Remarkable levels of Vitamin B₁, Vitamin B₆, nicotinic acid and pantothenic acid are found in the meal and expeller (Table 46-33)⁽⁹¹⁾.

Table 46-32: Essential amino acid profile of rape-seed products and true amino acid availability (%) of canola meal for Atlantic salmon (*Salmo salar*)

	Amino acid profile (g/16g N) ^(125, 163)			True amino acid availability ⁽¹³⁾
	Rape-seed meal	Rape-seed expeller	Canola meal	Canola meal
Arginine	2.11	1.93	3.32	96.7
Histidine	1.00	0.90	1.07	95.0
Isoleucine	1.41	1.38	1.51	87.3
Leucine	2.55	2.40	2.65	85.0
Lysine	2.12	1.68	2/27	92.0
Methionine	0.70	0.68	0.70	99.9
Phenylalanine	1.43	1.39	1.52	89.2
Threonine	1.61	1.51	1.71	93.2
Tryptophan	0.44	0.42	0.44	-
Valine	1.83	1.76	1.94	83.8

Table 46-33: Mineral and vitamin contents of rape-seed meal and rape-seed expeller (as fed)

	Minerals ⁽⁹³⁾		Vitamins (per 1,000 g) ^(91, 170)				
		Rape-seed expeller	Rape-seed meal			Rape-seed meal	Rape-seed expeller
Calcium	%	0.57	0.62	Vitamin E	mg	1.7	-
Phosphorus	%	0.90	1.07	Vitamin B ₁	mg	6.0	5.2
Potassium	%	1.18	1.36	Vitamin B ₂	mg	3.3	3.7
Magnesium	%	0.46	0.50	Vitamin B ₆	mg	11.2	-
Sulphur	%	-	1.47	Biotin	mg	-	0.7
Manganese	mg/kg	51.5	67.1	Folic acid	mg	-	2.3
Iron	mg/kg	576	373	Nicotinic acid	mg	171.6	159.5
Zinc	mg/kg	54.2	66.2	Pantothenic acid	mg	10.3	9.5
Copper	mg/kg	7.6	6.0	Choline	g	7.5	9.0
Lead	mg/kg	-	2.0				
Cobalt	mg/kg	0.27	0.18				
Selenium	mg/kg	-	0.90				
Molybdenum	mg/kg	1.1	0.54				
Cadmium	mg/kg	-	0.14				

Physiological Properties

The digestible energy of rape-seed meal is rather low due to the high crude fibre content (Table 46-34). The indigestible lignin is 11.3% of the rape-seed meal⁽⁹¹⁾. This also explains why the digestibility is generally low (Table 46-35). The true amino acid digestibility of canola meal for Atlantic salmon (*Salmo salar*) ranges between 83.8 and 99% (Table 46-32)⁽¹³⁾. Lower amino acid digestibilities for rainbow trout have been reported^(64, 123).

Table 46-34: Energy values of rape-seed meal per kg

Species	Gross energy		Metabolisable energy		Digestible energy		References
	kcal	MJ	kcal	MJ	kcal	MJ	
	4,598	19.2	-	-	-	-	(160)
Chinook salmon	-	-	-	-	2,725	11.4	(13)
Rainbow trout	-	-	2,715	11.4	2,685	11.2	(13, 160)
Chicken ¹	-	-	2,250	9.4	3,050	12.8	(46)
Pigs	-	-	-	-	2,900	12.1	(170)

¹Rape-seed expeller

Table 46-35: Digestibility (%) of rape-seed meal

Species	Crude protein	Fat	Organic matter	Energy	References
Rainbow trout	76.9	61.4	-	-	(13)
	-	-	-	43.6	(64)
Chicken	-	-	66.0	-	(54)
Pigs	-	-	72.0	-	(170)

Deleterious Substances

Erucic acid (C22:1n-9 [*cis*-13-Docosenoic acid]) is characteristic of all crucifers and may cause disorders and damages of the myocardium. Rape-seed oil may contain as much as 40% erucic acid. It appears that erucic acid is not dangerous for rainbow trouts, because no differences in growth between feeding of rape-seed oil, high and low in erucic acid, were observed⁽⁶⁰⁾.

In the old cultivars between seven and 70 different glucosinolates were identified^(46, 68) and were a major limiting factor. Only three of these (progoitrin, gluconapin, gluco-brassicinapin) are of physiological importance⁽⁹¹⁾. The glucosinolates *per se* are themselves

quite harmless to animals. But the rape-seed contains an enzyme, myrosinase, which breaks the glucosinolates into a variety of toxic compounds. They are dangerous because they impair thyroid functions (goitre) and cause other undesired symptoms^(46, 170).

Rape-seed meal from new cultivars must contain less than^(67, 91, 170):

- 2.0 % Erucic acid,
- 30.0 micromol/g Glucosinolates.

Tannins (3.0%) and sinapine (1.5%) also negatively affect the feeding value of rape-seed meal. Tannin lowers the protein and energy digestibility and sinapine reduces the palatability of the ration as found in pigs⁽¹⁷⁰⁾.

46.10.3 Feeding Value

Dietary levels of 20% canola meal have been used for rearing coho salmon successfully⁽⁶⁷⁾. Chinook salmon performance was not impaired by the inclusion of 13 to 16% of dietary protein (16 to 20% of dietary dry matter) as canola meal⁽⁶⁸⁾. A negative performance of chinook salmon (*Oncorhynchus tshawytscha*) is not expected at dietary levels of canola meal between 30 and 32% of dry matter (25% of dietary protein) as long as total glucosinolate content of the diet on a dry matter basis is less than 300 mmoles/g.

The addition of 3,5,3-triiodothyronine (T_3) to diets containing high levels of canola meal in the diets for Pacific salmon (*Oncorhynchus* spp.) and rainbow trout (*Salmo gairdneri*) could destroy the anti-thyroid effect of glucosinolates^(69, 88).

A maximum amount of around 30% canola meal has been found feasible for channel catfish after seven weeks of feeding it at levels of 0 to 42%. The fish fed the control diet (0% canola meal) had the least weight gain, and lowest feed efficiency⁽¹⁰⁸⁾.

Tilapia hybrids (*Oreochromis mossambicus* x *Oreochromis aureus*) were fed diets containing increasing levels of dietary protein from canola meal by replacing soybean meal protein⁽⁷⁰⁾. Complete replacement of soybean meal protein by protein from canola meal did not significantly depress performances (Table 46-36).

Table 46-36: Effect of feeding canola meal to hybrid tilapia (*Oreochromis mossambicus* x *Oreochromis aureus*)⁽⁷⁰⁾

Canola meal	%	0	10.6	21.1	31.6
Soybean meal	%	23.0	15.3	7.7	0

Daily weight gain	g	4.41	4.06	3.66	3.82
Daily feed intake	g	4.90	4.76	4.61	4.82
Feed efficiency	%	0.90	0.85	0.80	0.79
SGR	%/day	4.48	4.44	4.38	4.38
Mortality	%	2.0	0	4.0	0

Good growth of the tilapia (*Sarotherodon mossambicus*) was reported even when 50% fish meal was substituted by low glucosinolate rape-seed meal. Higher levels of substitution gave depressed growth⁽⁷⁷⁾.

46.10.4 Recommended Inclusion Rates

Although under experimental conditions in fish, levels of 63% OO-rape-seed meal were used⁽¹⁶⁴⁾, for practical conditions it is recommended to restrict the inclusion to the following levels:

- Meals from old type rape-seed (high erucic and glucosinolate content): 2.0 to 5.0%
- OO-rape-seed meals (low erucic and glucosinolate content): 5.0 to 10.0%.

46.11 Safflower Meal

46.11.1 Description

Safflower (*Carthamus tinctorius*) is an oilseed, grown for its edible oil (see Chapter 45.12). The by-product, after removal of oil, is safflower meal and expeller, respectively, depending on the process of obtaining the oil.

The characteristic of safflower seeds is its extremely high content of hulls which amounts to 45% of the seed thus, hampering the use of safflower meal in feeds. The meal is only 20% and the oil content is around 35%⁽⁴⁰⁾. Removal of all the hulls prior to processing is difficult due to the hardness of the seed coat⁽⁴⁶⁾. Genetical selection of seeds low in hulls has not been very promising.

46.11.2 Chemical, Physiological and Other Properties

Chemical Properties

Although safflower meal and expeller are protein feedstuffs, the protein is not of high value for poultry⁽⁴⁹⁾. The crude protein content of corticated safflower meal is not more than 20 to 23%. Partially decorticated meal may have as much as 50% crude protein (Table 46-01). Totally decorticated meals have a crude protein content of between 60 and 70% and a crude fibre content of only 4.0 to 5.0%⁽³⁸⁾ but totally decorticated safflower meal is costly and hardly found in the market.

Lysine is the first limiting amino acid of safflower meal followed by methionine and cystine (Table 46-37).

The hulls of safflower consist of about 60% crude fibre of which 70% is cellulose and 21% is lignin. Only 3.0% of the carbohydrates in the hulls are available for monogastric animals⁽³⁸⁾.

Safflower meal is a plant product rich in iron. Except for biotin and Vitamin B₆ the vitamin content of safflower meal is generally low (Table 46-38).

Physiological Properties

The high crude fibre content and the high portion of indigestible lignin results in low digestible and metabolisable energy values in productive farm animals (Table 46-39). Relevant figures for farmed aquatic animals are not available.

For the common carp digestibility data are⁽⁶⁴⁾:

- Protein: 90.0%

Table 46-37: Essential amino acid profile of safflower products (g/16 g N)^(46, 49, 163)

	Corticated safflower		Decorticated ¹ safflower	
	Meal	Expeller	Meal	Expeller
Arginine	2.00	1.29	3.43	2.75
Histidine	0.53	0.46	0.99	0.91
Isoleucine	0.52	0.42	1.46	1.60
Leucine	1.34	1.16	2.35	2.44
Lysine	0.70	0.69	1.24	1.04
Methionine	0.30	0.40	0.60	0.79
Phenylalanine	1.03	1.08	1.76	1.75
Threonine	0.62	0.52	1.26	1.36
Tryptophan	0.23	0.30	0.52	0.68
Valine	1.06	1.05	2.03	2.15

¹Partially decorticated

Table 46-38: Mineral and vitamin contents of safflower meal

Minerals ^(38, 46, 49, 120, 125)				Vitamins (per 1,000 g) ^(46, 125)			
		Corti- cated	Decorti- cated			Corti- cated	Decor- cated ¹
Calcium	%	0.32	0.40	Vitamin E	mg	-	0.9
Phosphorus	%	0.92	0.64	Vitamin B ₁	mg	1.6	1.6
Sodium	%	0.05	0.04	Vitamin B ₂	mg	18.0	1.5
Potassium	%	0.72	0.84	Biotin	mg	1.40	1.42
Magnesium	%	0.33	0.33	Folic acid	mg	0.4	7.7
Sulphur	%	0.05	0.14	Nicotinic acid	mg	85.8	15.0
Manganese	mg/kg	17.8	30.6	Pantothenic acid	mg	4.0	58.7
Iron	mg/kg	500.0	462.0	Choline	mg	-	816.0
Zinc	mg/kg	39.8	-				
Copper	mg/kg	9.7	16.8				

¹Partially decorticated

Table 46-39: Energy values of safflower meal per kg

Species	Metabolisable energy		Digestible energy		Reference
	kcal	MJ	kcal	MJ	
Pigs, 4% crude fibre	-	-	3,790	15.9	(38)
35% crude fibre	-	-	2,650	11.1	(38)
17% crude fibre	-	-	3,504	14.7	(38)
Chicken ¹	1,290	5.4	1,590	6.7	(46)
2	1,780	7.5	2,770	11.6	(46, 49)

¹Corticated meal; ²Decorticated meal

- Carbohydrates: 67.5%
- Dry matter: 80.9%

Deleterious Substances

Aside from the high crude fibre and lignin content, safflower meal also contains phenolic glucosides

- Matairesinol- β -glucoside,
- 2-Hydroxyratiin- β -glucoside.

The first one imparts a bitter flavour to the meal and the latter has cathartic properties. The amount of glucosides is 0.39 to 1.62% of the dry matter. The meal can be debittered without any negative effect on the chemical composition (Table 46-01)⁽¹⁰²⁾.

46.11.3 Feeding Value

Safflower meal comes from a minor oil seed crop. In aquaculture, no attention has been paid to this protein feedstuff since the feeding value also for monogastric farm animals is low.

46.11.4 Recommended Inclusion Rates

The recommendation for the use of partially decorticated safflower meal as land animal feed vary widely from zero to 15%^(36, 38, 49). Based on the experiences from land animals, the following guidelines should be observed when safflower meal is used for aquaculture diets:

- Only partially or completely decorticated safflower meal should be used;
- The crude fibre content should be as low as possible because it is the limiting factor;
- The meal should not be used in starter and grower feed;
- The meal is more applicable for herbivorous/omnivorous than carnivorous fish;
- The meal is hardly suitable for crustacean feed;
- The inclusion rate of safflower meal should be in the range of 5.0 to 7.0% and the diet has to be supplemented with lysine and methionine.

46.12 Sesame Meal

46.12.1 Description

Sesame (*Sesamum indicum*, family *Pedaliaceae*) is basically a crop of tropical and sub-tropical zones. The seeds of sesame are very small and 1,000 seeds weight is only 2.0 to 4.0 g⁽¹³⁷⁾. The seeds have a wide range of colours depending on the variety.

Sesame is grown for its oil and the by-product is either the meal from solvent extraction or the expeller from screw pressing. The meal is around 48% of the seeds. Decorticated seeds provide about 30% meal and 18% hulls. The oil portion is 52%⁽⁴⁰⁾.

After oil extraction, the annual sesame production of about 2.45 million MT provides around 1.2 million to 1.3 million MT of sesame meal and sesame expeller, respectively.

46.12.2 Chemical, Physiological and Other Properties

Chemical Properties

The crude protein content of sesame meal with an average of 42 to 44% depends very much on the variety (Table 46-01). Sesame meal is a good source of methionine, cystine and tryptophan, but it is low in lysine as the first limiting amino acid (Table 46-40). Sesame meal is used to produce lysine-deficient diets in experiments⁽³¹⁾. It appears that threonine is the second limiting amino acid⁽¹³⁷⁾.

Table 46-40: Essential amino acid profile (g/16 g N) and apparent and true digestibilities (%) of sesame meal for common carp (*Cyprinus carpio*)

	Amino acid profile (g/16 g N) <small>(31, 46, 49, 120, 138)</small>	Apparent digestibility <small>(71)</small>	True digestibility <small>(71)</small>
Arginine	4.78	81.1	83.5
Histidine	1.07	84.1	-
Isoleucine	1.86	82.4	85.6
Leucine	3.10	82.9	85.2
Lysine	1.25	80.5	86.9
Methionine	1.25	82.5	90.8
Phenylalanine	2.08	81.0	83.1
Threonine	1.58	82.0	85.8
Tryptophan	0.65	-	-
Valine	2.23	81.5	86.6

Decortication of sesame meal reduces the crude fibre content by about 50% but even de-hulled meal may have quite a high crude fibre content which makes it less suitable for aquaculture feed.

The ash content of both sesame meal and sesame expeller is high (Table 46-01). Sesame meal is rich in calcium, phosphorus, magnesium and trace minerals. It is not particularly rich in vitamins with the exception of choline (Table 46-41).

Table 46-41: Mineral and vitamin contents of sesame meal

Minerals ^(23, 31, 46, 49, 120, 138)			Vitamins (per 1,000 g) ^(46, 49, 138)		
Calcium	%	2.33	Vitamin E	mg	4.0
Phosphorus	%	1.29	Vitamin B ₁	mg	7.4
Sodium	%	0.24	Vitamin B ₂	mg	3.8
Potassium	%	1.28	Vitamin B ₆	mg	12.0
Magnesium	%	0.86	Biotin	mg	0.34

Table 46-41: Continued

Minerals ^(23, 31, 46, 49, 120, 138)			Vitamins (per 1,000 g) ^(46, 49, 138)		
Manganese	mg/kg	36.8	Nictonic acid	mg	51.0
Iron	mg/kg	175.0	Pantothenic acid	mg	6.8
Zinc	mg/kg	100.0	Choline	g	1.6
Copper	mg/kg	32.4			

Physiological Properties

There is more information on the energy content of sesame meal from land animals than from aquatic animals (Table 46-42). Digestibility data for sesame meal protein for common carp are similar to that for pigs (Table 46-43).

More than 80% of the individual amino acids are utilised by the common carp (Table 46-40). Although the lysine digestibility is high in rabbits, growth rates were unsatisfactory due to the low lysine content of the sesame meal⁽⁸⁹⁾.

The phosphorus availability of sesame meal is as low as 0.39 to 0.60%^(46, 49) and so is calcium availability which is due to high phytin and oxalic acid content of the meal^(40, 138).

Table 46-42: Energy values of sesame meal per kg

Species	Metabolisable energy		Digestible Energy		References
	kcal	MJ	kcal	MJ	
Fish ¹	-	-	3,065	12.8	(120)
Poultry	2,281	9.5	3,450	14.4	(46, 49)
	2,360	9.9	3,520	14.7 ²	(46)
Pigs	-	-	3,130	13.1	(138)

¹Species not specified; ²Sesame expeller

Table 46-43: Digestibility (%) of sesame meal

Species		Crude protein	Organic matter	Energy	Reference
Common carp	¹	78.9	-	69.9	(71)
	²	82.9	-	-	(71)
Pigs		79.2	79.0	-	(54, 138)
		81.0 ³	77.0	-	(54)

¹Apparent digestibility; ²True digestibility; ³Sesame expeller

Deleterious Substances

Sesame meal contains about 5.0% phytate and 350 ppm oxalates. The hulls have a particularly high content of phytate. These compounds interfere with the assimilation of the minerals Ca, P, Mg, Mn, Zn and possibly Fe^(40, 62, 137).

Dark coloured meals are less palatable than lighter coloured ones. Their bitter taste is caused by the oxalic and phytic acids^(40, 138). Sesame expeller can be contaminated with mycotoxins (aflatoxin)⁽¹⁶²⁾.

46.12.3 Feeding Value

Common carp (*Cyprinus carpio*) were fed a diet with a total protein content of 40%. The fish meal protein was increasingly replaced with sesame expeller protein. Results of the recorded parameters for the sesame meal-fed were inferior to the all fish meal fed group. Even at the lowest sesame expeller level, growth rate was considerably lower than for the fish meal-fed fish. Digestibility also decreased as sesame expeller levels increased (Table 46-44)⁽⁷²⁾.

Table 46-44: Feeding value of sesame expeller in common carp (*Cyprinus carpio*) (Trial period: 8 weeks)⁽⁷²⁾

Protein from:					
- Sesame expeller	%	-	25	50	75
- Fish meal	%	100	75	50	25
Crude protein	%	40.6	40.2	39.5	40.5

Weight gain	%	643	341	194	106
SGR	%/day	3.6	2.7	1.9	1.3
Feed conversion	1:	2.1	2.9	3.7	6.3
Mortality	%	0	0	0	6.3
Digestibility of dry matter	%	76.2	61.9	53.3	50.9

Sesame expeller as a partial substitute for fish meal in diets for the Indian major carp (*Labeo rohita*) fry gave also unsatisfactory results in comparison to the fish meal fed group (Figure 46-04)⁽⁶²⁾.

46.12.4 Recommended Inclusion Rates

Corticated sesame meal and sesame expeller are not suitable for aquaculture feeds. Even de-hulled sesame meal/expeller have a relatively high crude fibre content. The following inclusion rates should not be exceeded:

- Carnivorous fish: 10.0%
- Herbivorous/Omnivorous 20.0%

When sesame meal is used at levels of more than 10.0%, the supplementation of the diet with amino acid and minerals (zinc) has to be considered⁽¹³⁸⁾.

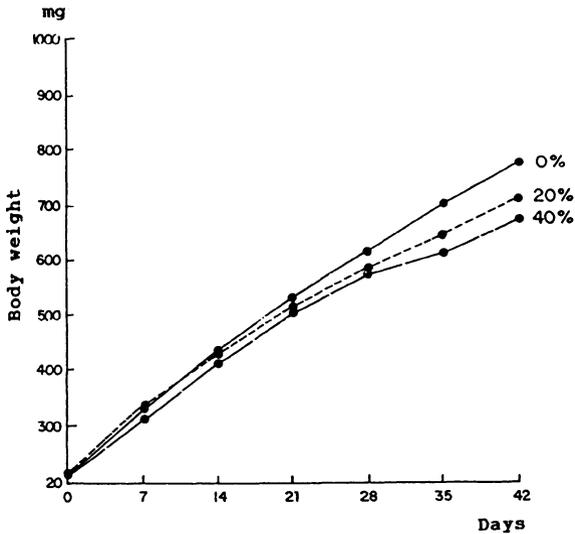


Figure 46-04. Growth response of Indian major carp (*Labeo rohita*) fry to various levels of sesame expeller⁽⁶²⁾

46.13 Soybean Meals

46.13.1 Description

Soybean meal is the by-product after the removal of the oil from soya beans (*Glycine max*) (see also Chapter 42 and 45.14). Presently, soybean meal is the most important protein source as feed of productive farm animals and as partial or entire replacement of fish meal. It is commonly used not only because of its high protein content but also due to its worldwide availability.

Not less than 82 kg of soybean meal and 18 kg of soybean oil are obtained from 100 kg soya beans. De-hulling the seeds, prior to oil extraction, produces 75 kg meal and 7.0 kg hulls⁽⁴⁰⁾.

For about 20 years, meal from whole soya beans, called “full-fat soya bean meal, has been used as animal feed⁽¹⁵³⁾.

Products obtained from soya beans and their processing are as follows:

- Soybean meal, solvent extracted;
- Soybean meal from de-hulled seeds, solvent extracted;
- Soybean expeller;
- Soybean expeller from de-hulled seeds;
- Full-fat soybean meal;
- Full-fat soybean meal from de-hulled seeds.

46.13.2 Chemical, Physiological and Other Properties

Chemical Properties

The chemical composition of soybean meals is fairly consistent (Table 46-01). The crude protein level depends on the soybean meal quality and a guide for the meal protein content is as follows:

- Soybean meal: 44%
- De-hulled soybean meal 48%
- Full-fat soybean meal 36%.

Factors that cause variations in the protein content are soil, cultivars, weather condition during vegetation period, and season among others.

Soybean meal has one of the best amino acid profiles of all vegetable oil meals (Table 46-45). The limiting amino acids are methionine and cystine while arginine and phenylalanine are in good supply⁽¹²⁰⁾.

Table 46-45: Essential amino acid profile of soybean products (g/16 g N)
(4, 48, 153, 180)

	Soybean meal	Soybean meal, de-hulled	Full-fat soybean meal
Arginine	6.94	7.38	7.44
Histidine	2.64	2.58	2.58
Isoleucine	5.01	5.15	5.31
Leucine	7.54	7.76	7.08
Lysine	6.28	6.45	6.30
Methionine	1.38	1.46	1.29
Phenylalanine	5.03	4.84	5.20
Threonine	4.92	3.93	4.18
Tryptophan	1.18	1.40	1.44
Valine	4.72	5.24	4.97

The fat content of the solvent extracted soybean meal is insignificant, but soybean expeller has an oil content between 6.0 and 7.0% while full-fat soybean meal contains 18 to 20% fat (Table 46-01).

Soybean meal and soybean expeller are lower in macro and trace elements than fish meal. There is no substantial difference between the individual soybean meal products (Table 46-46). The calcium content is low and the phosphorus level is rather high, however, the phosphorus is bound to phytic acid, and the availability for aquatic animals is, therefore, limited. The available phosphorus amounts only to 0.19 to 0.26% as reported for land animals which is around 30% of the total phosphorus content of soybean meals^(46, 49). A phosphorus availability of 50% for channel catfish (*Ictalurus punctatus*) and 40% for white leg shrimps (*Penaeus vannamei*) has been established⁽⁷⁾.

Table 46-46: Macro and trace mineral content of soybean meals and expeller^(39, 46, 110, 124)

		Soybean meal	Soybean expeller	Soybean meal, dehulled soybean meal	Full-fat soybean meal
Calcium	%	0.28	0.26	0.28	0.25
Phosphorus	%	0.68	0.63	0.66	0.59
Sodium	%	0.08	0.04	0.03	0.07
Potassium	%	1.92	1.89	2.09	1.45
Magnesium	%	0.27	0.26	0.26	0.24
Chlorine	%	0.04	0.06	0.04	0.03
Sulphur	%	0.43	0.33	0.44	0.22
Manganese	mg/kg	32.2	34.9	32.5	30.8
Iron	mg/kg	186.5	188.5	131.5	82.0
Zinc	mg/kg	53.5	56.4	54.0	46.8
Copper	mg/kg	19.9	20.2	18.0	17.2
Selenium	mg/kg	0.04	0.06	0.04	0.03
Iodine	mg/kg	0.05	-	0.05	-

Soybean meals and expeller are a reasonable source of B-vitamins. For most vitamins, there are insignificant differences between the different products. However, full-fat soybean meal tends to be higher in some vitamins. While the products are a good source of choline, the Vitamin B₁₂ content is low (Table 46-47), and nicotinic acid and pantothenic acid are damaged by heat treatment. Losses may amount to 10% to 75%⁽¹³³⁾.

Table 46-47: The vitamins of soybean meals and expeller (per 1,000 g)^(46, 110, 123, 169)

		Soybean meal	Soybean expeller	Soybean meal, de-hulled	Full-fat soybean meal
Vitamin A	I.U.	365	400	-	800
Vitamin E	mg	2.5	4.2	2.6	8.9
Vitamin B ₁	mg	6.5	4.2	2.6	8.9
Vitamin B ₂	mg	3.1	3.2	2.9	2.7
Vitamin B ₆	mg	7.1	8.6	4.0	7.2
Vitamin B ₁₂	mg	0.02	-	-	-
Biotin	mg	0.31	0.33	0.31	0.94
Folic acid	mg	2.81	3.45	0.7	3.18
Nicotinic acid	mg	30.1	27.3	21.0	22.0
Pantothenic acid	mg	14.6	14.5	13.9	15.5
Choline	g	2.8	2.9	2.5	2.6

Physiological Properties

The digestible energy of soybean meals over all fish species ranges from 2,572 to 3,340 kcal/kg (10.8 to 14.0 MJ/kg (Table 46-48).

The metabolisable and digestible energy of full-fat soybean meal increases with the increase of the heating temperature at a given time due to the inactivation of the trypsin inhibitors (Table 46-48).

Table 46-48: Energy values of soybean meal per kg

Species	Gross energy		Metabolisable energy		Digestible energy		References
	kcal	MJ	kcal	MJ	kcal	MJ	
1. <u>Soybean meal</u>							
	4,518	18.9	-	-	-	-	(97, 110, 160)
Fish	-	-	-	-	2,925	12.4	(120)
Rainbow trout	-	-	2,921	12.2	3,266	13.7	(110, 158)
Channel catfish	-	-	-	-	2,572	10.8	(97, 136)
Nile tilapia	-	-	-	-	3,340	14.0	(124)
2. <u>Soybean meal from de-hulled seeds</u>							
	4,326	18.1	-	-	-	-	(110)
Rainbow trout	-	-	2,947	12.3	-	-	(124)
3. <u>Full-fat soybean meal</u>							
Rainbow trout	-	-	2,564	10.7 ¹	2,905	12.2	(161)
	-	-	3,641	15.2 ²	4,083	17.1	(161)
	-	-	4,033	16.9 ³	4,349	18.2	(161)

¹Roasted at 127°C for 10 min.; ²Roasted at 175°C for 10 min.; ³Roasted at 204°C for 10 min.

Apparently on the average, shrimps digest the crude protein of soybean meal better (91.1%) than fish (84.9%). But the residual fat of soybean meal is better digested by the fish (88.6%) than by the shrimp (78.6%). The digestibility parameters for full-fat soybean meal follow the observations made with the energy values (Table 46-49).

Table 46-49: Digestibility (%) of soybean meals

Species	Dry matter	Crude protein	Fat	Crude fibre	Carbo-hydrates	Energy	References
1. <u>Soybean meal</u>							
Salmonids	77.6	86.3	-	-	54.0	-	(64)
Common carp	44.1	78.1	86.0	51.5	67.3	53.6	(64, 151)
Grass carp	81.8	96.2	98.8	-	63.4	82.7	(64)
Channel catfish	-	81.8	81.0	-	-	51.4	(64, 93, 142)
European eel	68.0	94.0	-	-	-	-	(64)
Tiger prawn	60.1	92.1	75.5	-	63.4	-	(6, 30)
Kuruma prawn	63.6	90.1	-	-	75.8	-	(6)
White leg shrimp	59.8	90.8	70.4	-	73.5	-	(6, 8)
Giant freshwater prawn	99.0	90.5	-	-	90.0	-	(85)
2. <u>Full-fat soybean meal</u>							
Salmonids	-	65.0	-	-	-	66.9	(64)
Rainbow trout	-	40.3 ¹	-	-	-	51.3	(160)
	-	69.9 ²	-	-	-	71.7	(160)
	-	78.2 ³	-	-	-	77.3	(160)

¹Roasted at 127°C for 10 min.; ²Roasted at 175°C for 10 min.; ³Roasted at 204°C for 10 min.

Protein digestibility does not always reflect the digestibility of essential amino acids. Based on the available data, the overall amino acid digestibility of soybean meal by channel catfish is better than the protein digestibility. On the contrary, shrimps digest protein better than amino acids of soybean meal (Tables 46-50).

The mineral digestibility of soybean meal for white leg shrimp varies very widely and is negative for some elements (Table 46-50).

The carbohydrate fraction of soybeans is different from cereals. About 30% carbohydrates of soya beans are subdivided into 10% soluble carbohydrates (oligosaccharides) and 20% insoluble carbohydrates (polysaccharides)^(16, 94) (see Chapter 2.3). Results of a study in Atlantic salmon (*Salmo salar*) suggest that the alcohol-soluble fraction of soya beans (mainly alcohol-soluble carbohydrates) is partially responsible for the insufficient nutritional value of soybean meals⁽¹⁶⁾ which is more anti-nutrient than the heat sensitive substances⁽¹²⁹⁾.

Table 46-50: Amino acid and mineral digestibilities of soybean meal

Essential amino acid digestibility (%) ^(8, 142)			Apparent mineral digestibility (%)	
	Channel Catfish ⁽¹⁴²⁾	White leg shrimp ⁽⁸⁾		White leg shrimp ⁽¹⁰⁾
Arginine	96.7	91.4	Calcium	-84.1
Histidine	87.9	86.3	Phosphorus	39.9
Isoleucine	79.8	90.2	Magnesium	88.7
Leucine	83.5	88.4	Potassium	92.0
Lysine	94.0	91.5	Sodium	-88.7
Methionine	84.6	-	Iron	18.2
Phenylalanine	84.4	89.6	Zinc	15.0
Threonine	81.9	89.3	Copper	60.1
Valine	78.7	87.9	Manganese	33.0

Deleterious Constituents and Other Properties

Trypsin Inhibitors: About 6.0% of the total protein of soya beans⁽⁸⁰⁾ reduce activities of trypsin and chymotrypsin which are pancreatic enzymes and involved in protein digestion⁽¹⁸⁶⁾. The trypsin inhibitors are not fully understood, but are responsible for the poor performance of certain fish species^(2, 21, 160, 176, 184). Furthermore, feeding of raw, unprocessed soya beans enlarges the pancreas⁽³¹⁾.

Determination of trypsin inhibitors in soybean meals is difficult and expensive. Urease activity is correlated with trypsin inhibitors and can be easily determined, hence, its determination is used for routine analysis of trypsin inhibitors in soybean meals⁽¹⁵³⁾. Other methods to determine the activity of trypsin inhibitors are: Formaldehyde titration, cresole red dye-binding (phthalin test), orange dye binding and the fluorescence test⁽¹⁸⁰⁾.

Trypsin inhibitors are inactivated by proper heating time and temperature, often referred to as “cooking” or “roasting”. The longer the heating time, the more trypsin inhibitors are destroyed but high quality soybean meals should neither be “overcooked” nor “undercooked” because both reduce the feeding value. Inactivation of the trypsin inhibitors improve the feeding value of soybean meals as demonstrated in broilers (Table 46-51).

Table 46-51: Effect of duration of heating of soybean meal on urease activity, trypsin inhibitor content and feeding value (broilers)⁽¹⁸²⁾

Heating time Min.	Urease activity pH	Trypsin inhibitor mg/g	Weight gain g
0	2.26	-	248
30	1.74	8.2	376
35	0.48	5.0	393
40	0.40	5.5	405
45	0.25	4.6	416
50	0.18	4.8	403
55	0.11	4.6	415
60	0.05	2.5	409

Lectins: This is another type of toxic protein and is chemically hemagglutinin, which causes agglutination of red blood cells⁽⁹²⁾. They are bound to the intestinal mucosa and damage the micro-villi, promoting invasion of gut lining by pathogenic bacteria and impair absorption of nutrients^(31, 153,180). There are indications that lectins reduce the nutritive value of soybean meal for salmonids but are inactivated by treatment of the meals^(63, 76).

Other Anti-nutritional Factors: In raw soya beans, there are other anti-nutritional factors present such as tannins, alkaloids, estrogens, saponins, glycosides and urease. Whether these substances are injurious to aquatic animals is not yet well defined^(94, 180).

Other Properties: For some fish, soybean meal is unpalatable. While chinook salmon (*Oncorhynchus tsachawytscha*) do not accept soybean meal coho salmon (*Oncorhynchus kisutch*) is not so delicate⁽⁵³⁾. Herbivorous and omnivorous species are less choosy. The size or age of the fish may also affect the palatability of soybean meal⁽⁶⁾.

Pelletising Ability: High levels of soybean meal may reduce the pelletising ability of the diets. When soybean meal at levels of 42% and more were used, the water durability was significantly reduced⁽⁹⁴⁾. Full-fat soybean meal and soybean expeller have a better press capacity and give the pellet die a longer life than soybean meal due to their higher fat content but there are no differences in pellet quality^(55, 66).

46.13.3 Feeding Value

Comprehensive research work has been done to evaluate soybean meals as a replacement of animal protein sources in diets for farmed aquatic animals but the replacement of all fish meal by soybean meal, has not been very successful perhaps due to the limiting amino acids and insufficient heat treatment of the soybean meals.

Fishes

Salmonids: The use of soybean meal at different levels in diets for juvenile rainbow trouts (*Salmo gairdneri/Onchorhynchus mykiss*) as replacement of fish meal resulted in depressed growth. The negative response increased with increasing levels of soybean meal in the diet^(37, 113, 152). However, when soybean meal diets were fed to older rainbow trouts and compared to fish meal based diets, no significant differences were found^(12, 35).

Increasing levels of soybean meals as replacement for quality fish meal in diets for the Atlantic salmon (*Salmo salar*) reared in seawater and rainbow trout reared in fresh-water caused significant decrease in growth. Best results were obtained with full-fat soybean meal, followed by soybean expeller and soybean meal (Figure 46-05)⁽¹²⁸⁾.

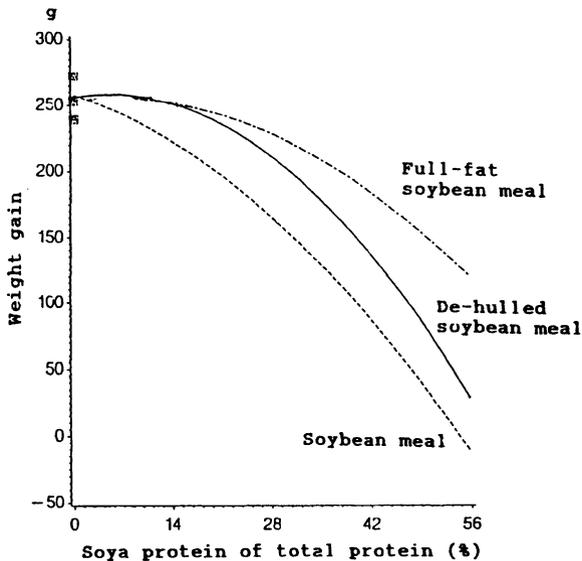


Figure 46-05. The effect of different levels of soybean meal, de-hulled soybean meal and full-fat soybean meal on the weight gain of Atlantic salmon (*Salmo salar*)⁽¹³⁰⁾

On the other hand, good growth was obtained in rainbow trout (*Salmo gairdneri*) fed full-fat soybean meal (roasted at 177°C for 10 min.) as the predominant protein source and without fish meal. The positive effects were most probably due to the addition of

3.0% cod liver oil to the test diet⁽¹⁶⁵⁾. At the low level of full-fat soybean meal (7.5%) there was no difference in the performances of rainbow trout compared to 7.5% anchovy meal, the control, but fish fed 40% full-fat soybean meal in replacement for 30% anchovy meal required more time to reach the final weight of the control and consumed more feed per kg growth⁽¹⁶¹⁾.

Additional heating of full-fat soybean meal reduces the weight gain of rainbow trout compared to a fish meal-soybean meal diet⁽³⁴⁾. When 75% heat-treated full-fat soybean meal and 5.0% fish meal were fed to rainbow trouts, fishes developed better than the control, and the higher energy content of the diet produced carcasses with the highest fat content⁽¹³⁹⁾.

Common Carp: No differences in growth were observed when common carp (*Cyprinus carpio*) were fed either with 45% soybean meal (+ 10% fish meal) or 20% soybean meal (+22% fish meal). Other trials however, showed that growth performance and feed efficiency of common carp were reduced when dietary fish meal was replaced by soybean meal. There were no differences in performance between extruded full-fat soybean meal and oil-reconstituted soybean meal⁽¹⁷⁶⁾. It is claimed that soybean meal is deficient in available energy and lysine as well as methionine for carp. Supplementation of soybean meal diets with methionine coated with aldehyde treated casein significantly improved utilisation of the amino acid by the common carp^(113, 114).

Lack of phosphorus rather than the sulphur amino acids may be the cause for poor results when 40% soybean meal diets were fed to common carp. Addition of 2.0% di-sodiumphosphate improved performances⁽⁸⁴⁾. But in another study a reduced phosphorus content of the diet, obtained when replacing fish meal with soybean meal, did not affect the growth of carp⁽¹⁷⁸⁾.

But replacing a diet for mirror carp (*Cyprinus carpio*) half of the fish meal by 50% full-fat soybean meal, fish obtained only 60% to 65% of the weight gain of the control group and carcasses were fatter than the control⁽²⁾.

Channel Catfish: Channel catfish (*Ictalurus punctatus*) fed on all-plant protein diets grew significantly less than fish fed diets containing fish meal⁽¹⁰¹⁾. Growth was substantially reduced when menhaden fish meal was replaced by soybean meal at an isonitrogenous basis⁽¹⁴⁾.

The partial replacement of fish meal by soybean meal in the diet for the channel catfish or the increase of the diet's energy and phosphorus content resulted in better performances of the fish. It is claimed that fish meal and dietary phosphates provide sulphur amino acids and available phosphorus, respectively, of which soybean meal is deficient^(90, 112, 115). Adding crystalline sulphur amino acids to improve the soybean protein did not improve the growth of channel catfish⁽¹⁴⁾ but significantly improved weight gains of channel catfish was reported when the soybean meal diet was fortified with either coated or uncoated methionine⁽¹¹³⁾.

Full-fat soybean meal, heat treated differently, replaced fish meal and/or soybean meal at low and high levels in diets for channel catfish showed that replacement at moderate level of full-fat soybean meal gave satisfactory results. However, fish carcasses had higher fat contents and the fish had a "greasy taste"^(27, 147).

Tilapia: Growth and feed efficiency were significantly depressed when soybean meal replaced fish meal at the optimum protein level (30%) in a diet (32% crude protein) for fingerling hybrid tilapia (*Oreochromis niloticus* x *Oreochromis aureus*). When the protein of the diet was below optimum level (24%), fish meal could be partially replaced by soybean meal⁽¹⁵⁴⁾. Without any supplements, soybean meal has been used to replace 50% of the fish meal in a tilapia diet (25% crude protein) without any negative effects⁽¹⁷⁴⁾.

On the other hand, the growth of the hybrid tilapia was reduced when a 30% crude protein diet contained 24% soybean meal but by adding 2.0 to 3.0% di-calciumphosphate to the diet, growth rate of tilapia was comparable to the control⁽¹⁷⁷⁾. In another experiment, the growth of Nile tilapia (*Oreochromis niloticus*) was improved when a brown fish meal was replaced by soybean meal plus added methionine⁽¹⁶⁷⁾. Addition of supplemental oil, lysine, methionine and vitamins to a diet for tilapia did not prevent significant growth depression and poor feed efficiency when fish meal was completely substituted by soybean meal⁽¹⁷⁵⁾. But growth of tilapia (*Sarotherodon mossambicus*) was depressed when fed a diet in which 50% or more fish meal was replaced by soybean meal⁽⁷⁷⁾.

Full-fat soybean meal at reasonable levels with and without supplements in diets for Nile tilapia and hybrid tilapia may replace fish meal without affecting performances negatively. But these fish species when on higher levels of full-fat soybean meal in the diet have higher fat content in the carcass than lower levels of the full-fat meal^(154, 167).

Milkfish: Without any adverse effect on growth and feed conversion, soybean meal with a methionine supplement could replace up to 67% fish meal in diets for milkfish (*Chanos chanos*)⁽¹⁵⁵⁾.

Table 46-52: Responses of tiger prawn (*Penaeus monodon*) juveniles to diets containing soybean meal (Trial period: 8 weeks)⁽¹³⁴⁾

Soybean meal	%	15.0	35.0
Fish meal	%	30.0	16.0
Crude protein	%	48.0	44.0
Crude fat	%	13.0	11.0

Weight gain	%	244	194
Feed conversion	1:	2.6	3.5
SGR	%/day	2.2	1.9
Survival	%	71.0	67.0

Crustaceans

Penaeid shrimps: Growth, feed conversion and survival of tiger prawn (*Penaeus monodon*) juveniles fed two levels of soybean meal under laboratory conditions were lower by the higher level of soybean meal (Table 46-52)⁽¹³⁴⁾. Weight gain and survival rate of tiger prawns fed

a 45% soybean meal diet was inferior to those fed 35% soybean meal diet⁽⁹⁾. On the other hand, no significant differences in growth and survival could be established when soybean meal at levels from 15% to 55% replaced partially or completely fish meal in diets for tiger prawns stocked in cages in ponds at 10 or 20 shrimps/m². Under the conditions of the trial, production results (final weight x survival) were higher at the stocking rate of 20 shrimps/m² (Figure 46-06)⁽¹³⁵⁾ and decreased at 45 to 55% level of replacement.

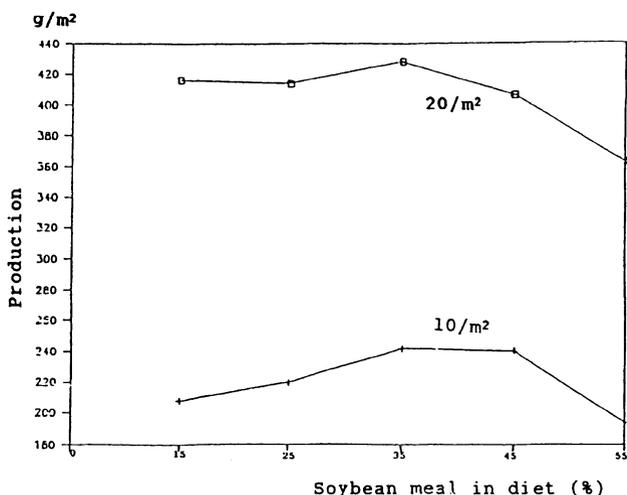


Figure 46-06. Production results (final weight x survival) of different levels of soybean meal in diets for tiger prawn (*Penaeus monodon*) reared at various stocking rates⁽¹³⁵⁾

Banana shrimps (*Penaeus merguensis*) responded negatively to fish meal-free diets and a soybean meal level of 55%. The partial replacement of fish meal did not seem to affect performances (Table 46-53)⁽²⁵⁾.

Table 46-53: Increasing levels of soybean meal as partial or complete replacement of fish meal in diets for banana shrimps (*Penaeus merguensis*) (Feeding period: 56 days)⁽²⁵⁾

Soybean meal	%	25.0	35.0	45.0	55.0
Fish meal	%	23.4	15.6	7.8	-
Fish oil	%	4.1	4.7	5.4	6.0
Crude protein	%	39.0	40.0	39.2	38.6
Fat	%	9.6	10.3	10.9	10.4

Weight gain	%	2,884	2,914	3,920	2,400
Feed conversion	1:	1.66	1.75	1.70	1.81
Survival rate	%	88.9	76.7	86.7	74.2

White leg shrimps (*Penaeus vannamei*) did not require any marine animal meals, except a chemo-attractant, and had excellent performances when fed isonitrogenously balanced diets containing 75% soybean meal. In a related experiment under field conditions there were no differences in growth of white leg shrimps fed 10% or 40% soybean meal in the diets⁽⁸⁷⁾.

Results of basic experiments with soybean meal in other penaeid shrimps have demonstrated that there are species and size differences in the ability of marine shrimps to utilise soybean meal. For these trials, three initial liveweight were used: 0.04 g, 0.5 g, 5.0 g⁽⁸⁷⁾. Smaller shrimps are more sensitive to the level of soybean meal in the diet than larger animals. In these trials, soybean meal levels ranging between 15% to 75% replaced menhaden fish meal and shrimp head meal accordingly⁽⁸⁷⁾.

There was good acceptance of soybean meal by pink shrimp (*Penaeus duorarum*) when fish meal and shrimp meal were replaced in the diet⁽¹⁵⁶⁾. On the other hand, growth of common prawn (*Palaemon serratus*) was inferior when fish meal was completely substituted by soybean meal⁽⁵¹⁾.

Freshwater Shrimps: Soybean meal could successfully replace fish meal and shrimp meal in the diet for the giant fresh water prawn (*Macrobrachium rosenbergii*)^(19, 20). Adult giant fresh water prawns utilised soybean meal better than juveniles⁽⁸⁶⁾.

Other Aquatic Animals

Soybean meal may be an alternative protein source for formulated feed for abalone (*Haliotis* spp.)⁽⁴⁷⁾. It could also be a suitable protein source for formulated feed for frogs (*Rana* spp.). Hatchery-reared frog (*Rana perezii*) larvae have been reared on diets containing soybean meal⁽¹⁰⁷⁾.

46.13.4 Recommended Inclusion Rates

Soybean meals may replace animal proteins in diets for aquatic animals to a certain extent. However, with increasing substitution of e.g. fish meal by soybean meal the performances of fish decline. Herbivores may tolerate higher levels of soybean meals than carnivores.

It appears that full-fat soybean meal is more beneficial for cold water fish than for warm water species due to the better utilisation of the energy from the soya bean product by the former. However, unbalanced diets with full-fat soybean meal may affect the fat content of the fish carcass.

Only properly heat-treated soya bean products should be used for aquaculture feeds. Furthermore, it is advisable to use only soybean meals processed from de-hulled seeds in order to reduce the crude fibre in the diet.

Guidelines for suitable application rates of soybean meals are in Table 46-54. Supplementation of the diet with marine oils, phosphates and essential amino acids has to be evaluated.

Table 46-54: Guideline for the use of soybean meal, soybean expeller, de-hulled soybean meal and full-fat soybean meal in diets for aquatic animals

	Starter feed %	Grower feed %	Finisher feed %
1. Fishes			
Carnivores	5.0	10.0	15.0
Herbivores/omnivores	10.0	20.0	30.0
2. Crustaceans			
Marine shrimps	3.0	8.0	15.0
Freshwater shrimp	5.0	10.0	20.0

46.14 Sunflower Meal

46.14.1 Description

Sunflower meal is the residue of oil extraction from sunflower seeds (*Helianthus annuus*), family (*Asteraceae*) which is basically a plant of temperate zones. The by-product is rich in protein and used as a feedstuff. The non-oil-containing portion of sunflower seeds amount to about 70%. When the seeds are de-hulled, the meal portion is 62% and 8.0% are hulls⁽⁴⁰⁾. This means that of the world production of 21 million MT sunflower a year, theoretically 14.0 to 15.0 million MT sunflower meal and sunflower expeller are available.

Corticated sunflower meal is not a suitable feedstuff. Sunflower meal is commonly of gray colour because most sunflower seeds have a black hull⁽⁴³⁾.

46.14.2 Chemical, Physiological and Other Properties

Chemical Properties

The crude protein content of sunflower meal varies with the method of processing and ranges between 25% (corticated) and 50% (decorticated). Partly decorticated meal has a crude protein content of 30 to 35% (Table 46-01).

The protein of sunflower meal is deficient in lysine which is the first limiting amino acid, but methionine and arginine are higher than in soybean meal⁽⁴³⁾. Due to the higher protein content of decorticated meal, the amino acid levels are also higher than in corticated meal (Table 46-55).

The fat content depends on the oil extraction method. Un-dehulled meal has only 0.5% fat but sunflower expeller may have 5.0 to 7.0% fat. The linoleic acid content of whole sunflower seeds is high.

Table 46-55: Essential amino acid profile of sunflower products (g/16 g N)^(43, 46, 49, 125, 163)

	Corticated meal	Decorticated	
		Meal	Expeller
Arginine	2.88	3.60	4.00
Histidine	0.81	1.04	1.08
Isoleucine	1.38	2.07	2.06
Leucine	2.15	2.99	2.67
Lysine	1.10	0.73	1.79
Methionine	0.65	0.78	1.24
Phenylalanine	1.56	2.20	2.17
Threonine	1.29	1.68	1.57
Tryptophan	0.37	0.55	0.56
Valine	1.76	2.34	2.29

The crude fibre content of sunflower meal is the best indicator as to whether the meal is from decorticated seeds or not. Corticated sunflower meal may contain up to almost 30% crude fibre (Table 46-01). The ash content is about 6.0%. Phosphorus and potassium content is high. Sunflower meal is a useful source of nicotinic acid and choline. In general, the vitamins of sunflower meal are significantly higher than in soybean meal (Table 46-56)⁽⁴⁰⁾. But it is unknown how stable these vitamins are during storage and feed mixing^(43, 80).

Table 46-56: Mineral and vitamin contents of sunflower meal and sunflower seeds (as fed)

Minerals ^(43, 46, 49, 120, 125)				Vitamins (Per 1,000 g) ^(46, 49, 125)		
		Meal	Whole seeds			Meal
Calcium	%	0.43	0.18	Vitamin A	I.U.	14,000
Phosphorus	%	1.3	0.66	Vitamin E	mg	11.1
Sodium	%	0.15	0.03	Vitamin B ₁	mg	18.5
Potassium	%	1.20	0.78	Vitamin B ₂	mg	3.2
Magnesium	%	0.65	-	Vitamin B ₆	mg	12.5
Chlorine	%	0.15	0.01	Biotin	mg	0.08
Sulphur	%	0.21	0.02	Nicotinic acid	mg	249.0
Manganese	mg/kg	33.3	21.6	Pantothenic acid	mg	30.3
Iron	mg/kg	108.3	30.0	Choline	g	3.1
Zinc	mg/kg	99.0	-			
Copper	mg/kg	12.0	-			
Selenium	mg/kg	1.8	-			

Physiological Properties

The digestible energy of sunflower expeller is higher than that of sunflower meal due to the higher fat content of the former (Table 46-57).

Table 46-57: Energy values of sunflower meal per kg

Species	Metabolisable energy		Digestible energy		Reference
	Kcal	MJ	kcal	MJ	
Fish ¹	-	-	3,394	14.2 ²	(120)
	-	-	2,827	11.8	(120)
Chicken	2,052	8.6	2,650	11.1	(46, 49)
Pigs	-	-	3,057	12.7 ³	(43)
	-	-	2,425	10.1 ⁴	(43)
	-	-	2,337	9.8 ⁵	(43)

¹Species not specified; ²Sunflower expeller; ³Decorticated meal; ⁴Partly decorticated; ⁵Corticated

For the common carp (*Cyprinus carpio*), the dry matter, carbohydrate, and crude fibre digestibility for sunflower meal is low but protein digestibility is in the medium range (Table 46-58).

Table 46-58: Digestibility (%) of sunflower meal)

Species	Dry matter	Crude protein	Fat	Crude fibre	Carbo-hydrates	Organic matter	Reference
Common carp	46.1	76.6	86.4	46.5	40.9	-	(64, 151)
Pigs	-	73.8	-	-	-	46	(54)
	-	74.7	-	-	-	46 ¹	(54)

¹Sunflower expeller

Deleterious Substances

Sunflower meal contains tannins, protease inhibitors, an arginine inhibitor, but does not have a trypsin inhibitor⁽¹⁶⁶⁾. Contamination of sunflower meal and sunflower expeller with aflatoxin is possible.

46.14.3 Feeding Value

The sunflower meal is a good replacement for soybean meal in rations for rainbow trout (*Salmo gairdneri*)⁽¹⁰⁵⁾.

Sunflower meal had no adverse effect on growth performance and feed conversion when rainbow trout were fed with increasing levels of sunflower meal in replacement for soybean meal and wheat flour. However, the total substitution of soybean meal by sunflower meal with methionine supplementation was not successful. Increasing sunflower meal levels in the diet also decreased the dry matter digestibility which most probably is caused by the high crude fibre content of sunflower meal (Table 46-59)⁽¹⁶⁶⁾. Also sunflower meal-fed rainbow trout (initial liveweight: 39 g) did not perform as well as the fish meal-fed fish⁽²⁹⁾.

Table 46-59: Increasing levels of sunflower meal in diets for rainbow trout (*Oncorhynchus mykiss*) (trial period 150 days)⁽¹⁶⁶⁾

Sunflower meal	%	0	11	22	36.5	36.3
Soybean meal	%	15	8	0	0	0
Fish meal	%	40	40	40	35	35
Methionine	%	-	-	-	-	0.2
Crude protein	%	44.1	45.6	44.4	43.9	44.2
Crude fat	%	14.2	14.7	14.8	12.7	12.3
Crude fibre	%	1.5	3.8	6.3	10.0	9.2

Weight gain	%	425	458	420	421	354
SGR/day	%	1.1	1.1	1.1	1.1	1.0
Feed conversion	1:	1.6	1.4	1.5	1.5	1.7
PER		1.4	1.5	1.5	1.5	1.3
Apparent digestibility:						
- Dry matter	%	62.2	53.1	54.9	42.9	47.9
- Organic matter	%	67.8	58.1	58.6	47.8	52.5
- Nitrogen	%	84.7	82.2	82.2	79.2	79.4

46.14.4 Recommended Inclusion Rates

The high crude fibre content of sunflower meal limits its use in aquaculture diets. Only decorticated sunflower meal should be used for aquatic animals. The following inclusion rates for sunflower meal and sunflower expeller should not be exceeded:

- Carnivorous fish: 10.0%
- Herbivorous/Omnivorous fish: 20.0%

46.15 Legal Aspects

Meal from solvent extraction or expeller from screw pressing of vegetable oil seeds are generally recognised as useful feedstuffs in animal production. Regulations for their use

in animal feeds may differ from country to country.

In the EU-countries, the use of these products is laid down by the EU-Commission in the Directive 92/87 EWG of 26 October 1992⁽¹⁸³⁾. The U.S.A. Feed Ingredient Definitions for vegetable oil meals is similar⁽¹⁾.

The German feedstuff legislation has added to the EU-Regulations minimum and maximum requirements for each individual feedstuff of this category (Table 46-60)⁽¹⁸³⁾.

Table 46-60: Minimum/maximum requirements by the German feedstuff law for meal from solvent extraction and cakes from screw pressing of vegetable oil seeds (%)⁽¹⁸³⁾

	Moisture	Crude Protein	Fat	Crude fibre	Ash	Misc.
	Max.	min.	max.	min.	max.	max.
1. Meal from solvent extraction						
Copra meal	13.0	21.0	4.0	-	-	-
Copra	6.0	-	60.0	-	-	-
Cotton-seed meal, decorticated	13.0	43.0	4.0	13.5	-	-
Cotton-seed meal, partly decorticated	13.0	34.0	4.0	18.0	-	-
Cotton-seed meal	13.0	-	4.0	30.0	-	-
Ground-nut meal, decorticated	13.0	48.0	4.0	6.0	-	-
Ground-nut meal, partly decorticated	13.0	40.0	4.0	13.0	-	-
Ground-nut meal	13.0	-	4.0	30.0	-	-
Linseed meal ¹	13.0	33.0	4.0	-	-	-
Palm-kernel meal	13.0	16.0	4.0	-	-	-
Olive meal	13.0	-	4.0	30.0	-	-
Rape-seed meal ²	13.0	34.0	4.0	-	-	-
Rape-seed meal, low in Goitrine ²	13.0	34.0	4.0	-	-	0.35 ³
Safflower meal, decorticated	13.0	45.0	4.0	10.0	-	-
Safflower meal, partly decorticated	13.0	-	4.0	35.0	-	-
Sesame meal	13.0	40.0	4.0	-	5.0	-

Table 46-60: Continued

	Moisture Max.	Crude Protein min.	Fat max.	Crude fibre min.	Ash max.	Misc. max.
<u>1. Meal from solvent extraction</u>						
Soybean meal	13.0	42.0	5.0	8.0	-	-
Soybean meal, decorticated	13.0	48.0	4.0	3.0	-	0.4 ⁴
Sunflower meal, decorticated	13.0	40.0	4.0	16.0	-	-
Sunflower meal, partly decorticated	13.0	30.0	4.0	22.0	-	-
Sunflower meal	13.0	-	4.0	30.0	-	-
<u>2. Cake from screw pressing</u>						
Copra cake	13.0	19.0	5.0	-	-	-
Cotton-seed cake, decorticated	13.0	41.0	5.0	13.0	-	-
Cotton-seed cake, partly decorticated	13.0	32.0	5.0	17.5	-	-
Cotton-seed cake	13.0	-	-	29.0	-	-
Ground-nut cake, decorticated	13.0	45.0	5.0	6.0	-	-
Ground-nut cake, partly decorticated	13.0	-	-	28.0	-	-
Linseed cake ¹	13.0	31.0	5.0	-	-	-
Palm-kernel cake	13.0	15.0	5.0	-	-	-
Olive cake	13.0	-	-	27.0	-	-
Rape-seed cake ²	13.0	30.0	5.0	-	-	-
Safflower cake, decorticatec	13.0	43.0	5.0	9.0	-	-
Safflower cake, partly decorticated	13.0	-	-	35.0	-	-
Sesame cake	13.0	38.0	5.0	-	5.0	-

Table 46-60: Continued

	Moisture Max.	Crude Protein min.	Fat max.	Crude fibre min.	Ash max.	Misc. max.
<u>2. Cake from screw pressing</u>						
Soybean cake	13.0	42.0	5.0	8.0	-	-
Sunflower cake, decorticated	13.0	38.0	5.0	16.0	-	-
Sunflower cake, partly decorticated	13.0	29.0	5.0	21.0	-	-
Sunflower cake	13.0	-	-	30.0	-	-

¹Min. 93% Botanical purity; ²Min. 94% botanical purity; ³Vynylthio-oxazolidone; ⁴Urease-activity

Meals and expellers from the following mustard species are “undesirable feedstuffs” according to German feedstuff legislation and cannot be used as a component for compound feed:

- Abyssinia mustard (*Brassica carinata*)
- Black mustard (*Brassica nigra*)
- Chinese yellow mustard (*Brassica juncea*, va. *Lutea*)
- Indian brown mustard (*Brassica juncea*, var. *integrifolia*)
- Sarepta mustard (*Brassica juncea juncea*)

Other undesirable substances in vegetable oil meals and expeller may not exceed certain levels in the product as laid down by law (Table 46-61).

Table 46-61: Undesirable substances in by-products of vegetable oil seeds processing, according to German feedstuff legislation⁽¹⁸³⁾

Undesired substance	Feedstuff	Max. content per kg
Aflatoxin B ₁	all	0.02 mg
Prussic acid	linseed meal	} 350.0 mg
	linseed meal	
	linseed cake	
Endosulfan	all	0.5 mg
Gossypol (free)	Cotton-seed meal	} 1,200.00 mg
	Cotton-seed cake	

46.16 References

1. *AAFCO* (1995): Official Publication 1995. Ass. of American Feed Control Officials (publisher). Sacramento, CA/USA.
2. *Abel, H.J.; Becker, J.; Meske, C.H.R.; and Friedrich, W.* (1984): Possibilities of using heat-treated full-fat soybeans in carp feeding. *Aquaculture*, 42., 97-108.
3. *Abu-Hassan, I.; Sayuthi, S.; Chiam, C.S.* (1984): Fabrication of feed suitable for smallholder aquaculture. Rome, RAO, FI:DPP/MAL/77/008 Field Document, 2., 262-278.
4. *ADCP* (1983): Quoted from: *Paulraj, R.* (1995).
5. *Ahamed, M.T.; Mollah, M.F.A.* (1992): Effects of various levels of wheat bran and mustard oilcake in the culture media on tubificid production. *Aquaculture*, 107., 107-113.
6. *Akiyama, D.M.* (1988): Soybean meal utilization in fish feeds. Pres. Korean Feed Asso. Conference, Seoul, Korea, August 1988.
7. *Akiyama, D.M.* (1991). The use of soy products and other plant protein supplements in aquaculture feeds. Proc. Aquaculture Feed Processing and Nutrition Workshop, Thailand and Indonesia, 19 to 25 September 1991, 199. (American Soybean Asso., Singapore).
8. *Akiyama, D.M.* (1991): Soybean meal utilization by marine shrimp. Proc. Aquaculture Feed Processing and Nutrition Workshop, Thailand and Indonesia, 19 to 25 September 1991, 207. (American Soybean Asso., Singapore).
9. *Akiyama, D.M.; FSGP Aquaculture Research* (1989): The use of soybean meal to replace white fish meal in commercially processed *Penaeus monodon* Fabricius feeds in Taiwan, R.O.C. Proc. Aquaculture Feed Processing and Nutrition Workshop, Thailand and Indonesia, 19 to 25 September 1991, 289-299 (American Soybean Asso., Singapore).
10. *Akiyama, D.M.; Dominy, W.G.; Lawrence, A.L.* (1991): Penaeid shrimp nutrition for the commercial feed industry: Revised Proc. Aquaculture Feed Processing and Nutrition Workshop, Thailand and Indonesia, 19 to 25 September 1991, 80 (American Soybean Asso., Singapore).
11. *Alexis, M.; Filioglou, M.; Theochari, V.* (1988): Apparent digestibility measurements of feedstuffs having potential for use in rainbow trout diets. *Thalassographica*, 11., 19-26.
12. *Alexis, M.N.; Paparaskeva P.E.; Eheochari, V.* (1985): Formulation of practical diets for rainbow trout (*Salmo gairdneri*) made by partial or complete substitution of fish meal by poultry by-products and certain plant by-products. *Aquaculture*, 50., 61-73.
13. *Anderson, J.S.; Lall, S.P.; Anderson, D.M.; Chandrasoma, J.* (1992): Apparent and true availability of amino acids from common feed ingredients for Atlantic salmon (*Salmo salar*) reared in seawater. *Aquaculture*, 108., 111-124.
14. *Andrews, J.W.; Page, J.W.* (1974): Growth factors in the fish meal component of catfish, *J. Nutr.*, 109., 1508-1511.
15. *Armas, A.B.; Chicco, C.F.* (1977): Use of palm-kernel meal of the oil palm (*Elaeis guineensis* Jacq) in broiler chicken diets. *Agronomia Tropical*, 27., 339-343.
16. *Arnesen, P.; Bråtås, L.E.; Olli, J.; Krogdahl, A.* (1989): Soybean carbohydrates appear to restrict the utilization of nutrients by Atlantic salmon (*Salmo salar* L.). Proc. Third Int'l. Symposium on Feeding and Nutrition in Fish. Toba, Japan. 28 August to 1 September, 273-280.
17. *Arthur, D.* (1971): Quoted from: *Bowland, J.P.* 1990.
18. *Babatunde, G.M.; Fetuga, B.L.; Odemosu, O.; Oyenuga, V.A.* (1975): Palm kernel meal as the major protein concentrate in the diets of pigs in the tropics. *J. Sci. Fd. Agric.*, 26., 1279-1291.
19. *Balazs, G.H.; Ross, E.* (1976): Effect of protein source and level on growth and performance on the

- captive freshwater prawn, *Macrobrachium rosenbergii*. Aquaculture, 7., 299.
20. Balazs, G.H.; Ross, E.; Brooks, C.C. (1973): Preliminary studies on the preparation and feeding of crustacean diets. Aquaculture, 2., 369.
 21. Balogun, A.M.; Ologhobo, A.D. (1989): Growth performance and nutrient utilization of fingerling *Clarias gariepinus* (Burchell) fed raw and cooked soybean diets. Aquaculture, 76., 119-126.
 22. Bardach, J.C.; Ryther, J.H.; McLarney, W.O. (1972): Aquaculture farming and husbandry of freshwater and marine organisms. John Wiley and Sons, Inc. New York/USA.
 23. Bath, D.; Dunbar, J.; King, J.; Berry, S.; Leonard, R.O.; Olbrich, S. (w/o year): Composition of by-products and unusual feedstuffs (Mimeograph).
 24. Bell, J.F.; Raynard, R.S. (1990): Effects of high linoleic acid diet on the fatty acid composition of leucocytes from Atlantic salmon (*Salmo salar*). Tran. Biochem. Soc., 18., 911-912.
 25. Boonyaratpalin, M.; Promkunthong, W.; Supamataya, K. (1988): Quoted from: Akiyama, D.M. (1988).
 26. Bowland, J.P. (1990): Linseed meal. In: Thacker, P.A.; Kirkwood, R.N. (eds.): Nontraditional feed sources for use in swine production. Butterworth Publisher, Stoneham, MA/USA.
 27. Brandt, T.M. (1979): Use of heat treated full-fat soybeans in channel catfish and golden shiner feeds. Proc. 1979, Fish Farming Conference and Annual Meeting Convention, Catfish farmers of Texas, 17 to 19 January, Texas A&M Univ. 52-61.
 28. Brown, P.B.; Robinson, E.H.; Clark, A.E.; Lawrence, A.L. (1989): Apparent digestible energy coefficients and associative effects in practical diets for red swamp crayfish. J. World Aquacult. Soc., 20., 122-126.
 29. Cardenete, G.; Morales, A.E.; Higuera, M. de la; Sanz, A. (1993): Nutritive evaluation of sunflower meal as a protein source for rainbow trout. Proc. 4th Int'l. Symp. on Fish Nutrition and Feeding. Institut de National de la Recherche Agronomique., Paris/France, 61., 927-931.
 30. Catacutan, R.M. Quoted from: *Feed Development Section* (1994).
 31. Cheeke, P.R. (1987): Rabbit feeding and nutrition. Academic Press, Inc., Orlando Florida/U.S.A.
 32. Chen, H.Y.; Zein-Eldin, Z.P.; Aldrich, D.V. (1985): Combined effects of shrimp size and dietary protein source on growth. J. World Maricul. Soc., 16., 288-296.
 33. Chow, K.W. (1982): India: Carp Nutrition Research at the Freshwater Aquaculture Research Training Centre, Dhauri, Establishment of a Nutrition laboratory and Initiation of a FI:DP/IND/75/031, Field Document. (4), 30.
 34. Cocker, J.E.; Cho, C.Y.; Slinger, S.G. (1978): Growth of rainbow trout on a diet containing a high level of full-fat soybean meal. Fish Ame. Rep. Ontario (Canada), Ministry of Natural Resources. 14-36.
 35. Coelho, J.F.S.; De Castro, C.A.M.; Gomes, E.F.S. (1988): Quoted from: Olli, J.J. et al. (1994).
 36. Cuca, M.; Sunde, M.L. (1967): Quoted from: Ravindran, V. (1990).
 37. Dabrowski, K.; Poczynski, P.; Köck, G.; Berger, B. (1989): Effect of partially or totally replacing fish meal protein by soybean meal protein on growth, food utilisation and proteolytic enzyme activities in rainbow trout (*salmo gairdneri*). New *in vivo* test for exocrine pancreatic secretion. Aquaculture, 77., 29-49.
 38. Darroch, C.S. (1990): Safflower meal. In: Thackers, P.A.; Kirkwood, R.N. (eds.): Non-traditional feed sources for use on swine production. Butterworth Publishers, Stoneham/USA.
 39. Davis, D.A.; Kurmaly, K. (1993): Advances in mineral nutrition for aquatic species. Conference Contribution at VICTAM ASIA'93. 25 October, Bangkok/Thailand.
 40. De Boer, F.; Bickel, H. (1988): Livestock feed resources and feed evaluation in Europe. Elsevier Sciences Publishers, Amsterdam/The Netherlands.
 41. De la Hoz, L.; Ordoñez, J.A.; Asension, M.A.; Cambero, M.I.; Sanz, B. (1987). Effects of diets supplemented with olive oil bagasse or technical rendered fat on the apolar lipids and their fatty acid composition of trout (*Salmo gairdneri*) muscle. Aquaculture, 66., 149-162.

42. *Devendra, C.* (1977): Quoted from: *Hertrampf, J.W.* (1989).
43. *Dinussen, W.E.* (1990): Sunflower meal. In: Thacker, P.A.; Kirkwood, R.N. (eds.): Nontraditional feed sources for use in swine nutrition. Butterworths Publishers, Stoneham, MA/U.S.A., 465-480.
44. *Dorsa, W.J.; Robinette, H.R.; Robinson, E.H.; Poe, W.E.* (1982): Effects of dietary cottonseed meal and gossypol on growth of young channel catfish. *Trans. Amer. Fish. Soc.*, 3., 651-655.
45. *El Sayed, A.F.M.* (1990): Long-term evaluation of cottonseed meal as a protein source for Nile tilapia (*Oreochromis niloticus* Linn.). *Aquaculture*, 84., 315-320.
46. *Evans, M.* (1985): Nutrient composition of feedstuffs for pigs and poultry. Queensland Dept. of Primary Industries Information Series Q185001. (Birsbane/Australia).
47. *Fallu, R.* (1991): Abalone farming. Fishing News Book, Oxford, England.
48. *Feed Development Section* (1994): Feeds and feeding of milkfish, Nile tilapia, Asian sea bass, and tiger shrimp. SEAFDEC Aquaculture Dept., Tigbauan, Iloilo, Phil.
49. *Feltwell, R.; Fox, S.* (1978): Practical poultry feeding. Faber and Faber, London and Boston.
50. *Fernandez, R.R.; Lawrence, A.L.* (1989): Nutritional responses of three species of postlarval penaeid shrimp to cottonseed meal. ASEAN/UNDP/FAO Regional Small-scale Coastal Fisheries Dev. Project. RAS84/016, December. 23. (Manila/Philippines).
51. *Forster, J.R.M.; Beard, T.W.* (1973): Quoted from: *Akiyama, D.M.* (1988).
52. *Fowler, L.G.* (1980): Substitution of soybean and cottonseed products for fishmeal in diets fed to chinook and coho salmon. *Prog. Fish. Cult.* 42., 87-91.
53. *Fowler, L.G.* (1981): Quoted from: *Lovell, R.T.* (1989).
54. *Friesecke, H.* (1984): Hanbuch der praktischen Fütterung von Rind, Schaf., Pferd., Schwein, Geflügel and Süßwasserfischen. BLV Verlagsges, München/Germany.
55. *Gill, C.* (1993): Chemistry for high quality pellets. *Feed International* 14., (3), 10-11).
56. *Göhl, B.* (1981): Tropical feeds. FAO Animal Production and Health Series No. 12: 529.
57. *Hale, O.M.; McCormick, W.C.* (1981): Value of peanut skins (testa) as feed ingredient for growing-finishing swine. *J. Animal Sci.*, 53., 1006-1010.
58. *Halverson, A.W.; Hendrick, C.M.; Olson, O.E.* (1955): Quoted from: *Bowland, J.P.* (1990).
59. *Haroon, A.K.Y.* (1990): Freshwater prawn farming trials in Bangladesh. *Naga, the ICLARM Quarterly*. July 1990, 6-7.
60. *Hartfiel, W.; Schulz, D.; Greuel, E.* (1981): Untersuchungen über die Futterverwertung der Regenbogenforelle (*Salmo gairdneri*). II. Einsatz von zwei rohen Rapsölen mit stark unterschiedlichem Eruksäuregehalt im Vergleich zu Sonnenblumenöl in einer synthetischen Futtermischung. *Fischwirt*, 31., 63-64.
61. *Hasan, M.R.; Alam, M.G.M.; Islam, M.A.* (1989): Evaluation of some indigenous ingredients as dietary protein sources for catfish (*Clarias batrachus*, Linnaeus) fry. *Proc. Asian Seminar on Aquaculture, IFS, Malang, Indonesia*, 14 to 18 November 1988, 125-137.
62. *Hasan, M.R.; Azad, A.K.; Farooque, A.M.D.; Akand, A.M.; Das, P.M.* (1991): Evaluation of some oilseed cakes as dietary protein sources for the fry of Indian major carp (*Labeo rohita* Hamilton). *Proc. 4th Asian Fish Nutrition Workshop. Asian Fish. Soc. Spec. Publ. No. 5 Asian Fisheries Soc., Manila, Philippines*, 107-117.
63. *Hendricks, H.G.C.J.M.; Ingh, T.S.G.A.M. van den; Krogdahl, A.; Olli, J.J.; Koninkx, J.F.J.G.* (1990): Quoted from: *Olli, J.J. et al.* (1994).
64. *Hepher, B.* (1988): Nutrition of pond fishes. Cambridge Univ. Press, Cambridge/UK.
65. *Hertrampf, J.W.* (1989): Die Ölpalme - Lieferant von Futtermitteln. *Kraftfutter*, 72., 334-341/388-390.
66. *Hertrampf, J.W.* (1992): On the water durability of aquaculture feed pellets - A review. *Advances in Feed Techn.*, (7), 18-38.

67. Higgs, D.A. Market, J.R.; Macquarrie, D.W.; McBride, J.R.; Dosanjh, B.S.; Nicholo, C.; Hoskins, G. (1979): Development of practical diets for coho salmon (*Oncorhynchus kisutch*) using poultry by-products meal, feather meal, soybean and rapeseed meals as major protein sources. Proc. Finfish Nutrition and Fish Feed Technology. Vol. 2, 191-218. Berlin/Germany.
68. Higgs, D.A.; McBride, J.R.; Markert, J.R.; Dosanjh, B.S.; Plotnikoff, M.D.; Clarke, C. (1982): Evaluation of tower and candle rapeseed (canola) meal and Bronowski rapeseed protein concentrate as protein supplements in practical dry diets for juvenile chinook salmon (*Oncorhynchus tshawytscha*). Aquaculture, 29., 1-31.
69. Higgs, D.A.; Fagerlund, U.H.M.; McBride, J.R.; Plotnikoff, M.D.; Dosanjh, B.S.; Markert, J.R.; Davidson, J. (1983): Protein quality of Altex canola meal for juvenile chinook salmon (*Oncorhynchus tshawytscha*) considering dietary protein and 3,5,3-triiodo-L-thyronine. Aquaculture, 34., 213-238.
70. Higgs, D.A.; Dosanjh, B.S.; Little, M.; Roy, R.J.J.; McBride, J.R. (1990): Potential for including canola products (meal and oil) in diets for *Oreochromis mossambicus* x *Oreochromis aureus* hybrids. The current status of fish nutrition in aquaculture. Proc. Third Int'l. Symp. on Feeding and Nutrition in Fish. Toba, Japan. 28 August to 1 September 1989. 301-314.
71. Hossain, M.A.; Jauncey, K. (1989): Studies on the protein, energy and amino acid digestibility of fish meal, mustard oilcake, linseed and sesame meal for common carp (*Cyprinus carpio* L.). Aquaculture, 83., 59-72.
72. Hossain, M.A.; Jauncey, K. (1989): Nutritional evaluation of some Bangladesh oilseed meals as partial substitutes for fish meal in the diet of common carp (*Cyprinus carpio* L.). Aquacult. and Fish. Mgt., 20., 255-268.
73. Huang, Y.; Liu, Y. (1990): Availabilities of Ca and P in nutritive salts and Ca, P, Mg, Fe in feeds for grass carp (*Ctenopharyngodon idellus*). Acta Hydrobiol. Sing. Shuishen Shengwy Xuebo, 14., 145-152.
74. Huner, J.V. (1995): Ecological observations of red swamp crayfish (*Procambarus clarkii* Gerard [1852]) and white river crayfish (*Procambarus zonangulus* Hobbs and Hobbs [1990]) as regards their cultivation in earthen ponds. Proc. Freshwater crayfish 10th Int'l. Symp. Astacology, LSU 1995, 456-458.
75. Hutagalung, R.I. (1981): The use of tree crops and their by-products for intensive animal production. Proc. Intensive Animal Production in Developing Countries. Br. Soc. Anim. Prod. Occas. Paper, N. (4), 151-184.
76. Ingh, T.S.G.A.M. van den; Krogdahl, A.; Olli, J.J.; Hendricks, H.G.C.J.M.; Koninx, J.F.J.G. (1991): The effect of soybean containing diets on small intestine in Atlantic salmon (*salmo salar*): A morphological study. Aquaculture, 94., 297-305.
77. Jackson, A.J.; Capper, B.S.; Matty, A.J. (1982): Evaluation of some plant proteins in complete diets for the tilapia *Sarotherodon mossambicus*. Aquaculture, 27., 97-109.
78. Jauncey, K.; Ross, B. (1982): A guide to Tilapia feeds and feeding. Institute of Aquaculture, Univ. of Stirling, Scotland.
79. Jensen, L.S.; Chang, C.H. (1976): Fractionation studies on a factor in linseed meal protecting against selenosis in chicks. Poultry Sci., 55., 594-599.
80. Kakade, M.L.; Rackis, J.J.; McGhee, J.E.; Puski, G. (1974): Quoted from: Vohra, P.; Kratzer, F.H. (1991).
81. Kamarudin, M.S.; Kaliapan, K.M.; Siraj, S.S. (1989): The digestibility of several feedstuffs in red tilapia. Proc. Third Asian Fish Nutrition Network Meeting, Asian Fisheries Society Special Publication, 4., 118-122.
82. Kanazawa, A. (1984): Feed formulation for penaeid shrimp, sea bass, grouper and rabbit fish culture in Malaysia. FAO/FI:DP/MAL/77/008 Field Document 2, 61-78.
83. Khan, M.S. (1994): Apparent digestibility coefficients for common feed ingredients in formulated diets for tropical catfish, *Mystus nemurus* (Cuvier & Valenciennes). Aquacult. Fish. Mgt., 25., (2), 167-174.
84. Kim, I.B.; Oh, J.K. 1985): Quoted from: Lim and Dominy (1991).

85. Law, A.T. (1986): Digestibility of low cost ingredients in pelleted feed by grass carp (*Ctenopharyngodon idella*). *Aquaculture*, 51., 97-103.
86. Law, A.T.; Chin, K.S.S.; Ang, K.J.; Kamarudin, M.S. (1990): Digestibility of low cost ingredients in pelleted feeds by *Macrobrachium rosenbergii* (de Man). Proc. Second Asian Fish. Forum, Tokyo, Japan, 17 to 22 April 1989. 333-336.
87. Lawrence, A.L.; Castillo, F.L. Jr.; Sturmer, L.N.; Akiyama, D.M. (1986): Nutritional response of marine shrimp to different levels of soybean meal on feeds. Pres. USA-ROC and ROC-USA Economic Councils 10th Anni. Joint Business Conf., Taipei, Taiwan/ROC, December 1986.
88. Leatherland, J.F.; Hilton, J.W.; Slinger, S.J. (1987): Effects of thyroid hormone supplementation of canola meal-based diets on growth and interrenal and thyroid gland physiology of rainbow trout (*Salmo gairdneri*). *Fish. Physiol. Biochem.*, 3., 73-82.
89. Lebas, F. (1993): Quoted from: Cheeke, P.R. (1987).
90. Leibowitz, H.E. (1981): Quoted from: Lovell, R.T. (1991).
91. Lennerts, L. (1988): Rapsextraktionschrot und Rapskuchen/expeller. *Die Mühle + Mischfüttertechnik*, 125., 627-629.
92. Liener, I.E. (ed.): (1969): Toxic constituents of plant foodstuffs. Academic Press, New York/USA.
93. Lim, C.; Dominy, W. (1991): Utilisation of plant proteins by warmwater fish. Proc. Aquacult. Feed Processing and Nutrition Workshop. 19 to 25 September 1991, Thailand and Indonesia (Ame. Soybean Asso., Singapore), 163-172.
94. Lim, C.; Akiyama, D.M. (1991): Full-fat soybean meal utilization by fish. Proc. Aquaculture Feed Processing and Nutrition Workshop Thailand and Indonesia, 19 to 25 September 1991, (Ame. Soybean Asso., Singapore), 188.
95. Liu, C.Q.; Rimmer, R.; Salama, H.S.; Morris, O.N. (1993): Making Canola even better. IDRC-Report, 21., 20-21.
96. Lochmann R.; McClain, W.R.; Gatlin, D.M. (1992): Evaluation of practical feed formulations and dietary supplements for red swamp crayfish. *J. World Aquaculture Soc.*, 23., 217-227.
97. Lovell, R.T. (1979): Formulating diets for aquaculture species. *Feedstuffs*, 51., 29-32.
98. Lovell, R.T. (1989): Nutrition and feeding of fish. Van Nostrand Reinhold, New York/USA.
99. Lovell, R.T. (1991): The use of soybean products in diets for aquaculture species: Revised Proc. Aquaculture Feed Processing and Nutrition Workshop, Thailand and Indonesia, 19 to 25 September 1991, 173-187.
100. Lovell, R.T.; Prather, E.E.; Tres-Dick, J.; Chhorn, L. (1974): Effects of addition of fish meal to all-plant feeds on the dietary protein needs of channel catfish in ponds. Proc. 28th Annual Conf. Southeastern Asso. of Game and Fish Commission. 222-227.
101. Lyman, C.M.; Holland, B.R.; Hale, F. (1944): Quoted from: Tanksley, T.D. (1990).
102. Lyon, C.K.; Gumban, M.R.; Betschart, A.A.; Robbins, D.J.; Saunders, R.M. (1979): Removal of deleterious glucosides from safflower meal. *J. Amer. Oil Chem. Soc.* 560-564.
103. Madu, C.T.; Ajibola, R.F. (1988): Dietary protein requirements of mudfish (*Clarias anguillaris*) fingerlings. Ann. Rep. National Inst. for Freshwater Fish. Res., Fed. Ministry Sci. and Tech. 110-116 (New Bussa/Nigeria).
104. Madu, C.T.; Tumba, T.T. (1988): The optimum crude protein level for the diet of mudfish fingerlings in an outdoor rearing system. Ann. Rep. National Inst. for Freshwater Fish. Res., Fed. Ministry Sci. and Tech. 104-109 (New Bussa/Nigeria).
105. Martinez, C.A. (1986): Quoted from: Cardenete et al., 1993.
106. Martinez, P.J.; Fernandez, C.J. (1980): Composicion, digestibilidad, valor nutritivo relaciones entre ambos de diversos piensos papra conejos. Proc. 2nd World Rabbit Congr. 2. 214-224.
107. Martinez, J.P.; Herraes, M.P.; Alvarez, R. (1994): Response of hatchery-reared *Rana perezi* larvae fed

- different diets. *Aquaculture*, 128, 235-244.
108. May, J.L.; Brown, P.B. (1993): Canola meal as a protein source for channel catfish. Proc. Discovery to Commercialization. European Aquaculture Soc., Oostende/Belgium. 19., 242.
 109. McDonald, P.; Edwards, R.A.; Greenhalgh, J.F.D. (1981): Quoted from: Hasan et al. (1991).
 110. Meyer, H.; Heckötter, E. (1986): Futterwerttabellen für Hunde und Katzen. Schlütersche Verlagsanstalt und Druckerei GmbH & Co., Hannover/Germany.
 111. Miller Jones, J. (1992): Food safety. Eagan Press, St. Paul, Minnesota/USA.
 112. Mohsen, A.A. (1988): Quoted from: Lim, C.; Dominy, W. (1991).
 113. Murai, T.; Ugatta, H.; Nose, T. (1982): Methionine coated with various materials supplemented to soybean meal diet for fingerling carp *Cyprinus carpio* and channel catfish *Ictalurus punctatus*. Bull. Jap. Soc. Sci. Fish., 48., 85-88.
 114. Murai, T.; Ugatta, H.; Kosutarak, P.; Arai, S. (1986): Effects of amino acid supplementation and methanol treatment in utilisation of soy flour by fingerling carps. *Aquaculture*, 56., 197-206.
 115. Murray, M.G. (1982): Quoted from: Lovell, R.T. (1991).
 116. Nandeesh, M.C.; Srikanth, G.K.; Varghese, T.J.; Keshavanat, P.; Shetty, H.P.C. (1989): Growth performance of an Indian major carp *Catla catla* (Ham) on fish meal-free diets. Proc. Third Asian Fish Nutrition Workshop. Asian Fish. Soc. Spec. Publ. 4, Asian Fish. Soc., Manila/Philippines. 137-142.
 117. Nandeesh, M.C.; Srikanth, G.K.; Varghese, T.J.; Keshavanat, P.; Shetty, H.P.C. (1989): Influence of silkworm pupa based diets on growth organoleptic quality and biochemical composition of *Catla rohu* hybrid. Proc. Asian Seminar on Aquaculture, IFS, Malang, Indonesia, 14 to 18 November 1988, 211-221.
 118. Nandeesh, M.C.; Srikanth, G.K.; Keshavanat, P.; Das, S.K. (1991): Protein and fat digestibility of five feed ingredients by an Indian major carp *Catla catla* (Ham.). Fish nutrition research in Asia. Proc. 4th Asian Fish Nutrition Workshop. Asian Fish. Soc. Spec. Publ. 5. Asian Fisheries Society, Manila, Philippines, 75-81.
 119. Nandeesh, M.C. (1993): Aquafeeds and feeding strategies in India. Proc. FAO/AADCP Regional Expert Consultation on Farm Made Aquafeeds. FAO-RAPA/AADCP. 14 to 18 December 1992; 213. (Bangkok/Thailand).
 120. New, M. (1987): A manual on the preparation and presentation of compound feeds for shrimps and fish in aquaculture. UNDP/FAO/ADCP/REP/87/26.
 121. New, M.B.; Singholka, S. (1982): Quoted from Paulraj, R. (1995).
 122. Newton, G.L.; Hale, O.M.; Haydon, K.D. (1990): Peanut kernels. In: Thacker, P.A.; Kirkwood, R.N. (eds.): Non-traditional feed sources for use in swine production. Butterworth Publisher, Stoneham, MA/U.S.A.
 123. NRC (1981): Nutrient requirements of coldwater fish. Nutrient requirements of domestic animals. No. 16. National Academy Press, Washington D.C./U.S.A.
 124. NRC (1983): Nutrient requirements of warmwater fishes and shellfishes (revised ed.). Nutrient requirements of domestic animals. National Academy Press, Washington D.C./U.S.A.
 125. NRC (1993): Nutrient requirement of fishes. National Research Council, National Academy Press, Washington D.C./U.S.A.
 126. Oduro-Boateng, F. (1986): Studies on the feeding of tilapia discolor in floating cages in Lake Bosomtwi (Ghana). Proc. African Seminar on Aquaculture Organized by the Internatinal Foundation for Science in Kisumu, Kenya, 7 to 11 October 1985, 115-122.
 127. Ofojekwu, P.C.; Ejike, C. (1984): Growth response and feed utilization in the tropical cichlid *Oreochromis niloticus* (Linn.) fed on cottonseed-based artificial diets. *Aquaculture*, 42., 27-36.
 128. Ogbonna et al. (1988): Quoted from: Herrampf, J. (1989).
 129. Olli, J.; Krogdahl, A. (1994): Nutritive value of four soybean products as protein sources in diets for

- rainbow trout (*Oncorhynchus mykiss*, Wahlbaum) reared in freshwater. Acta Agric. Scand., Sect. A., Animal Sci., 44., 185-192.
130. Olli, J.; Krogdahl, A.; Ingh, T.S.G.A.M. van den; Bråtton, L.E. (1994): Nutritive value of four soybean products in diets for Atlantic salmon (*Salmo salar* L.), Acta Agric. Scand., Sect. A, Animal Sci., 44., 50-60.
 131. Omoregie, E.; Ogbemudia, F.I. (1993): Effect of substituting fish meal with palm-kernel meal on growth and good utilisation of the Nile tilapia (*Oreochromis niloticus*). Bamidgeh, 45., 113-119.
 132. Pantha, M.B. (1993): Aquafeeds and feeding strategies in Nepal. Proc. FAO/AADCP Consultation on Farm-Made Aquafeeds, 14 to 18 December 1992, 213-254, FAO-RAPA/AADCP, Bangkok/Thailand.
 133. Paulraj, R. (1995): Aquaculture feed (2nd edition). Marine Prod. Export Dev. Authority, Kochi India (Publ.)
 134. Piedad-Pascual, F.; Catacutan, M. (1990): Defatted soybean meal and leucaena leaf meal as protein sources in diets for *Penaeus monodon* juveniles. Proc. The Second Asian Fisheries Forum, 1991. Asian Fish. Soc., Manila, Philippines, 345.
 135. Piedad-Pascual, F.; Cruz, E.M.; Sumalangcay, A. Jr. (1991): Supplemental feeding of *Penaeus monodon* juveniles with diets containing various levels of defatted soybean meal. Aquaculture, 89., 1983-191.
 136. Popma, T.J. (1982): Quoted from: Lovell, R.T. (1991).
 137. Randall, J.M.; Reuter, F.W.; Wales, A.C. (1975): Quoted from: Newton, G.L., et. al. (1990).
 138. Ravindran, V. (1990): In: Thacker, P.A.; Kirkwood, R.N. (eds.): Sesame meal. Nontraditional feed sources for use in swine nutrition. Butterworth Publishers, Stoneham/U.S.A.
 139. Reinütz, G.L.; Orme, L.E.; Lenim, C.A.; Hitzel, F.H. (1978): Full-fat soybean meal in rainbow trout diets. Feedstuff, 50., (3), 23-24.
 140. Robinson, E.H. (1991): Improvement of cottonseed meal protein with supplemental lysine in feeds for channel catfish. J. Appl. Aquacult., 1., 1-14.
 141. Robinson, E.H.; Brent, J.R. (1989): Use of cottonseed meal in channel catfish feeds. J. World Aquacult. Soc., 20., 250-255.
 142. Robinson, E.H.; Li, M.H. (1994): Use of plant proteins in catfish feeds: Replacement of soybean meal with cottonseed meal and replacement of fishmeal with soybean meal and cottonseed meal. J. World Aquacult. Soc., 25., 271-276.
 143. Robinson, E.H.; Wilson, R.P. (1985): Nutrition and Feeding. In: Tucker, C.S. (ed.): Channel catfish culture 323-404. Elsevier, New York.
 144. Robinson, E.H.; Li, M.H.; Rawless, S.D.; Stickney, R.R. (1984): Evaluation of glanded and glandless cottonseed products in catfish diets. Prog. Fish. Cult., 46., 92-97.
 145. Roehm, J.N.; Lee, D.J.; Sinnhuber, R.O. (1967): Accumulation and elimination of dietary gossypol in the organs of rainbow trout. J. Nutrition, 92., 425-428.
 146. Roehm, J.N.; Lee, D.J.; Wales, J.H.; Polityka, S.D.; Sinnhuber, R.O. (1970): The effect of dietary stercoulic acid on the hepatic lipid of rainbow trout. Lipids, 5., 80-84.
 147. Saad, C.R.B. (1979): Quoted from: Lim, C.; Dominy, W. (1991).
 148. Santiago, C.B.; Aldaba, M.B.; Laron, M.A. (1982): Dietary crude protein required for *Tilapia nilotica* fry. Kalikasan Philipp, J. Biol. 11., 255-265.
 149. Santiago, C.B.; Reyes, O.S.; Aldaba, M.B. and Laron, M.A. (1986): An evaluation of formulated diets for Nile tilapia fingerlings. Fish. Res. J. Philipp. 11., 5-12.
 150. Sanz, B.; De la Hoz, L.; Ordóñez, J.A. (1985): Quoted from: De la Hoz et al. (1987).
 151. Scerbina, M.A. (1970): Quoted from: Steffens, W. (1985).
 152. Schulz, D.; Goerlich, R.; Hartfiel, W.; Greuel, E. (1985): Vergleichende Untersuchungen an Regenbogenforellen (*Salmo gairdneri* R.) über den Futterwert eines herkömmlichen Sojafleinmehles und eines Sojaproduktes ohne antigen-wirkung. Z. Tierphysiol, Tierernährung, Futtermittelkd. 53., 199-207.

153. Schutter, A.C. de; Morris, J.R. (1990): Soybeans: Full-fat. In: Thacker, P.A.; Kirkwood, R.N. (eds.): Nontraditional feed sources for use in swine production. Butterworth Publishers, Stoneham, MA/U.S.A.
154. Shiau, S.Y.; Chuang, J.L.; Sun, C.L. (1987): Inclusion of soybean meal in tilapia (*Oreochromis niloticus* x *O. aureus*) diets of two protein levels. *Aquaculture*, 65., 251-261.
155. Shiau, S.Y.; Pan, B.S.; Chen, S.; Yu, H.L.; Lin, S.L. (1988): Successful use of soybean meal with a methionine supplement to replace fish meal in diets fed to milkfish (*Chanos chanos* Forskal). *J. World Aqua. Soc.*, 19., 14-19.
156. Sick, L.V.; Andrews, J.W. (1973): The effect of selected dietary lipids, carbohydrates and protein on the growth, survival and body composition of *Penaeus duorarum*. *J. World Mariculture Soc.*, (4), 263.
157. Sinnhuber, R.O.; Lee, D.J.; Wales, J.H.; Ayres, J.L. (1968): Dietary factors and hepatoma in rainbow trout (*Salmo gairdneri*). II. Co-carcinogenes by cyclopropanoid fatty acids and the effects of gossypol and altered lipids in aflatoxin induced liver cancer. *J. Nat. Cancer Inst.*, 41., 1293-1301.
158. Smith, R.R. (1976): Quoted from: Lovell, R.T. (1991).
159. Smith, R.R. (1977): Recent research involving full-fat soybean meal in salmonid diets. *Salmonid*, 1., 8-11.
160. Smith, R.R.; Peterson, M.C.; Allred, A.C. (1980): Effect on leaching on apparent digestion coefficients of feedstuffs for salmonids. *Progr. Fish Culturist*, 42., 195-199.
161. Smith, R.R.; Kincaid, H.L.; Regenstein, J.M.; Rumsey, G.L. (1988): Growth, carcass composition and taste of rainbow trout of different strains fed diets containing primarily plant or animal protein. *Aquaculture*, 70., 309.
162. Steffens, W. (1985): Grundlagen der Fischernahrung. VEB Gustav Fischer Verlag, Jena/Germany.
163. Tacon, A.G.J. (1987): The nutrition and feeding of farmed fish and shrimp - A Training Manual 2. Nutrient Sources and Composition. FAO Field Document No. 5. 128 (Brasilia, Brazil).
164. Tacon, A.G.J (1993): Feed ingredients for warmwater fish, fish meal and other processed feedstuffs. FAO Fisheries Circular No. 856. 64. FAO, Rome.
165. Tacon, A.J.; Beveridge, M. (1981): Analysis of NIFI Clarias Diet, THA/75/012/WP 12:6, FAO, Rome.
166. Tacon, A.G.J.; Webster, J.L.; Martinez, C.A. (1984): Use of solvent extracted sunflower seed meal in complete diets for fingerling rainbow trout (*Salmo gairdneri* Richardson). *Aquaculture*, 43., 381-389.
167. Tacon, A.G.J.; Jauncey, R.; Falaye, A.; Pantha, M.; McGowan, I.; Stafford, E.A. (1983): Quoted from: Lim, C.; Dominy, W. (1991).
168. Tanksley, T.D. (1990): Cotton-seed meal. In: Thacker, P.A.; Kirkwood, R.N. (eds.): Nontraditional feed sources for use on swine production. Butterworth Publishers, Stoneham, MA/U.S.A.
169. Täufel, A.; Tannes, W.; Tunger, L.; Zobel, M. (1993): Lebensmittel-Lexikon. Behr's Verlag, Hamburg/Germany.
170. Thacker, P.A. (1990): Canola meal. In: Thacker, P.A.; Kirkwood, R.N. (eds.): Nontraditional feed sources for use on swine production. Butterworth Publishers, Stoneham, MA/U.S.A.
171. Thorne, P.J.; Cole, D.J.A.; Wiseman, J. (1990): Copra meal. In: Thacker, P.A.; Kirkwood, R.N. (eds.): Nontraditional feed sources for use on swine production. Butterworth Publishers, Stoneham, MA/U.S.A.
172. Unprasert, N. (1989): Fish feeds and feedstuffs used for aquaculture in Thailand. FAO field document, ASEAN/UNDP/FAO Regional Small-Scale Coastal Fisheries Development Project, Report SEAN/SF/89/Fen/11, Manila/Philippines, 147-155.
173. Viola, S. (1977): Energy values of feedstuffs for carp. *Bamidgeh*, 29., 29-30.
174. Viola, S.; Arieli, Y. (1983): Nutrition studies with tilapia (*Sarotherodon*). 1. Replacement of fish meal by soybean meal in feeds for intensive tilapia culture. *Bamidgeh*, 35., 8-17.
175. Viola, S.; Arieli, Y. (1983): Nutrition studies with tilapia hybrids. The effects of oil supplements to practical diets for intensive aquaculture. *Bamidgeh*, 35., 44-52.
176. Viola, S.; Mokady, S.; Arieli, Y. (1983): Effects of soybean processing methods on the growth of carp

- (*Cyprinus carpio*). *Aquaculture*, 32., 27-38.
177. Viola, S.; Zohar, G.; Arieli, Y. (1986): Phosphorus requirements and its availability from different sources for intensive pond culture species in Israel. Part. I. Tilapia. *Bamidgeh*, 38., 3-12.
178. Viola, S.; Zohar, G.; Arieli, Y. (1986): Requirement of phosphorus and its availability from different sources for intensive pond culture species in Israel. Part. II. Carp culture. *Bamidgeh*, 38., 44-54.
179. Viveen, W.J.A.R.; Richter, C.J.J.; Van Oordt, P.G.W.J.; Janseen, J.A.L.; Huisman, E.A. (w/o year): Practical manual for the culture of the African catfish (*Clarias gariepinus*). Univ. of Wageningen Wageningen, Netherlands.
180. Vohra, P.; Kratzer, F.H. (1991): Evaluation of soybean meal determines adequacy of heat treatment. *Feedstuffs*, 63., 34.
181. Wahlstrom, R.C.; Kamstra, L.D.; Olson, O.E. (1956): Quoted from: *Bowland, J.P.* (1990).
182. Waldroup, P.W.; Ramsey, B.E.; Helwig, H.M.; Smith, N.K. (1985): Optimum processing of soybean meal used in broiler diets. *Poultry Sci.* 64., 2314-2320.
183. Weinreich, O.; Koch, V.; Knippel, J. (1994): *Futtermittelrechtliche Vorschriften*. Buchedition Agrimelda. Hamburg/Germany.
184. Wilson, R.P.; Poe, W.E. (1985): Effects of feeding soybean meal with varying trypsin inhibitor activities on growth of fingerling channel catfish. *Aquaculture*, 46., 19-25.
185. Wilson, R.P.; Robinson, E.H.; Poe, W.E. (1987): Quoted from: *Lim, C.; Dominy, W.* (1991).
186. Yen, J.T.; Jensen, A.H.; Smini, J. (1977): Quoted from: *Schutter, A.C. de; Morris, J.R.* (1990).
187. Yeong, S.W.; Mukherjee, T.K.; Hutagalung, R.I. (1983): The nutritive value of palm-kernel cake as a feed-stuff for poultry. Proc. Nat. Workshop on Oil Palm By-Product Utilization, 14-15 December 1981, Kuala Lumpur/Malaysia.
188. Zaher, M.; Mazid, M.A. (1993): Aquafeeds and feeding strategies in Bangladesh. Proc. FAO/AADCP Regional Expert Consultation on Farm Made Aquafeeds. FAO-RAPA/AADCP. 14, to 18 December 1992. 216. (Bangkok/Thailand).
189. Zazueta, A.J.S.; Price, R.L. (1989): Solubility and electrophoretic properties of processed safflower seed (*Carthamus tinctorius L.*) proteins. *J. Agric. Food Chem.*, 37., 308-312.

47. VERMI MEAL

47.1 Rationale

Invertebrate animals are a source of protein. One of the best known representatives of this category is the earthworm. The round, segmented worm of the genus *Lumbricus* (class: *Oligochaeta*) is very important in aerating and fertilising the soil and breaking-down and utilising human and animal wastes⁽¹⁷⁾ (Figure 47-01). The mealworm, the worm-like, 2.0 cm long larva of any of the various beetles of the genus *Tenebrio* which infests granaries and bakeries, can also supply protein. Other species of worms have been tried in fish feeds and in waste management.

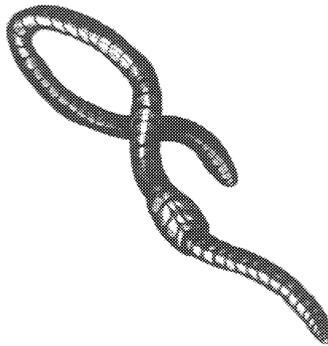


Figure 47-01. The red earthworm (genus: *Lumbricus*; class: *Oligochaeta*) can be 20 to 35 cm long and can live for as long as 10 years.

47.2 Culture of Worms

Vermiculture utilises only waste organic materials and manure. As much as 1.8 kg of biomass can be produced per m² of bedding. About 5.0 kg of fresh earthworms are needed for producing 1.0 kg of vermi meal⁽¹⁾. Vermiculture is a typical cottage industry. However, vermi meal can be also commercially produced^(1, 13).

47.3 Chemical, Physiological and other Properties

Chemical Properties

Vermi meal has a crude protein content of 52 to 70% and is remarkably higher than an average fish meal^(1, 4, 11, 13, 18). The protein content varies from species to species and

the substrate in which it has been cultured. This applies also for nutrients other than protein (Table 47-01). There is not much difference in the essential amino acid profile for various vermi meals (Table 47-02).

Earthworm meal is rich in highly unsaturated fatty acids (HUFA)⁽¹⁷⁾. The macro and trace mineral content of e.g. the African night crawler (*Eudrilus eugeniae*) is low (Table 47-03)⁽⁸⁾.

Table 47-01: Chemical composition (%) of various worm meals (in dry matter)^(3, 8, 11, 15, 17)

	<i>Eisenia foetida</i>	<i>Lumbricus terrestris</i>	<i>Allolobophora longa</i>	<i>Neries</i> sp.	<i>Eudrilus eugeniae</i>
Moisture	83.3	81.1	78.3	-	85.3
Crude protein	57.4	56.1	50.4	47.0	56.4
Crude fat	13.2	2.1	1.4	25.2	7.9
Ash	10.8	28.7	35.2	6.6	13.1
Crude fibre	0.7	-	-	-0.6	5.9
N-free extract	18.2	13.1	12.9	20.6	17.8

Table 47-02: Essential amino acid profile of vermi meals (g/16 g N)^(8, 11, 17)

	<i>Eisenia foetida</i>	<i>Lumbricus terrestris</i>	<i>Allolobophora longa</i>	<i>Eudrilus eugeniae</i>
Arginine	3.67	3.17	3.15	4.95
Histidine	1.39	1.38	1.01	1.58
Isoleucine	2.85	2.20	2.24	2.82
Leucine	4.90	4.11	3.57	5.22
Lysine	4.16	3.52	3.43	4.50
Methionine	0.83	1.11	0.5	1.04
Phenylalanine	2.65	2.02	2.65	2.47
Threonine	3.07	2.48	2.11	3.22
Tryptophan	0.67	0.44	-	0.63
Valine	3.11	2.30	2.46	3.39

Table 47-03: Macro and trace mineral contents of freeze dried vermi meal (*Eudrilus eugeniae*)⁽¹⁰⁾

Calcium	%	1.5
Phosphorus	%	0.9
Sodium	%	0.2
Iron	mg/kg	100.0
Zinc	mg/kg	122.5
Copper	mg/kg	7.8
Cadmium	mg/kg	21.0

Physiological Properties

The protein digestibility of vermi meal of 95% and above is high as found in the meal of some worm species. On the other hand the apparent dry matter digestibility of freeze-dried meal in rainbow trout (*Salmo gairdneri*) is low (Table 47-04).

Table 47-04: Digestibility (%) of vermi meal^(2, 5, 6, 8)

English name	Scientific name	Digestibility	
		Protein	Dry matter
Rainbow trout	<i>Salmo gairdneri</i>	94.6 ¹	69.2 ¹
Green sunfish	<i>Lepomis chanellus</i>	95.7 ²	-
Bluegill sunfish	<i>Lepomis macrochirus</i>	96.7 ²	-
Longear sunfish	<i>Lepomis microlophas</i>	97.4 ²	-
Perch	<i>Perca fluviatilis</i>	96.3 ³	-
Sole	<i>Solea solea</i>	96.0 ³	-

¹ *Eudrilus eugeniae* (African night crawler); ² *Tenebrio molitor* (mealworm); ³ *Oligochaetes* (worm meal)

Other Properties

Vermi meal may replace squid meal as an attractant⁽¹⁾. Undesirable substances may limit its use, as e.g. meal of the African night crawler is unpalatable⁽⁸⁾, and other vermi meals have been found to depress growth, perhaps due to the presence of a garlicky smell from the coelomic fluid of *Eisenia foetida*⁽¹⁴⁾.

47.4 Feeding Value

Vermi meal may replace fish meal and meat and bone meal. Broilers fed with earthworm meal consumed 13% less feed for the same weight gain than those fed with ordinary broiler diet, and ducks given live earthworms matured 15 days earlier than the control group without earthworms⁽¹³⁾

Fishes

Terrestrial lumbricoids (*Eisenia foetida*, *Allolobophora longa*, *Lumbricius terrestris*) were fed to rainbow trout (*Salmo gairdneri*). Frozen and to a lesser extent freeze-dried *Eisenia foetida* meal was found to be unpalatable to the fish while trout fed frozen *Allolobophora longa* and *Lumbricius terrestris* grew well or even better than fish fed a commercial trout diet⁽¹⁷⁾. However, freeze-dried meal from *Eudrilus eugeniae* could not satisfactorily replace fish meal in diets for rainbow trout⁽¹⁸⁾.

Dendrodrilus subrubicundus meal replaced fish meal up to 36% in diets for rainbow trout without negative effect on fish performance, but at 71% replacement fish growth

and feed utilisation decreased significantly⁽¹⁴⁾. Freeze-dried *Eisenia foetida* meal as a replacement for herring meal at increasing levels in diets for rainbow trout did not show any adverse effect when compared to fish fed a diet without earthworm meal, except for a significant increase in carcass fat (Table 47-05)⁽¹⁵⁾.

Tilapia (*Oreochromis niloticus*) fed with 15% vermi meal and 85% rice bran performed as well as a diet containing 25% fish meal and 75% rice bran⁽¹⁾.

Table 47-05: Response of rainbow trout (*Salmo gairdneri*) fed diets for 84 days with various inclusion levels of freeze dried *Eisenia foetida*⁽¹⁵⁾

<i>Eisenia foetida</i> meal	%	0	5.0	10.0	20.0	30.0
Crude protein	%	44.9	45.2	44.9	43.9	43.5
Crude fat	%	12.2	13.0	12.2	10.9	10.4

Weight gain	%	233.2	223.8	284.2	242.5	205.8
Daily feed intake	mg	312.7	311.9	360.5	351.5	303.0
Feed conversion	1:	1.55	1.61	1.63	1.45	1.42
SGR	%/day	1.43	1.34	1.60	1.54	1.33
Carcass composition (wet weight):						
- Crude protein	%	16.6	16.7	16.4	16.1	16.2
- Crude fat	%	7.8	8.6	9.0	9.0	8.1

Crustaceans

In diets for tiger prawn (*Penaeus monodon*) an earthworm meal at a level of 5.0% increased growth and survival and also served as a good attractant⁽¹⁰⁾

Under laboratory conditions tiger prawns of an initial mean weight of 0.54 g and 0,12 g, respectively, were fed with vermins, dried and fresh, for five weeks. Prawns grew better and had a higher survival rate when fed dried vermins than fresh ones. In a later trial 30% fish meal was replaced by *Eudrilus eugeniae* meal. The vermi meal was superior to the fish meal. There were no differences in the body composition of the prawns (Table 47-06)⁽¹¹⁾.

Marine annelids (*Nereis* sp.) are also fed to tiger prawn. The fresh or live annelid is given in the morning at 10% to 20% of biomass^(4, 9).

47.5 Recommended Inclusion Rates and Precautions

Recommended Inclusion Rates

Dietary inclusion rates of 5.0 to 40% earthworm (*Eisenia foetida*) meal in practical aquaculture feeds for carnivorous fish were observed⁽¹⁶⁾. An average inclusion rate is 15% but it should not exceed a level of 35%.

Precautions

Earthworms can be an intermediate host for gape worms of poultry (caused by *Syngamus trachea*) and lung worm in pigs. They may also harbour viruses⁽¹⁸⁾. In addition earthworm meal contains an undescribed toxin which can be removed by heating⁽⁴⁾.

Table 47-06: The effect of vermins in the diets for tiger prawns
(*Penaeus monodon*)⁽¹¹⁾

	<i>Eisenia foetida</i>		<i>Eudrilus eugeniae</i>	
Vermis, dried	-	10.0	-	10.0
Vermis, frozen	67.0	-	-	-
Fish meal	15.0	15.0	30.0	-
Shrimp head meal	17.0	17.0	15.0	15.0
Crude protein	33.3	33.8	41.2	38.4
Crude fat	12.5	12.7	11.5	11.3

Weight gain	97.8	156.6	178.0	345.0
Survival	46.7	63.3	50.0	72.0

47.6 References

1. *Anonymous* (1995): Earthworm meal for aquafeeds. Infofish International, (4), 40.
2. *Birkett, L.* (1969): Quoted from: *Hepher, B.* (1988).
3. *Cardenette, G.; Garzon, A.; Moyano, F.; Higuera, M. de la* (1993): Nutritive utilisation of earthworm protein by fingerling rainbow trout (*Oncorhynchus mykiss*). In: Fish nutrition in practice, INRA, Paris (ed.). Les Colloques, 61., 927-931.
4. *Feed Dev. Section* (1994): Feeds and feeding of milkfish Nile tilapia, Asian sea bass, and tiger shrimps. Aquaculture Extens. Manual, No. 21, SEAFDEC, Iloilo/The Philippines.
5. *Gerking, S.D.* (1952): Quoted from: *Hepher, B.* (1988).
6. *Gerking, S.D.* (1955): Quoted from: *Hepher, B.* (1988).
7. *Hepher, B.* (1988): Nutrition of pond fishes. Cambridge University Press, Cambridge/England.
8. *Hilton, J.W.* (1983): Potential of freeze-dried worm meal as a replacement for fish meal in trout diet formulations. Aquaculture, 32., 277-283.
9. *Millamena, O.M.; Primavera, J.H.; Pudadera, R.A.; Caballero, R.V.* (1986): The effect of diet on reproductive performance of pond-reared *Penaeus monodon* Fabricius broodstock. Proc. 1st Asian Fish. Forum, Manila/The Philippines, 593-596.
10. *Murai, T.; Sumalangcay, A., jr.; Pascual, F.P.* (1983): Supplement of various attractants to a practical diet for juvenile *Penaeus monodon* Fabricius. Fish Res. J. Philippines, 8., (2), 61-67.
11. *Piedad-Pascual, F.* (1985): An evaluation of three worms as feed ingredients in formulated diets for juvenile *Penaeus monodon*, Fish. Res. J. Philipp., 10., 9-15.

12. Roche, P.; Vallembois, P.; Davant, N.; Lassegues, M. (1981): Protein analysis of earthworm coelomic fluid. II. *Eisenia foetida* andrei factor (EFAF). *Comp. Biochem. Physiol. B*, 69., 829-836.
13. Sison, J.A. (1985): Handbook on crisis management on feedmilling and technology for the Philippines. Feedindex (Phils.), Quezon City/The Philippines.
14. Stafford, E.A.; Tacon, A.G.J. (1984): Nutritive value of earthworm, *Dendrodilus subribicundus*, grown on domestic sewage in trout diet. *Agriculture Wastes*, 9., 249-266.
15. Stafford, E.A.; Tacon, A.G.J. (1984): The nutritional evaluation of dried earthworm meal (*Eisenia foetida*, Savigny) included at low levels in productive diets for rainbow trout, *Salmo gairdneri* Richardson). *Aquaculture and Fish. Management*, 16., 213-222.
16. Tacon, A.G.J. (1995): The potential for fishmeal substitution in aquafeeds. *Inf fish International*, (3), 29-34.
17. Tacon, A.G.J.; Stafford, E.A.; Edwards, C.A. (1983): A preliminary investigation of the nutritive value of three terrestrial lumbricoid worms for rainbow trout, *Aquaculture*, 35., 187-199.
18. West, G.P. (1992): Black's veterinary dictionary. A & C Black, London/England, 17th ed.

48. VITAMIN C PRODUCTS

48.1 Rationale

Vitamin C, L-ascorbic acid, is a water-soluble vitamin widely distributed in plant and animal kingdoms. It is essential in nutrition, and in the food industry it is used to preserve processed food⁽¹⁷⁾.

Nearly all animal species synthesise L-ascorbic acid and do not require Vitamin C in their diet with the exception of man, other primates, guinea pigs, certain birds, fish and shrimps which cannot synthesise Vitamin C because they lack the liver enzyme L-gulonolactone oxidase^(14, 17).

Scurvy is one of the most known Vitamin C deficiency diseases from which people in ancient Egypt, Greece and Rome suffered, hence, Vitamin C is called the “antiscorbutic vitamin”.

In aquatic organisms, Vitamin C is involved in many metabolic processes, has certain biochemical functions, contributes to proper reproductive processes and increases resistance to diseases⁽³²⁾.

The large number of Vitamin C deficiency symptoms are more pronounced in the young fish, predominantly in the form of deformations of the gill and the spine. The “broken back syndrome” or scoliosis and lordosis is caused by severe Vitamin C deficiency (Figure 48-01)^(22, 23, 42). Skeletal deformation were also observed in bullfrog larvae (*Rana catesbeiana*) when fed Vitamin C deficient diets⁽²⁰⁾.

48.2 Synthesis

Small quantities of Vitamin C were manufactured by isolation from natural resources but subsequently replaced by the chemical synthesis of Vitamin C^(24, 25). Various derivatives and analogs have been prepared to find substances with greater activity than ascorbic acid. Derivatives such as C-2-scatyl-L-ascorbic acid have been synthesised but have little, if any, Vitamin C^(17, 37). Only salts and C-6-substituted esters have full vitamin C activity. Na-L-ascorbate, K-L-ascorbate, Ca-L-ascorbate and L-ascorbyl palmitate have commercial applications as Vitamin C and antioxidants⁽¹⁷⁾.

48.3 Properties

Ascorbic Acid

L-ascorbic acid is a white, odourless crystal or a powder with a sharp acidic taste. Its formula is $C_6H_8O_6$ with a molecular weight of 176.1 and a melting point of 190° to 192°C. Figure 48-02 shows the structural formula of L-ascorbic acid and its oxidised form (dehydro-ascorbic acid).

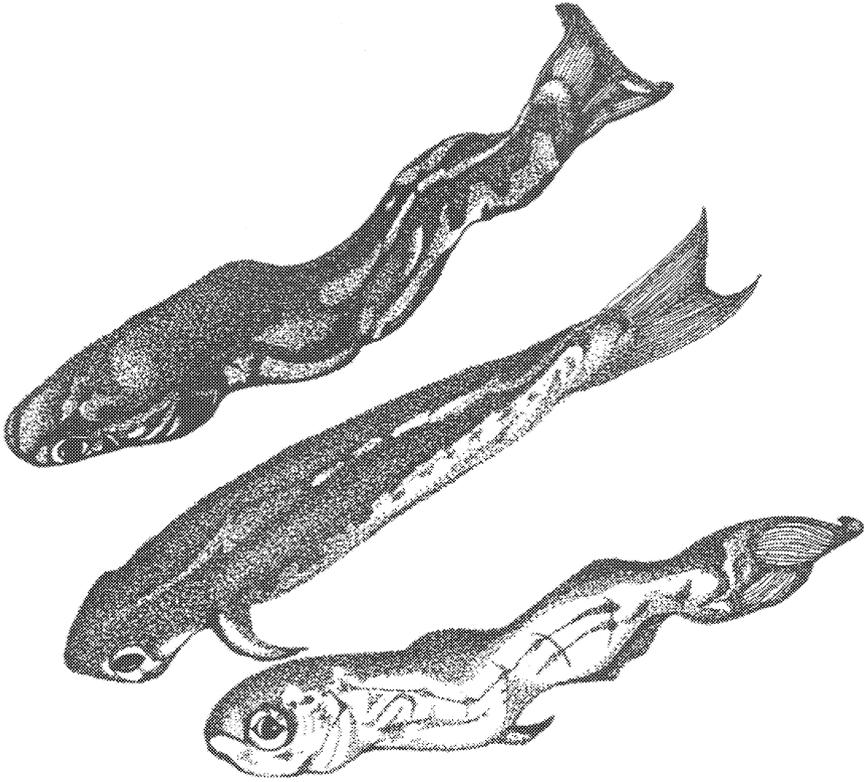


Figure 48-01. "Broken back syndrome: of Coho salmon (*Oncorhynchus kisutch*) (scoliosis [above], normal development [middle], lordosis [below]) redesigned from⁽⁴⁾.

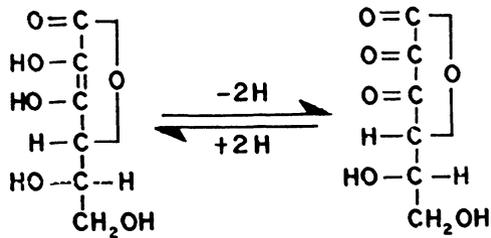


Figure 48-02. Structural formula of L-ascorbic acid (left) and its oxidised form dehydro-ascorbic acid (right)⁽¹³⁾.

Crystalline feed grade Vitamin C remains stable for a long period when properly stored in a hermetically sealed container in a cool and dry place but deteriorates rapidly when exposed to oxygen in air and water, forming dehydro-ascorbic acid. Oxidation accelerates as temperature increases. Normal processing of aquaculture feed destroys Vitamin C (Table 48-01)⁽¹⁾. Inherent Vitamin C of feedstuffs also deteriorate when stored, e.g. wheat after 12 months of storage loses 66.1% of the original Vitamin C content after harvest and after 18 months only 38.6% is retained⁽²⁾.

Table 48-01: The effect of pelletising temperature and feed's moisture content on the stability of Vitamin C (Vitamin C inclusion rate of test feed = 500 mg/kg)^(1,8)

Feed types	Pelletising temperature °C	Moisture of feed %	Retention of Vitamin C ¹ (%) after			
			Pelletising	Storage of... weeks		
				2	4	6
Mash	0	10.6	100	0	0	0
Pellets ²	80	11.6	54	50	32	27
Pellets	80	13.6	37	29	15	0
Pellets	65	9.7	84	97	72	58
Pellets	65	11.6	75	90	58	

¹The analytical error is $\pm 10\%$; ²Pellet diameter: 6.0 mm and 4.0 mm

Approximately 50% of Vitamin C supplement was lost during the extrusion processing of catfish feed. Extrusion is most damaging to vitamin C⁽²¹⁾. Conventional pelletising of aquaculture feed causes losses of 25 to 50%⁽²⁸⁾. The half life of ascorbic acid in pelletised trout feed is 14 to 35 days⁽¹⁶⁾. Storage losses of Vitamin C in pelletised feed averages 10 to 15% per week⁽²⁸⁾. Even low or zero heat processing of moist fish feeds may cause losses as high as 30% of the total added Vitamin C⁽²⁸⁾. This unstable property of Vitamin C is due to the C₂-position in the lactose ring of ascorbic acid which is highly reactive and susceptible to oxidation⁽³⁸⁾.

Surface coating of feed pellets for aquatic animals with a Vitamin C-oil emulsion is not of much value in effectively retaining Vitamin C since the emulsion leaches quickly into the water⁽³⁾.

Coating and Derivatives of Ascorbic Acid

Due to the high losses of crystalline Vitamin C during feed processing of aquaculture feed, alternative methods of delivering Vitamin C to cultured aquatic animals have been developed such as coating, encapsulating the ascorbid acid crystals or chemically reacting Vitamin C with other molecules to form more stable salts. Ascorbic acid is coated with either glycerides, gelatine, silicone, ethyl-cellulose, dichlormethan, hydrogenated soybean oil or a polymer.

Other ascorbic acid derivatives are:

- L-ascorbyl-2-monophosphate (AAP),
- L-ascorbyl-2-polyphosphate (AAP),
- Mg-L-ascorbyl-2-monophosphate (AAP-Mg),
- Na-L-ascorbyl-2 monophosphate (AAP-Ma),
- Na-L-ascorbyl-2-triphosphate (AAP-Na),
- Ca-L-ascorbyl-2-monophosphate (AAP-Ca),
- L-ascorbic acid-2-sulphate (AAS).

Stability of Coated and Derivatives of Ascorbic Acid

Coating of crystalline Vitamin C only slightly improves its stability compared to the unprotected Vitamin C in extruded fish feeds^(19, 40). Certain coated products may not be suitable for extruded or expanded feed as temperature and pressure may destroy the protective layer of ascorbic acid⁽²⁸⁾.

The stability of Vitamin C derivatives is better than coated Vitamin C. After pelletising or extruding and storage of feed for between four and 12 weeks, loss of L-ascorbyl-2-polyphosphate activity was 17.0% at the most (Table 48-02) while losses of activity of coated ascorbic acid was at least around 90%^(10, 40). The stability of L-ascorbyl-2-phosphate in pelletised feed is 45 to 83 times greater than crystalline Vitamin C⁽¹²⁾. Ascorbate-2-sulphate is considered the most stable Vitamin C derivative for pelletised feed and long storage⁽⁴⁰⁾.

The retention of ascorbic acid from pelletised or extruded fish feed immersed in seawater was best for L-ascorbyl-2-polyphosphate in an extruded feed (63%) and very poor for crystalline Vitamin C in a pelletised feed (Table 48-03)⁽¹⁹⁾.

Table 48-02: Storage stability of L-ascorbyl phosphate in pelletised and extruded aquaculture feed^(10, 12, 19, 34, 40)

Processing/Type of feed	Storage time weeks	Ascorbid acid activity		
		In feed after processing ppm	In pellets after storage ppm	Retained after storage %
<u>L-ascorbyl-2-polyphosphate</u>				
Extruded/salmon	5	430	417	96.7
Extruded/catfish	4	114	95	83.0
Pelletised/trout	12	250	227	90.0
Pelletised/shrimp	8	189	175	92.5
Pelletised shrimp	8	442	413	93.0
<u>L-ascorbyl-2-monophosphate</u>				
Pelletised/shrimp	2	730	690	94.5

Table 48-03: Retention of ascorbic acid preparations from pelletised and extruded salmonid feeds, immersed in seawater (24 to 28°C)⁽¹⁹⁾

Type of Ascorbic acid Preparation	Immersion in seawater min.	Retention of ascorbic acid in the feed after immersion (%)
-2-polyphosphate ¹	120	63
-2-polyphosphate ²	120	60
-2-monophosphate ²	120	51
-2-monophosphate ²	360	19
Crystalline	3	47.5
Crystalline	120	32
Crystalline	180	1.73
Fat coated 90% activity	120	31
Fat coated 70% activity	120	23

¹ Extruded feed; ² Pelletised feed

48.4 Biological Value

48.4.1 Fishes

Coated Ascorbic Acid

The bioavailability of L-ascorbic acid coated with hydrogenated soybean oil is equivalent to crystalline L-ascorbic acid (Table 48-04).

In trials with rainbow trout the bioavailability of polymer-coated Vitamin C was the same as that of crystalline ascorbic acid as determined by the free ascorbic acid content of the liver⁽³⁵⁾. Likewise, dehydro-L-ascorbic acid was found to be effectively utilised by rainbow trout⁽³¹⁾.

Table 48-04: Bioavailability of ascorbic acid coated with hydrogenated soybean oil and crystalline ascorbic acid in fish diets (trial period: 16 weeks)⁽²⁸⁾

Crystalline ascorbic acid	mg/kg	0	153	0
Coated ascorbic acid	mg/kg	0	0	283

Ascorbic acid in:				
• Liver	mcg/kg	56	264	244
• Kidneys	mcg/kg	32	196	198
• Brain	mcg/kg	39	90	137
Signs of deformation	%	15	0	0

Ascorbic Acid Phosphates

L-ascorbyl-2-polyphosphate was shown to have antiscorbutic activity in rainbow trout, channel catfish, fathead minnow (*Pimephales promelas*) and guppy (*Poecilia reticulata*) and was apparently comparable to that of ascorbic acid^(12, 43). The magnesium salt of L-ascorbyl-2-monophosphate (AAP-Mg) had equimolecular vitamin activity as Vitamin C for growth and collagen synthesis in channel catfish^(8, 23).

Na- and Mg-L-ascorbyl-2-monophosphate in steam pelletised feed for rainbow trout are adequate at less than 10 mg ascorbic acid-equivalent⁽⁷⁾. They are very bioavailable and stable in the presence of heat and moisture. Likewise, the sodium salt of L-ascorbyl-2-monophosphate has equimolecular activity as the magnesium salt derivative as an ascorbic acid source for growth and collagen synthesis in channel catfish even only at levels of 30 mg/kg feed (Table 48-05)^(27, 42).

Table 48-05: Effect of increasing levels of ascorbic acid from Na-L-ascorbyl-2-monophosphate (AAP-Na) and Mg-L-ascorbyl-2-monophosphate (AAP-Mg) ⁽²⁷⁾

Ascorbic acid source	Concentration in feed mg/kg	Weigh gain of fish g/fish	Hematocrit %	Deformed fish %	Bone collagen %
	0	2.8	29	26	20.9
AAP-Na	30	13.4	39	0	27.0
AAP-Mg	30	13.3	40	0	27.4
AAP-Na	60	13.5	42	0	27.1
AAP-Mg	60	13.3	39	0	27.8
AAP-Na	120	13.1	39	0	28.2
AAP-Mg	120	13.1	39	0	28.2

Female broodstock of rainbow trout were fed for six months prior to spawning with increasing levels of L-ascorbyl-2-monophosphate (AAP). The highest levels of AAP in the diet did not result in maximum tissue saturation of ascorbic acid, indicating insufficient utilisation of the derivative⁽⁵⁾.

Ascorbic Acid Sulphates

L-ascorbic acid-2-sulphate (AAS) was reported to have Vitamin C activity in salmonids⁽³⁹⁾ and in channel catfish^(6, 26). On the contrary, L-ascorbic-2-sulphate was found to be poorly utilised by salmonids^(9, 29, 30). The derivative had only 5.2% of the vitamin activity of L-ascorbic acid for growth of channel catfish⁽⁸⁾. No significant differences in growth, feed conversion and other recorded parameters were established when 70g rainbow trout were given L-ascorbic-2-sulphate and crystalline ascorbic acid⁽¹⁵⁾.

48.4.2 Crustaceans

The bioavailability of L-ascorbic acid, L-ascorbic acid-2-sulphate, and L-ascorbyl-2-monophosphate tested in diets for tiger prawn (*Penaeus monodon*) showed that 67 to 75% of the crystalline ascorbic acid were destroyed by the laboratory process while the derivatives had only losses of 21 to 24%⁽³³⁾.

The bioavailability of Mg-L-ascorbyl-2-monophosphate (AAP-Mg) compared to crystalline Vitamin C tested in juvenile kuruma prawn (*Penaeus japonicus*) showed good utilisation of AAP-Mg as a Vitamin C source. The optimum dietary level appears to be about 215 mg/kg diet⁽³⁴⁾.

48.5 Recommended Inclusion Rates

The Vitamin C requirement of cultured aquatic species is variable and may range widely⁽³⁶⁾. In experiments, crystalline ascorbic acid has been used at levels of 10 to 1,250 mg/kg fish diet and 50 to 10,000 mg/kg crustacean diet. For practical conditions, 400 to 1,000 mg crystalline ascorbic acid are recommended. The actual inclusion rate of Vitamin C derivatives is guided by their equivalent of crystalline Vitamin C.

48.6 Legal Aspects

The use of crystalline Vitamin C is not limited. However, the approval of using coated Vitamin C and Vitamin C derivatives in feed for cultured aquatic animals may vary from country to country. The local regulations have to be observed.

The GRAS status of the Feed and Drug Administration of U.S.A. have the Vitamin C products, listed in Table 48-06⁽¹⁾.

Table 48-06: Vitamin C products having the GRAS status of F.D.A.⁽¹⁾

Recognised English Name	Substance	Registration No./status
Ascorbic acid	Crystalline ascorbic acid, commercial feed grade	582.5013
L-ascorbyl-2-phosphate	Stabilised ascorbic acid, feed grade	582.5159 Aquatic species, guinea pigs, primates (non-human)
Calcium ascorbate	Commercial grade	582.3189 Vitamin C activity in dry feeds (less than 13% moisture) only/chemical preservative
Ascorbyl palmitate	Commercial grade	582.3159 Chemical preservative

Vitamin C products are in Annex I (no. E 672) of the EU Feed Additive Directive. The following products can be used without restrictions:

- L-ascorbic acid (crystalline)
- L-ascorbic-2-glucosid
- Ascorbyl phosphate
- Di-potassium-L-ascorbate-2-sulphate
- Di-sodium-L-ascorbate-2-sulphate.

The two latter derivatives are only permitted for fish feed⁽⁴²⁾.

48.7 References

1. AAFCO (1995): Official publication 1995. Ass. of American Feed Control Officials (publishers). Sacramento, CA/USA.
2. Alisheikhov (1994): Vitamin C and B₁₂ content of feed components. Poultry International, 33., (6), 51-52.
3. Andrews, J.W.; Davis, J.M. (1979): Surface coating of fish feeds with animal fat and ascorbic acid. Feedstuff. 51., (2).
4. Ashley, L.M.; Halver, J.E.; Smith, R.R. (1975): Ascorbic acid deficiency in rainbow trout and coho salmon and effects on wound healing. In: Pathology of fishes. Univ. of Wisconsin Press Wisconsin.769-785.
5. Blom, J.H.; Dabrowski, K. (1993): Ascorbyl monophosphate requirements of rainbow trout (*Oncorhynchus mykiss*, broodstock. European Aquaculture Soc., Oostende/Belgium 19., 186.
6. Brandt, T.M.; Deyoe, C.W.; Sick, P.A. (1985): Alternate sources of Vitamin C for channel catfish. Prog. Fish. Cult., 47., 55-59.
7. Cho, C.Y.; Cowey, C.B. (1993): Utilization of monophosphate esters of ascorbic acid by rainbow trout (*Oncorhynchus mykiss*). Fish Nutrition in Practice. Institut National de la Recherche Agronomique, Paris/France, 61., 149-156.
8. El Naggar, G.O.; Lovell, R.T. (1991): Effect of source and dietary concentration of ascorbic acid on tissue concentrations of ascorbic acid in channel catfish. J. World Aquaculture Soc., 22., 201-206.
9. Fenster, R. (1987): Vitamin C in fish nutrition. Animal nutrition events, Roche, Basle, Switzerland. F. Hoffman-La Roche & Co. Seminar on Vitamin Nutrition in Fish, Trondheim, August 1997.
10. Gadiant, M.; Fenster, R.; Laischa, T. (1991): Vitamin stability in aquaculture feeds. Fish farmer. Jan/Feb. 15., 27-28.
11. Gill, C. (1991): Quoted from J.H. (1988).
12. Grant, B.F.; Seib, P.A.; Liao, M.L.; Corpron, K.E. (1989): Polyphosphorylated L-ascorbic acid: A stable form of Vitamin C for aquaculture feeds. J. World Aquacult. Soc., 20., (3), 143-157.
13. Halver, J.E. (1989): Fish Nutrition. Academic Press, Inc. (San Diego, CA, U.S.A.)
14. Halver, J.E.; Ashley, L.M.; Smith, R.R. (1969): Ascorbic acid requirements of coho salmon and rainbow trout. Trans. Am. Fish. Soc., 90., 762-771.
15. Halver, J.E.; Felton, S.J.; Palmisano, A.N. (1993): Efficacy of L-ascorbyl-2-sulfate as a Vitamin C source for rainbow trout. Fish Nutrition in Practice. Institut National de la Recherche Agronomique. Paris/France, 61., 137-147.
16. Hilton, J.W.; Cho, C.Y.; Slinger, J. (1978): Effect of graded levels of supplemental ascorbic acid in practical diets fed to rainbow trout (*Salmo gairdneri*). J. Fish. Res. Board Can., 35., 431-436.
17. Jaffe, G.M. (1984): Vitamin C. In: Machlin, L.J. (ed.): Handbook on vitamins. Marcel Dekker, Inc., New York/USA.

18. *J.H.* (1988): A guide for reduced Vitamin C losses. *Animal Nutrition News*, 71/88 (June), BASF Aktienges., Ludwigshafen/Germany.
19. *Kurmaly, K.; Menasveta, P.; Piyatiratitivorakul; Gadiant, M.; Schai, E.* (1993): Advances in vitamin nutrition for aquatic species: Stability, leaching and bioavailability of ascorbic acid. Conference contribution at Victam Asia'93 Bangkok/Thailand 25th October, 1-20.
20. *Leibovitch, H.E.; Culley, D.D. Jr.; Geaghan, J.P.* (1982): Effects of Vitamin C and sodium benzoate on survival, growth and skeletal deformities of intensively cultured bull frog larvae (*Rana catesbeiana*) reared at two pH levels. *J. World Mar. Soc.*, (13), 322-328.
21. *Lim, C.; Lovell, R.T.* (1978): Pathology of the Vitamin C deficiency syndrome in channel catfish (*Ictalurus punctatus*). *J. Nutr.*, 108., 1137-1146.
22. *Lovell, R.T.* (1973): Essentiality of Vitamin C in feeds for intensively fed channel catfish. *J. Nutr.*, 103., 134-138.
23. *Lovell, R.T.; El-Naggar, G.O.* (1990): Vitamin C activity for L-ascorbic acid, L-ascorbyl-2-sulfate, and L-ascorbyl-2-phosphate Mg for channel catfish. Proc. Third International Symposium on Feeding and Nutrition in Fish. 28 August to 1 September 1989. 159-165. (Toba/Japan).
24. *McCay, C.M.; Tunison, A.V.* (1934): Quoted from: *Halver* (1989).
25. *McCollum, E.V.* (1957): The nature of antiscorbutic substance (ascorbic acid). In: A history of nutrition. The Riverside Press Cambridge. (Houghton Mifflin Co., Boston), 252.
26. *Murai, T.; Andrews, J.W.; Bauernfeind, J.C.* (1978): Use of L-ascorbic acid ethocel coated ascorbic acid and ascorbic acid 2-sulphate in diets of channel catfish (*Ictalurus punctatus*). *J. Nutr.* 108, 1761-1766.
27. *Mustin, W.G.; Lovell, R.T.* (1992): Na-L-ascorbyl-2-monophosphate as a source of Vitamin C for channel catfish. *Aquaculture*, 105., (1), 95-100.
28. *Pacifico, C.J.* (1992): Private communication.
29. *Sandness, K.; Lei, O.; Waagboe, R.* (1989): Normal ranges of some blood chemistry parameters in adult farmed Atlantic salmon (*Salmo salar*). *J. Fish. Biol.*, 32., 129-136.
30. *Sandness, K.; Hansen, T.; Killie, J.E.; Waagboe, R.* (1990): Ascorbate-2-sulfate as a dietary Vitamin C source for Atlantic salmon (*Salmo salar*) 1. Growth, bioactivity, haematology and humoral immune response. *Fish. Phys. Biochem.* (Amsterdam), 8., 419-427.
31. *Sato, M.; Mitani, T.; Yoshinaka, R.; Sakaguchi, M.* (1993): Efficacy of dehydro-L-ascorbic acid as a dietary Vitamin C source in rainbow trout. *Bull. Jap. Soc. Sci. Fish.*, 59., 171-176.
32. *Schliffka, W.* (1992): Vitamin C - ein wichtiger Faktor in der Fischernahrung. (Mimeograph).
33. *Shiau, S.U.; Hsu, T.* (1993): Stability of ascorbic acid in shrimp feed during analysis. *Bull. Jap. Soc. Sci. Fish.*, 59., 1535-1537.
34. *Shigueno, K.; Itoh, S.* (1988): Use of Mg-L-ascorbyl-2-phosphate as a Vitamin C source in shrimp diets. *J. World Aquacult. Soc.*, 19., 168-174.
35. *Skelbaek, T.; Anderssen, N.G.; Winning, M.; Westergaard, S.* (1990): Stability in fish feed and bioavailability to rainbow trout of two ascorbic acid forms. *Aquaculture*, 84., 335-343.
36. *Tacon, A.G.J.* (1991): Vitamin nutrition in shrimp and fish. Proc. Aquaculture Feed Processing and Nutrition Workshop. American Soybean Association, Singapore.
37. *Täufel, A.; Taynes, W.; Tunger, L.; Zobel, M.* (1993): *Lebensmittel-Lexikon* Behr's Verlag, Hamburg/Germany.
38. *Tolbert, B.M.; Downing, M.; Carlson, R.W.; Knight, M.K.; Baker, E.M.* (1975): Quoted from: *Halver* (1989).
39. *Tucker, B.W.; Halver, J.E.* (1984): Distribution of ascorbate-2-sulfate and distribution, half-life and turn over rates of (1-¹⁴C) ascorbic acid in rainbow trout. *J. Nutr.*, 114., 991-1000.
40. *Waagboe, R.; Oeines, S.; Sandness, K.* (1991): The stability and biological availability of different forms

- of Vitamin C feed for Atlantic salmon (*Salmo salar*). Fiskeridir.-SKR.-Ernæring, Bergen/Norway, 4., 95-101.
41. Weinreich, O.; Koch, V.; Knippel, J. (1994): Futtermittelrechtliche Vorschriften. Buchedition Agrimedia. Hamburg/Germany.
 42. Wilson, R.P.; Poe, W.E. (1973): Impaired collagen formation in the scorbutic channel catfish. *J. Nutr.*, 103., 1359-1364.
 43. Wilson, R.P.; William, E.P.; Robinson, E.H. (1989): Evaluation of 1-ascorbyl-2-polyphosphate (AsPP) as a dietary ascorbic acid source for channel catfish. *Aquaculture*, 81., 129-136.

49. WATER HYACINTH

49.1 Rationale

The hydrophylic water hyacinth (*Eichhornia crassipes*) related to the pickerelweed, is a pest⁽¹⁾. It is a fast growing plant found throughout tropical and subtropical Asia, the Americas and the Pacific⁽⁵⁾. Water hyacinth clogs streams and ponds easily and rapidly and clogged waterways may seriously restrict boat travel⁽⁴⁾.

In the culture of freshwater crayfish (*Procambarus* spp.) water hyacinth, if unchecked, may completely cover the surface of a pond resulting in reduced oxygen supply⁽¹⁾.

Fresh, cooked or ensiled water hyacinth are used as feed for pigs⁽¹⁶⁾, cattle^(2,3), and swamp buffaloes⁽²¹⁾. Rabbits responded negatively to dry water hyacinth as feed⁽⁸⁾.

The water hyacinth is used as an egg collector when natural spawning is practised in breeding common carp (*Cyprinus carpio*)⁽¹⁾. Due to its rapid growth and its removal of soluble nutrients from water (nitrogen and phosphorus) water hyacinth is a potential water purifier⁽⁴⁾.

This plant is also used as soil fertiliser, compost and biogas production, mushroom cultivation, cardboard manufacture and for making handicrafts⁽¹⁸⁾.

49.2 Processing

The swollen petioles or leaves that float on water are used as feed. They are fed fresh or have to be cooked, ensiled, composted or dried. Processing of the petioles is a backyard procedure. There is no particular method of processing although some have resorted to composting by mixing dried and freshly chopped water hyacinth⁽⁷⁾.

49.3 Chemical, Physiological and Other Properties

Chemical Properties

The chemical composition of water hyacinth varies widely in all nutrients (Table 49-01). It is not a real protein feedstuff as it is sometimes claimed⁽¹¹⁾. The mean protein content is only 15.5% (dry matter), which is in the range of wheat bran (17.4%) and wheat grain (14.2%). The fresh material with roots is higher in crude protein than fresh water hyacinth without roots⁽⁸⁾.

The crude fibre as well as the ash content of water hyacinth is extremely high. The ash content may be a limiting factor for its use in aquaculture feed⁽¹⁾. Calcium is high and the phosphorus content is low, resulting in a wide Ca:P-ratio of 1:3.4.

Table 49-01: Chemical composition of water hyacinth (*Eichhornia crassipes*)
(% in dry matter)^(1, 4, 9, 13, 15, 20)

	Mean	Variation
Dry matter	8.1	4.0 - 10.2
Crude protein	15.5	8.1 - 21.5
Crude fat	1.9	0.9 - 2.5
Ash	17.8	13.2 - 34.1
Crude fibre	25.3	15.0 - 31.8
N-free extract	37.8	18.3 - 50.8
Carbohydrates	65.6	65.4 - 65.9
Calcium	2.06	1.62 - 2.50
Phosphorus	0.60	0.43 - 0.77

Physiological Properties

The digestibility and digestible energy of water hyacinth are low because of the high crude fibre and ash content. Digestible energy, 1,807 kcal/kg (7.6 MJ/kg) and 1,620 kcal/kg (6.8 MJ/kg) for fishes⁽¹⁵⁾ and rabbits⁽⁴⁾, respectively, is rather similar. Increasing levels of water hyacinth in test diets caused a decline in the apparent protein digestibility in the Indian major carp (*Labeo rohita*) (Table 49-02)⁽¹¹⁾. No differences were observed between the protein digestibility of dried or composted water hyacinth in Nile tilapia (*Oreochromis nilotica*)⁽¹⁷⁾.

Table 49-02: Apparent protein digestibility of water hyacinth

Species	Protein of water hyacinth ¹ %	Protein digestibility ¹ %	References
Indian major carp	20.0	60.1	(10)
(<i>Labeo rohita</i>)	40.0	55.4	(10)
	25.0	77.6	(11)
	50.0	64.5	(11)
Nile tilapia	50.0 ¹	49.0 ³	(17)
(<i>Oreochromis nilotica</i>)	50.0 ¹	65.0 ⁴	(17)
	50.0 ²	46.0 ⁵	(17)
	50.0 ²	65.0 ⁴	(17)

¹Dried water hyacinth; ²Composted water hyacinth; ³In out-door concrete tanks;

⁴In recirculating water system; ⁵In static water system

Deleterious Substances

Water hyacinth tends to accumulate heavy metals. After feeding water hyacinth at levels of 25 and 50% to rabbits, the arsenic levels of muscle, liver and kidneys increased with higher percentage of water hyacinth in the diet⁽⁸⁾. Similar results from aquatic animals are unknown.

Water hyacinth contains also about 2.5% salts of oxalic acid ($[\text{COOH}]_2$). Free oxalic acid and its alkali salts are very toxic (lethal doses in man = 5.0 g). The calcium salt of oxalic acid has a very low solubility, and is not absorbed by the gut wall hence, is not toxic⁽¹⁹⁾.

49.4 Feeding Value

Water hyacinth has been tried as a substitute for fish meal in order to develop feeds for low cost aquaculture systems, particularly for herbivorous fish. However, not all herbivorous fish like to eat water hyacinth as e.g., grass carp (*Ctenopharyngodon idellus*) reluctantly eats it⁽¹⁾.

Increasing levels of dried water hyacinth were fed to about 7.0 g Nile tilapia. Best results were obtained with the highest protein level (35%) and the lowest water hyacinth content (20%) (Table 49-03)⁽¹³⁾. Nile tilapia fed only composted water hyacinth grew poorly compared to the control, but in combination with tilapia meal fish performed better when fed dried water hyacinth (Table 49-04)⁽⁷⁾.

Common carp fed 2.5 and 10.0%, composted and non-composted water hyacinth, respectively, grew better at both levels on non-composted than on composted water hyacinth, although the difference was not pronounced at the end of the trial period (Figure 49-01). *Seplat rawa* (*Trichogaster* sp.) responded negatively to water hyacinth feeding⁽¹²⁾.

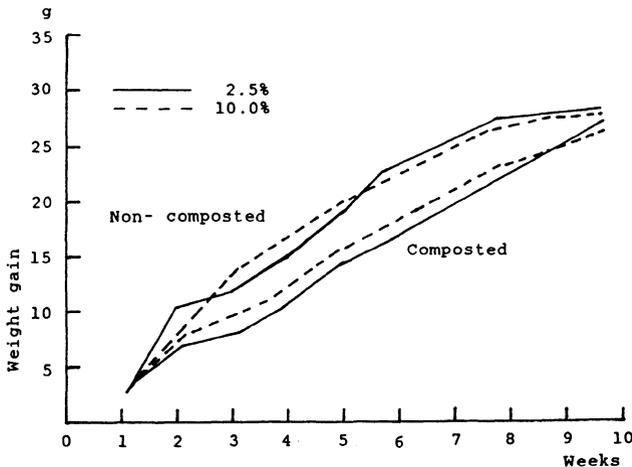


Figure 49-01. Weekly weight gain of common carp (*Cyprinus carpio*) fed non-composted and composted water hyacinth⁽¹²⁾.

Table 49-03: Growth of Nile tilapia (*Oreochromis niloticus*) fed various amounts of dried water hyacinth (feeding period: 11 weeks)⁽¹³⁾

Water hyacinth	%	-	40.0	30.0	20.0
Fish meal	%	-	18.5	37.0	60.0
Rice bran	%	-	34.3	26.8	13.9
Chicken pellets	%	+	-	-	-
Crude protein	%	16.81	16.0	25.0	35.0

Weight gain	%	238	117	213	282
SGR	%/day	1.58	1.01	1.49	1.74
Feed conversion	1:	2.6	4.3	2.7	2.1
Survival	%	97.8	98.9	97.8	98.9

Table 49-04: Growth of Nile tilapia (*Oreochromis niloticus*) fed composted water hyacinth (feeding period: 84 days)⁽⁷⁾

Composted hyacinth	%	100 ¹	75	50	25	-
Tilapia meal ²	%	-	25	50	75	100 ³

Weight gain	%	100	416	510	419	432
SGR	%/day	0.83	1.96	2.15	1.96	1.99
Feed Conversion	1:	4.89	2.18	2.19	2.57	2.63
PER		1.47	2.87	2.05	1.49	1.21

¹ The only feed; ² Prepared by - National Inland Fisheries Institute, Bangkok/Thailand;

³ Control

The performance of water hyacinth-fed Indian major carp (*Labeo rohita*) were inferior when fish meal protein was replaced by water hyacinth. Nevertheless, feeding of water hyacinth was economical under the conditions of this trial (Table 49-05)⁽¹¹⁾.

On the other hand, three-day old larvae of the rohu were successfully fed with an extract of water hyacinth⁽¹⁴⁾.

The effect of fresh, chopped water hyacinth mixed with raw or fermented rice bran were tested in fingerlings of Nile tilapia, common carp, grass carp and puntius carp (*Puntius gonionatus*). The water hyacinth improved the growth compared to common feeding in the Mekong Delta with rice bran only. Nile tilapia fed with water hyacinth grew better than the other species tested. Water hyacinth reduced the feeding cost considerably because it is available for free⁽²⁰⁾. The performance of tilapia (*Tilapia mossambica*) fed exclusively on water hyacinth was similar to the fish fed rice bran and an unspecified vegetable oil cake (1:1)⁽⁶⁾.

Table 49-05: Growth response of Indian major carp (*Labeo rohita*) fed diets containing water hyacinth (feeding period: 42 days)⁽¹⁰⁾

Water hyacinth	%	0	26.5	53.9
Fish meal	%	57.1	45.7	34.3

Initial weight	mg	209	204	210
Final weight	mg	776	583	531
SGR	%/day	3.13	2.50	2.21
Mortality	%	18.9	9.9	10.1
Feed conversion	1:	1.84	2.31	2.36
PER		1.31	1.04	1.05

49.5 Recommended Inclusion Rates

Water hyacinth is a feedstuff for farm-mixing of feed and simple farming systems where labour is easily available at low cost. It is a feedstuff for herbivorous/omnivorous freshwater fish, but unsuitable for carnivorous fish. The limiting factors for its use are its high crude fibre and ash content.

The most suitable inclusion rate depends very much on the farming system practised. A recommended guideline, follows:

- Supplementation of basic feed, e.g. rice bran, broken rice, chicken manure - 25.0 to 50.0%
- Replacement of protein sources in a formulated feed (fish meal, vegetable oil meals/cake) - 5.0 to 10.0%

49.6 Legal Aspects

Water hyacinth in any processed form is not a commercial feedstuff. Its use, therefore, is not bound to legal regulations. However, certain countries may have their restrictions in the use of water hyacinth.

49.7 References

1. Bardach, J.E.; Ryther, J.H.; McLarney, W.O. (1972): Aquaculture: Farming and husbandry of freshwater and marine organisms. John Wiley and Sons, Inc., New York/U.S.A.
2. Carberry, M.; Chatterjee, I.B.; Talapatra, b.K. (1937): Quoted from: *Devendra* (1985).
3. Chatterjee, I.B.; Hu, M.A. (1938): Quoted from: *Devendra* (1985).
4. Cheeke, P.R. (1987): Rabbit feeding and nutrition. Academic Press, Inc.
5. Devendra, C. (1985): Non-conventional feed resources in Asia and the Pacific. 2nd ed. FAO Regional

- Animal Production and Health Commission for Asia, the Far East and the South-West Pacific (APHCA), Bangkok.
6. Dey, S.C.; Sarman, S. (1982): Prospect of the water hyacinth (*Eichhornia crassipes*) fed to cultivable fishes. A preliminary study with *Tilapia mossambica* Peters. Matsya No. 8. 40-44.
 7. Edwards, P.; Kamal, M.; Wee, K.L. (1985): Incorporation of composted and dried water hyacinth in pelleted feed for the tilapia (*Oreochromis niloticus* Peters). Aquaculture and Fish. Manage., 1., 233-248.
 8. Gerard, C.; Troncoso, J. (1980): Quoted from: Cheeke, P.R. (1987).
 9. Gerpacio, A.L.; Castillo, L.S. (1979): Nutrient composition of some Philippine feedstuffs. College of Agriculture, Univ. of the Philippines, Los Baños, Laguna/Philippines.
 10. Hasan, M.R.; Moniruzzaman, Farooque, O. (1990): Evaluation of leucaena and water hyacinth leaf meal as dietary protein sources of the fry of Indian major carp (*Labeo rohita* Hamilton). The Second Asian Fisheries Forum. Asian Fish. Soc., Manila/Philippines. 275-278.
 11. Hasan, M.R.; Roy, F.K. (1994): Evaluation of water hyacinth leaf meal as dietary protein source for Indian major carp (*Labeo rohita*) fingerlings. The Third Asian Fisheries Forum, Singapore, 1992. Asian Fish. Soc., Manila/Philippines. 671-674.
 12. Hutabarat, J.; Syarani, L.; Smith, M.S.A. (1986): The use of freshwater hyacinth (*Eichhornia crassipes*) in cage culture in Lake Rawa Pening Central Java. The First Asian Fisheries Forum. Asian Fish. Soc., Manila/Philippines. 571-580.
 13. Klinnavee, S.; Tansakul, R.; Promkuntong, W. (1990): Growth of Nile tilapia (*Oreochromis niloticus*) fed with aquatic plant mixtures. The Second Asian Fisheries Forum. Asian Fish. Soc., Manila/Philippines. 283-286.
 14. Kumar, K.; Ayyapan, S.; Murijani, G.; Bhandari, S. (1991): Utilization of mashed water hyacinth as feed in carp rearing. Proc. Nat. Symp. New Horizons in Freshwater Aquaculture. 23 to 25 January, 89-91.
 15. New, M.B. (1987): Feed and feeding of fish and shrimp. A manual on the preparation and presentation of compound feeds for shrimps and fish in aquaculture. UNDP/FAO/ADCP/REP/87/26.
 16. Polprasert, C.; Kongsrichareorn, N.; Kanjanaprapin, W. (1994): Production of feed and fertilizer from water hyacinth plants in the tropics. Waste Manage. Res., 12., (1), 3-11.
 17. Pongsri, C. (1986): Quoted from: Wee (1991).
 18. Soerjani, M. (1987): Water enrichment and the possible utilization of aquatic plants. Sustainable Clean Water Proc. Regional Workshop in Limnology and Water Resources Management in the Developing Countries of Asia and the Pacific. 29 November to 5 December 1982. Univ. of Malaya, Kuala Lumpur/Malaysia. No. 28, 227-236.
 19. Täufer, A.; Ternes, W.; Tunger, Zobel, M. (1993): Lebensmittel-Lexicon. Behr's Verlag, Hamburg/Germany.
 20. Tuan, N.A.; Thuy, N.Q.; Tam, B.M., Ut, U.V. (1994): Use of water hyacinth (*Eichhornia crassipes*) as supplementary feed for nursing fish in Vietnam. Fish Nutrition Research in Asia. Proc. Fifth Asian Fish Nutrition Workshop, Manila/Philippines. Asian Fish. Soc. 101-106.
 21. Wanapat, M.; Sriwattanasombat, P.; Chanthai, S. (1983): Quoted from: Devendra (1985).
 22. Wee, K.L. (1991): Use of non-conventional feedstuff of plant origin as fish feeds - is it practical and economically feasible? Proc. Fourth Asian Fish Nutrition Workshop. Asian Fish. Soc. Spec. Publ. 5. Asian Fisheries Society, Manila/Philippines. 13-32.

50. WHEAT AND WHEAT BY-PRODUCTS

50.1 Rationale

Wheat is a cereal grown in temperate climates and is one of the peoples' staple foods. The genus *Triticum* which belongs to the botanical family of *Poaceae*, is comprised of many different species. The most common wheat species cultivated in Europe is *Triticum aestivum*, ssp. *vulgare* with a wide range of varieties^(12, 47).

Wheat is milled to flour, and by-products available as feedstuffs for aquatic and terrestrial animal diets are:

- Wheat bran,
- Wheat pollard (wheat middlings, mill run),
- Wheat germ,
- Wheat gluten.

The wheat grain comprises 84% endosperm (flour), 14.5% bran and 1.5% germ⁽³⁰⁾. Around 7.0 to 14.0% of the total wheat grain is gluten.⁽²²⁾

About 550 million to 590 million MT of wheat are produced annually. Only five countries produce more than 50% of the total world harvest (former USSR = 16.2%, P.R. China = 15.6%, U.S.A. = 10.0%, Canada = 5.6%, France = 4.7%). The World production of wheat gluten amounts to about 250,000 MT a year⁽²²⁾.

50.2 Milling Process

Steps in the milling process include: Cleaning, tempering, breaking, sifting, or separation of primary products, purifying, reducing, bolting, flour blending, and bleaching. Milling separates the endosperm from the bran and germ. When the main parts are not separated, the resulting product is whole wheat flour.

Wheat bran is the fibrous coating under the husk which contains most of the vitamins and protein of the wheat grain. It does not contain wheat germ⁽³⁴⁾.

The wheat berry may be separated in the process of milling, into portions, the percentage of bran progressively increasing with each portion named: patent, straight, first clear, second clear, red dog, flour middlings, shorts and bran⁽³⁰⁾. The last three are the parts that are often used in aquaculture diets.

Wheat pollard or mill run is also known as wheat middlings. It is less fibrous than wheat bran, contains more wheat protein (gluten) and has a higher feed value.

Wheat gluten is a by-product in the manufacture of starch from wheat. It is a water-insoluble protein complex. Gluten surrounds the starch granules as a matrix in the floury endosperm^(22, 47). Glutenin and gliadine, components of wheat gluten, have an elastic property which is why finely ground wheat forms a pasty mass in the mouth and is

unpalatable to land animals⁽¹²⁾. It is this elasticity that makes it a relatively good binder in aquaculture feed. Wheat gluten is widely used in the food industry⁽²⁵⁾.

50.3 Chemical, Physiological and Other Properties

Chemical Properties

The chemical composition of wheat is affected by the variety, precipitation, temperature, irrigation, texture and composition of the soil and to a great degree, the milling process, classes of wheat from which the flour or bran is milled, and use of fertilizers (Table 50-01)⁽³⁰⁾.

Table 50-01: Chemical composition of wheat and wheat products (% in dry matter)

	Wheat Grain <small>(9, 10, 12, 32, 34, 35, 46)</small>	What flour <small>(10, 32, 33, 38, 39, 43, 46, 49, 53)</small>	Wheat bran <small>(9, 10, 18, 20, 32, 33, 34, 35, 37, 38, 39, 46, 49, 53)</small>	Wheat pollard <small>(9, 18, 20, 32, 34, 35, 37, 38, 46, 48)</small>	Wheat germ <small>(19, 35, 45, 49)</small>	Wheat gluten <small>(10, 19, 32)</small>
Dry matter	87.7	88.0	88.7	89.4	88.7	91.4
Crude protein	13.5	14.3	15.6	16.9	28.5	80.1
Crude fat	1.9	1.7	4.7	4.4	8.8	1.5
Crude fibre	2.6	1.1	12.3	7.8	3.5	0.5
Crude ash	1.8	1.0	5.6	4.7	4.9	0.7
N-free extract	80.2	81.9	61.8	66.2	54.3	17.2
Starch	68.0	-	-	-	-	-
Sugar	3.1	-	-	-	-	-

The protein content of wheat varies widely. Hard spring wheat may have 15 to 16% protein, hard winter wheat 13 to 14% and soft wheat 10 to 14%⁽¹²⁾. Wheat and wheat products are relatively low in protein and its quality is also low. Lysine, threonine and valine are limiting amino acids (Table 50-02). Protein increases with fertilisation of the soil but lysine content of the crude protein decreases⁽¹²⁾.

Table 50-02: Essential amino acid profile of wheat and wheat products (g/16 g N)

	Wheat grain <small>(34, 35, 37, 46)</small>	Wheat flour <small>(10, 35, 46)</small>	Wheat bran <small>(10, 18, 34, 35, 37, 46)</small>	Wheat pollard <small>(18, 34, 35, 37)</small>	Wheat germ <small>(35, 46)</small>	Wheat gluten <small>(10)</small>
Arginine	0.63	0.45	1.11	1.06	1.99	3.80
Histidine	0.30	0.27	0.46	0.48	0.27	2.00
Isoleucine	0.51	0.50	0.54	0.69	0.92	3.70
Leucine	0.04	0.94	1.03	1.17	1.57	6.30
Lysine	0.50	0.31	0.59	0.61	1.67	4.90
Methionine	0.19	0.20	0.23	0.35	0.45	1.60
Phenylalanine	0.64	0.64	0.68	0.55	1.01	4.50
Threonine	0.40	0.35	0.51	0.56	1.03	1.60
Tryptophan	0.46	0.12	0.24	0.18	0.32	1.05
Valine	0.58	0.53	0.68	0.82	1.25	4.00

Wheat and wheat products are very low in calcium, containing only 0.04% to 0.22%, but relatively rich in phosphorus with an average of 0.40% and in wheat bran as high as 1.51% (Table 50-03). Most of the phosphorus is present in the form of phytate. The phosphorus availability is only about 30%⁽¹⁸⁾.

Table 50-03: Mineral content of wheat and wheat products

		Wheat grain <small>(10, 34, 35, 46)</small>	Wheat flour <small>(10, 39, 43, 46, 49)</small>	Wheat bran <small>(10, 18, 34, 35, 37, 39, 46, 49)</small>	Wheat pollard <small>(18, 34, 35, 37, 46)</small>	Wheat germ <small>(35, 46, 49)</small>	Wheat gluten <small>(10)</small>
Calcium	%	0.05	0.04	0.13	0.13	0.06	0.22
Phosphorus	%	0.34	0.20	1.51	1.09	1.05	0.10
Sodium	%	0.17	-	0.02	0.28	-	-
Potassium	%	0.30	0.22	1.11	1.07	0.83	1.25
Magnesium	%	0.17	-	0.66	0.56	0.28	-
Chlorine	%	-	-	1.06	0.03	-	-
Sulphur	%	-	-	0.24	0.25	-	-
Manganese	mg/kg	41.7	-	131.8	128.5	151.4	-
Iron	mg/kg	0.6	33.0	135.7	85.3	94.0	-
Zinc	mg/kg	50.5	-	102.1	69.7	135.7	-
Copper	mg/kg	6.5	-	13.9	17.6	10.6	-
Iodine	mg/kg	0.1	-	0.1	-	-	-
Selenium	mg/kg	-	-	0.5	0.8	-	-

Wheat feedstuffs are deficient in Vitamin A and D but are a good source of Vitamin B₁ and other B-complex vitamins (Table 50-04)⁽¹²⁾.

Table 50-04: The vitamins of wheat and wheat products (per 1,000 g)

		Wheat Grain <small>(35, 37)</small>	Wheat flour <small>(35, 37, 49)</small>	Wheat bran <small>(18, 35, 37, 49)</small>	Wheat pollard <small>(18, 35, 37)</small>	Wheat germ <small>(35, 37, 49)</small>
Vitamin E	mg	13.0	2.9	18.8	44.0	160.3
Vitamin B ₁	mg	4.8	3.2	7.8	18.0	23.0
Vitamin B ₂	mg	1.6	0.8	4.2	2.0	6.9
Vitamin B ₆	mg	4.2	1.0	11.0	9.8	12.9
Biotin	mg	0.12	-	0.43	0.3	0.24
Folic acid	mg	0.43	0.10	1.82	1.06	2.30
Nicotinic acid	mg	62.2	14.7	254.4	112.1	62.1
Pantothenic acid	mg	11.1	6.6	33.8	16.1	23.7
Choline	g	1.17	0.93	1.67	1.2	3.47

Physiological Properties

The energy values of wheat and wheat products may be improved by the degree of grinding or heat processing (Table 50-05).

Table 50-05: Energy values of wheat and wheat products per kg

	Gross Energy		Metabolisable energy		Digestible energy		Reference
	kcal	MJ	kcal	MJ	kcal	MJ	
1. <u>Wheat grain</u>							
	3,896	16.3	-	-	-	-	(32)
	2,915	12.2	-	-	-	-	(11)
Fish ¹	-	-	-	-	3,046	12.7	(34)
Pigs	-	-	-	-	3,402	14.2	(31)
Dogs	-	-	-	-	3,728	15.6	(32)
Rabbits	-	-	-	-	3,600	15.1	(8)
2. <u>Wheat bran</u>							
	4,519	17.4	-	-	-	-	(32)
Fish ¹	-	-	-	-	2,906	12.2	(34)
Dogs	-	-	2,581	10.8	-	-	(34)
Rabbits	-	-	-	-	3,600	15.1	(8)
3. <u>Wheat pollard</u>							
	4,015	16.8	-	-	-	-	(32)
Rainbow trout	-	-	1,509	6.3	1,804	7.5	(36)
	-	-	2,759	11.5 ²	3,034	12.7 ²	(36)
Fish ¹	-	-	-	-	2,965	12.4	(34)
Dogs	-	-	2,390	10.0	3,633	15.2	(32)
Rabbits	-	-	-	-	3,600	15.1	(8)

¹ Species not specified; ² Finely ground

The protein and fat digestibility are high but they are relatively lower for the dry matter, energy and carbohydrate. There are only slight differences in protein and fat utilisation of wheat and wheat products between carnivores and herbivores/omnivores (Table 50-06).

Other Properties

Wheat flour aside from its energy value is a common pellet binder for shrimp feeds at 20% to 30% levels. It is cost effective compared to wheat gluten, another good pellet binder for aquaculture feeds⁽³⁾. The water durability of pellets will depend on the gluten content of the wheat flour (Figure 50-01). No differences in the water durability exist between different types of wheat flour⁽⁴²⁾.

Wheat inhibits fish amylases. Studies on scorpion fish (*Scorpaena ustulata*) and golden mullet (*Mugil auratus*) showed 10% to 20% inhibition of fish amylase by wheat when used in the diets⁽⁴⁴⁾.

Table 50-06: Digestibility (%) of wheat and wheat products

Species	Dry Matter	Crude protein	Fat	Crude fibre	Carbo-hydrates	Energy	Reference
1. <u>Wheat grain</u>							
Atlantic Salmon	57.0	88.0	95.0	-	34.0	-	(5)
¹	49.0	84.0	95.0	-	28.0	-	(5)
²	74.0	85.0	95.0	-	95.0	-	(5)
Common carp	-	85.8	-	51.3	-	-	(24)
Channel catfish	-	83.8	96.0	-	96.0	60.4	(24)
White leg shrimp ³	52.5	-	-	-	-	67.7	(11)
2. <u>Wheat flour</u>							
Tiger prawn	81.2	79.7	82.7	-	80.8	-	(44)
3. <u>Wheat bran</u>							
Salmonids	68.0	83.2	91.6	-	58.8	39.9	(5, 24)
Common carp	-	92.0	78.5	68.0	76.5	-	(24)
Channel catfish	-	82.0	-	-	-	56.2	(24)
White leg shrimp	-	85.4	-	-	-	98.0	(3)
4. <u>Wheat pollard</u>							
Rainbow trout	25.0	78.7	20.3	-	-	39.6	(9, 36)
⁴	-	67.7	-	-	-	52.8	(36)
5. <u>Wheat germ</u>							
Salmonids	-	76.8	-	-	-	60.0	(24)
Common carp	-	93.6	-	-	-	-	(24)
6. <u>Wheat starch</u>							
Rainbow trout	-	90.0	-	-	-	-	(6)
White leg shrimp	50.6	-	-	-	-	71.3	(11)

¹Pre-extruded wheat; ²Extruded after milling; ³*Penaeus vannamei*; ⁴Finely ground

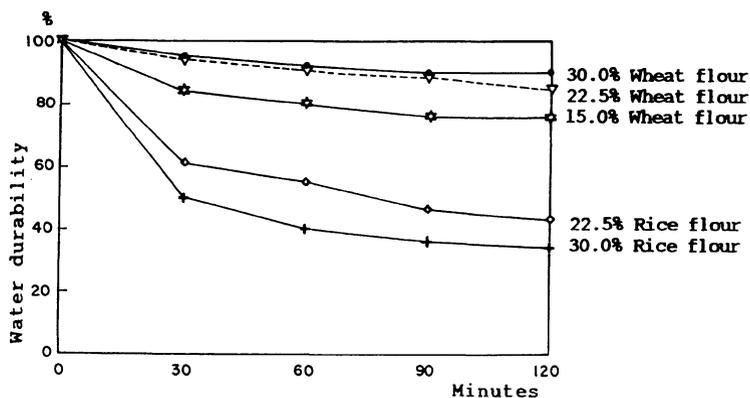


Figure 50-01. Water durability of feed pellets containing 5.0% wheat gluten and wheat flour and extruded rice, respectively (data from: 41).

50.4 Feeding Value

50.4.1 Wheat Grain

Atlantic salmon (*Salmo salar*) (175 g mean weight) grown in seawater for 101 days were fed diets containing increasing levels of whole wheat extruded in various ways. With increasing levels of whole wheat in the diet the growth significantly declined (Table 59-07)⁽⁵⁾.

Carp (*Cyprinus carpio*) fingerlings were successfully fed with wheat in a balanced diet at different stocking rates (1,500 to 3,000 fingerlings per ha)⁽⁴⁵⁾.

Table 50-07: Growth of Atlantic salmon (*Salmo salar*) fed differently processed wheat⁽⁵⁾

Wheat bran	%	25	25	25	25	25	25	25
Whole wheat	%	-	15	45	-	-	-	-
Pre-extruded wheat	%	-	-	-	15	45	-	-
After milling								
Extruded wheat	%	-	-	-	-	-	15	45

Weight gain	g	301	305	264	290	267	302	275
	Rel.	100	101	88	96	89	100	91

50.4.2 Wheat Flour

Fishes

Rainbow trout (*Salmo gairdneri*) fed different types of raw or extruded wheat and wheat starches grew better when fed the extruded wheat starch (126.7 g) compared to extruded wheat (110.8 g)⁽²⁹⁾.

Catfish (*Clarias batrachus*) larvae were fed various amounts of wheat flour and fish meal with worm (*Tubifex* sp.) as the control. The diet with 14% wheat flour and 56% fish meal had a survival rate (90.2%) comparable to the larvae fed the worm (*Tubifex* sp.)⁽⁴⁾.

Wheat flour was found to be effective food for the European eel (*Anguilla anguilla*). Performances were best for the diet containing 40% protein and 38% wheat flour regardless of whether the fish were reared indoors or outdoors (Table 50-08)^(13, 14).

Wheat flour at levels of 5.0% with various seaweeds and carrageenan were tested for their effects on growth of snakehead (*Channa striatus*) fry. A 10% wheat flour diet was used as control. The best growth rate and feed efficiency were observed for fish fed the wheat flour-carrageenan combination⁽²³⁾.

The mullet (*Liza parsia*) fry performed well when given a diet of wheat flour and fish meal (1:1) containing 31.4% protein compared to pond fertilisation with inorganic and organic fertiliser⁽⁷⁾.

Table 50-08: Growth and feed utilization of the European eel (*Anguilla anguilla*) fed various levels of wheat flour and protein⁽¹³⁾

Wheat flour		%	20	38	56
Fish meal		%	35	25	15
Crude protein		%	50	40	30

Weight gain	outdoors	%	253	290	239
	indoors	%	572	722	616
Feed conversion	outdoors	%	1.84	1.61	1.95
	indoors	%	2.97	2.20	2.45
Protein retention	outdoors	%	18.5	29.1	26.3
	indoors	%	9.6	19.3	21.8

¹Cultured outdoors for 50 days; ² Cultured indoors for 71 days

Crustaceans

Wheat flour (30%) with toasted brown rice (30%) in diets for tiger prawns (*Penaeus monodon*) did not significantly affect growth and survival of the shrimps⁽²⁶⁾. Diets containing only wheat flour showed significantly better feed efficiency than those fed diets containing different levels of extruded rice⁽⁴¹⁾. The weight gain between the wheat flour and the lowest rice level was not significantly different.

There were no differences in the feeding value of three types of wheat flour straight, first grade clear and second grade clear when evaluated for their feeding value in diets for tiger prawn (*Penaeus monodon*)⁽⁴²⁾.

50.4.3 Wheat Bran

Fishes

Few reports are available on wheat bran in fish feeding. A diet containing 10% wheat bran gave better performance in the carp than when 20% wheat bran was used⁽⁴⁰⁾.

Mullet fry (*Mugil auratus*) readily accept the artificial food made of fish meal and wheat bran at the ratio of 3:1. Maximum growth rate (13 mg/day) was observed in the group that received the maximum food of 10% of body weight indicating that mullet fry can be reared on a wheat bran-fish meal diet⁽¹⁷⁾.

Crustaceans

Wheat bran (22%) supplemented with mussel meal, squid meal, soybean meal, fish meal and live *Artemia nauplii*, respectively, produced the best growth and survival rates in post larvae and juvenile blue shrimp (*Penaeus stylirostris*)⁽²¹⁾.

Wheat bran appears to be unsuitable as mono diet for brine shrimp *Artemia salina*⁽¹⁵⁾. But using it in the cultivation of the harpacticoid copepod (*Nitocra spinipes*) under laboratory conditions, the density increased to over 150,000 individuals per liter compared to various vegetables and micro-algae⁽²⁸⁾.

50.4.4 Other Wheat Products

Wheat middlings in the diet of juvenile red drum (*Sciaenops ocellatus*) were used as source of energy with menhaden fish oil. Weight gain and survival decreased as the amount of wheat middlings was increased in the diet⁽¹⁶⁾. Feed efficiency, apparent net protein and net energy retentions also decreased with increasing amounts of wheat middlings (Table 50-09).

Artificial soft diets containing *wheat germ*, fish, shrimp meal, yeast, seaweed, sucrose, vitamins and trace minerals gave comparable growth with crab viscera diet for adult maintenance of snail (*Hemissenda*) mariculture⁽⁵²⁾.

Wheat germ agglutinin (WGA) (20 mg/kg dry food) was found to promote the bacterial resistance of Chinese prawn (*Penaeus orientalis*) and increased survival of shrimp⁽⁵¹⁾.

50.5 Recommended Inclusion Rate

The use of wheat and wheat products in diets for aquatic animals is limited, especially in the use of wheat bran, wheat pollard and wheat middlings because of the high crude fibre contents (Table 50-01)^(2, 27). Levels of wheat and wheat product in diets for fishes may be higher than in crustacean feed. In experimental diets for crustaceans, wheat flour and wheat gluten is used from 2.0 to 26.0% and from 5.0 to 16.0%, respectively. The recommendations for commercial diets are in Table 50-10.

50.6 Legal Aspects and Precautions

According to EU-Regulations wheat and wheat by-products are so called basic products for manufacturing of compound feed. The AAFCO⁽¹⁾ list of feed ingredient definitions contains the following wheat products:

- | | | | |
|----------------------------|---|----------|-------------------------|
| • Wheat bran | - | No. 93.1 | |
| • Wheat flour | - | No. 93.2 | (max. 1.5% crude fibre) |
| • Wheat germ meal | - | No. 93.3 | |
| • Wheat mill run | - | No. 93.4 | (max. 9.5% crude fibre) |
| • Wheat middlings | - | No. 94.5 | (max. 9.5% crude fibre) |
| • Wheat shorts | - | No. 93.6 | (max. 7.0% crude fibre) |
| • Wheat red dog | - | No. 93.7 | (max. 4.0% crude fibre) |
| • Defatted wheat germ meal | - | No. 93.8 | (min. 30.0% protein) |

The Feedstuff Legislation of the Federal Republic of Germany describes the minimum requirements of wheat and wheat by-products (Table 50-11)⁽⁵⁰⁾.

Following the “Codex Alimentarius” vital wheat gluten should internationally meet the following standards⁽²⁵⁾:

- | | | |
|-----------------------------|------|-------|
| • Protein (N x 6.25 in /DM) | min. | 80.0% |
| • Moisture | max. | 10.0% |
| • Ash | max. | 2.0% |
| • Fat (ether extract) | max. | 2.0% |
| • Crude fibre | max. | 1.5% |

Wheat and wheat by-products are natural carriers of moulds and when improperly stored can develop mycotoxins, particularly aflatoxin. According to German Feedstuff Legislation the maximum allowable aflatoxin content is 0.05 mg/kg wheat and wheat by-products⁽⁵⁰⁾.

Table 50-09: Various levels of wheat middlings in diets for juvenile red drum (*Sciaenops ocellatus*)⁽¹⁶⁾

Wheat middlings	%	28.0	40.7	53.5
Fish oil (menhaden)	%	4.5	4.3	4.0
Crude protein	%	31.5	32.2	32.4
Gross energy	kcal/kg	1,611	1,736	1,891
	MJ/kg	9.8	8.5	10.0

Weight gain	%	481.5	378.4	281.3
Feed efficiency	%	0.38	0.33	0.26
Net protein retention	%	19.8	16.5	13.5
Net energy retention	%	10.8	7.5	5.9
Survival rate	%	88.3	85.0	88.0

Table 50-10: Recommended inclusion rates for wheat and wheat products in diets for cultured aquatic animals

	Fish feed	Crustacean feed
Wheat grain ¹	10.0 to 15.0	5.0 to 10.0
Wheat flour	10.0 to 15.0	5.0 to 10.0
Wheat flour as pellet binder	-	up to 25.0
Wheat pollard	10.0 to 20.0	3.0 to 5.0
Wheat middlings	10.0 to 20.0	3.0 to 5.0
Wheat bran	2.0 to 5.0 ²	2.0 to 5.0 ²
Wheat germ	2.0 to 5.0	2.0 to 5.0
Wheat gluten	2.0 to 5.0	5.0 to 10.0 ³

¹ Wheat should be extruded for maximum utilisation; ²Higher levels may be used in extensive production systems; ³When used as a pellet binder

Table 50-11: Minimum requirements of wheat and wheat by-products in accordance with the Feedstuff Legislation of the Federal Republic of Germany⁽⁵⁰⁾

		Wheat				
		Grain	Bran	Pollard	Germ	Gluten
Moisture	max.	14.0	14.0	14.0	12.0	13.0
Crude protein	min.	-	-	-	-	70.0
Starch	min.	58.0	-	40.0	-	-
Crude fibre	max.	-	12.5	3.5	-	-
Ash	max.	-	-	-	-	1.5
Components to be declared:		Starch, crude fibre	Crude fibre	Starch, crude fibre	Crude protein, crude fibre, fat	Crude protein, ash

50.7 References

1. *AAFCO* (1995): Official publication 1995. Ass. of American Feed Control Officials (publisher). Sacramento, CA/USA.
2. *Akiyama, D.M.; Dominy, W.G.; Lawrence, A.A.* (1991): Penaeid shrimp nutrition for the commercial feed industry. Proc. Aquaculture Feed Processing and Nutrition Workshop, Thailand and Indonesia, 19 to 25 September 1991, 80-98. (Revised).
3. *Akiyama, D.M.; Coelho, S.R.; Lawrence, A.L.; Robinson, E.H.* (1988): Apparent digestibility of feedstuffs by the marine shrimp *Penaeus vannamei* Boone. Bull. Japan. Soc. Sci. Fish., 55., 91.
4. *Alam, M.S.; Mollah, M.F.A.* (1958): Formulation of an artificial diet for primary nursing of catfish (*Clarias batrachus* L.) larvae. Bangladesh J. Fish., 11., 71-75.
5. *Arnesen, P.; Krogdahl, A.* (1993): Crude and pre-extruded products of wheat as nutrient sources in extruded diets for atlantic salmon (*Salmo salar* L.) grown in seawater. Aquaculture, 118., 105-117.
6. *Bergot, G.* (1993): Digestibility of native starches of various botanical origins by rainbow trout (*Oncorhynchus mykiss*). Fish Nutrition in Practice. Paris-France Institutional de la Recherche Agronomique, Paris/France, 61., 857-865.
7. *Chakrabarty, N.M.; Roy, A.K.; Halder, D.D.* (1981): Studies on the effect of supplementary feed and fertilizer and fertilizer alone on the growth and survival of *Liza parsia* fry. J. Inland Fish. Soc., India, 13., 92-99.
8. *Cheeke, P.R.* (1987): Rabbit feeding and nutrition. Academic press, Inc., Orlando, Florida/USA.
9. *Cho, C.Y.; Cowey, C.; Watanabe, T.* (1985): Finfish nutrition in Asia: Methodological approaches to research and development. IDRC, Ottawa/Canada, 233e.
10. *Chou, R.* (1993): Aquafeeds and feeding strategies in Singapore. Proc. FAO/AADCP Regional Expert Consultation on farm-Made Aquafeeds, 14 to 18 December 1992, (Bangkok/Thailand). 354-364. FAO-RAPA/AADCP, Bangkok, Thailand.
11. *Davis, D.A.; Arnold, C.R.* (1993): Evaluation of five carbohydrates sources for *Penaeus vannamei*. Aquaculture, 114., 285-292.
12. *De Boer, F.; Bickel, H.* (1988): Livestock feed resources and feed evaluation in Europe. Elsevier Sciences Publishers, Amsterdam/The Netherlands.
13. *Degani, G.; Viola, S.* (1987): The protein sparing effect of carbohydrates in the diet of eels (*Anguilla anguilla*). Aquaculture, 64., 283-291.
14. *Degani, G.; Viola, S.; Levanon, D.* (1986): Effects of dietary carbohydrates source on growth and body comparing of the European eel (*Anguilla anguilla* C.). Aquaculture, 52., 97-104.
15. *Dobbelier, J.; Adams, N.; Bossuyt, E.; Bruggeman, E.; Sorgeloos, P.* (1979): New aspects of the use of inert diets for high density culturing of brine shrimp. The brine shrimp Artemia, 3, Ecology, culturing use in aquaculture. Proc. Int'l. Symposium on the Brine Shrimp *Artemia salina*, Corpus Christi, Texas, 20 to 23 August. 165-174.
16. *Ellis, S.C.; Reigh, R.C.* (1991): Effects of dietary lipid and carbohydrate levels on growth and body composition of juvenile red drum, *Sciaenops ocellatus*. Aquaculture, 97., 383-394.
17. *Enbayah, M.A.; Abuissa, A.A.A.* (1987): Studies of the effect of feeding rate and frequency of feeding on the growth rate and food conversion efficiency of *Mugil auratus* fry. Bull. Mar. Biol. Res. Cent., Tajura, 8., 61-70.
18. *Evans, M.* (1985): Nutrient composition of feedstuffs for pigs and poultry. Queensland Dept. of Primary Industries, Brisbane.
19. *Feed Development Section* (1994): Feeds and feeding of milkfish, Nile tilapia, Asian sea bass and tiger

- shrimp. SEAFDEC Aquaculture Dept., Tigbauan, Iloilo/Philippines.
20. Feltwell, R.; Fox, S. (1978): Practical poultry feeding. Faber and Faber, London and Boston.
 21. Fenucci, J.L.; Saez, M.B.; Petriella, A.M.; Muller, M.I. (1984): Estudios sobre la nutrición de *Penaeus stylirostris* en la Argentina. Re. Latinoam. Acuicult., 19., 22-28.
 22. Grace, G. (1988): Preparation of vital wheat gluten. Proc. World Congress on Vegetable Protein Utilization and Human Foods and Animal Feedstuff, Singapore, October. 112-115.
 23. Hashim, R.; Mat Saat, N.A. (1992): The utilization of seaweed meals as binding agents in pelleted feeds for snakehead (*Channa striatus*) fry and their effects on growth. Aquaculture, 108., 299-308.
 24. Hopher, B. (1988): Nutrition of pond fishes. Cambridge Univ. Press. Cambridge/UA.
 25. Hesser, J.M. (1988): World food uses of vital wheat gluten. Proc. World Congress on Vegetables Protein Utilization and Human Foods and Animal Feedstuffs, Singapore, October. 116-122.
 26. Huang, Y.S. (1988): Growth effect of *Penaeus monodon* fed with different combination of dry heat toasted brown rice and wheat flour diet. J. Fish. Soc., Taiwan, 15., 21-31.
 27. Hughes, S.G. (1990): Use of triticale as a replacement for wheat middlings in diets for Atlantic salmon. Aquaculture, 90., 173-178.
 28. Kahan, D.; Azoury, M. (1981): Laboratory cultivation of *Nitocra spinipes* Boeck from the solar pond (Gulf of Aqaba-Red Sea). Research on intensive aquaculture. European Mariculture Ass. Bredene/Belgium, 6., 117-131.
 29. Kaushik, S.J.; Medale, F.; Facconneau; Blanc, D. (1989): Effect of digestible carbohydrates on protein/energy utilization and on glucose metabolism in rainbow trout (*Salmo gairdneri* R.). Aquaculture, 79., 63-74.
 30. Lowe, B. (1943): Experimental cookery from the chemical and physical standpoint, 3rd ed. John Wiley and Sons, Inc. 410-413.
 31. Magowan, W.I. (1990): Wheats: Soft and hard. In: Thacker, P.A.; Kirkwood, R.N. (eds.) Nontraditional feed sources for use in swine production. Butterworth Publishers, Stoneham, MA/U.S.A.
 32. Meyer, H.; Heckötter, E. (1986): Futterwerttabellen für Hunde und Katzen. Schlütersche Verlagsanstalt and Druckerei GmbH & Co., Hannover/Germany.
 33. Nandeesh, M.C. (1993): Aquafeeds and feeding strategies in India. Proc. FAO/AADCP Regional Expert Consultation on Farm-Made Aquafeeds, 14 to 18 December 1992. 2313-254 (Bangkok, Thailand). FAO-RAPA/AADCP, Bangkok/Thailand. 434.
 34. New, M. (1987): Feed and feeding of fish and shrimps. A manual on the preparation and presentation of compound feeds for shrimp and fish in aquaculture. UNDP/FAO/ADCP/REP8726, Rome/Italy.
 35. NRC (1977): Nutrient requirements of warmwater fishes. Nat. Acad. Press, Washington D.C., U.S.A.
 36. NRC (1981): Nutrient requirement of cold water fish. Nutrient Requirements of Domestic Animals, No. 16. Nat. Academy Press, Washington D.C., U.S.A.
 37. NRC (1983): Nutrient requirements of warmwater fishes and shellfishes. Nat. Acad. Press, Washington D.C., U.S.A.
 38. NRC (1993): Nutrient requirements of fish. Nat. Academy Press, Washington D.C., U.S.A.
 39. Pantha, M.B. (1993): Aquafeeds and feeding strategies in Nepal. Proc. FAO/AADCP Regional Expert Consultation on Farm-Made Aquafeeds, 14 to 18 Decemer 1992. 213-254 (Bangkok/Thailand). FAO-RAPA/AADCP, Bangkok, Thailand.
 40. Rahman, N.; Mustafa, S. (1989): Effects of artificial diet on growth and protein content in the carp *Cyprinus carpio*. J. Ecobibl., 1., 215-222.
 41. Sheen, S.; Chen, J.C. (1993): The feasibility of extruded rice in shrimp feed to replace wheat flour for tiger prawn, *Penaeus monodon*. J. Fish. Soc., Taiwan, 20., 65-72.
 42. Shiau, S.Y.; Lin, S.F.; Lu, L.J. (1991): Effects of different types of wheat flour in feed for grass prawn

- Penaeus monodon*. Nippon Suisan Gakkaishi, 57., 705-710.
43. *Somsueb, P.* (1993): Aquafeeds and feeding strategies in Thailand. Proc. FAO/AADCP Regional Expert Consultation on Farm-Made Aquafeeds, 14 to 18 December 1992. 213-254 (Bangkok/Thailand). FAO-RAPA/AADCP, Bangkok, Thailand.
 44. *Sturmbauer, C.; Hofer, R.* (1985): Can amylase inhibitors from wheat reduce the digestibility of starch and the growth rate in fish? Nutrition and Feeding in Fish. 265-267.
 45. *Szumeic, J.* (1993): Improvement of carp fingerling culture. Effect of different numbers and stock quality on production results. Acta Hydrobiol., 35., 243-260.
 46. *Tacon, A.G.J.* (1987): The nutrition and feeding of farmed-fish and shrimp - A training manual 2. Nutrient Sources and Composition. GC/RLA/075/2TA. Field Document. 5E. FAO. Brasilia, Brazil.
 47. *Täufel, A.; Ternes, W.; Tunger, Zobel, M.* (1993): Lebensmittel-Lexikon. Behr's Verlag, Hamburg/Germany.
 48. *Utama, C.M.* (1993): Aquafeeds and feeding strategies in Malaysia. Proc. FAO/AADCP Regional Expert Consultation on Farm-Made Aquafeeds, 14 to 18 December 1992. 282-296 (Bangkok/Thailand). FAO-RAPA/AADCP, Bangkok/Thailand.
 49. *Watt, B.K.; Merrill, A.L.* (1963): Composition of Foods Agri. Handbook, No. 8, Agri. Res. Service, U.S. Dept. Agri., Washington D.C.
 50. *Weinreich, O.; Koch, V.; Knippel, J.* (1994): Futtermittelrechtliche Vorschriften. Buchedition Agrimedia, Pinneberg/Germany.
 51. *Xu, B.; Ji, W.; Xu, H.; Shief, J.* (1992): The immunologic competence of wheat germ agglutinin in *Penaeus orientalis*. 5. Ocean. Univ. Qingdao-Qingdao Hairing Daozul Xuebao, 22., 29-34.
 52. *Yamoah, E.; Kuzirian, A.M.; McPihie, D.; Matzel, L.* (1988): Artificial diets of fish food are potentially useful for *Hemissenda* mariculture. Biol. Bull. Mar. Biol. Lab., Woodshole, 175., 309.
 53. *Zaher, M.; Mazid, M.A.* (1993): Aquafeeds and feeding strategies in Bangladesh. Proc. FAO/AADCP Regional Expert Consultation on Farm-Made Aquafeeds, 14 to 18 December 1992. 282-296. (Bangkok/Thailand). FAO-RAPA/AADCP, Bangkok/Thailand.

51. WHEY (DE-HYDRATED)

51.1 Rationale

In ancient times the Greek physician *Hippocrates of Kos* (460 to 377 B.C.) used whey to cure phthisis and jaundice, and in modern times whey is used for curing certain metabolic disorders⁽¹⁸⁾.

Whey is utilised fresh, for human consumption and as a feedstuff, particularly for pigs. It is decomposed into protein, lactose and non-protein whey fractions and serves as a substrate for fermentation. Alcohol and acetic acid may be distilled from whey and finally is dehydrated into whey powder⁽¹⁸⁾.

Whey powder is used in the food industry (bakeries, sausage making, dietetics, sweets, confectionery), pharmaceutical industries and as a feedstuff^(18, 22).

51.2 Manufacture and Processing

Dehydration of whey with its low dry matter content is relatively costly because the moisture content has to be reduced from 93% to only 8.0%. Drying the liquid material is the most common form of preserving the dry matter of whey (Figure 51-01).

Drum-drying is less costly than spray-drying. However, the use of high temperature for drum-drying may damage the nutrients of the product because the whey-film is in direct contact with the heated drum. A more careful process that minimises the loss of nutrients is spray-drying. Here the very fine spray-droplets are only indirectly in contact with the heat source^(18, 26).

Whey powder has a creamy colour and a slightly salty taste. Reducing the mineral content of the whey prior to drying gives a so called sweet whey powder⁽²²⁾.

51.3 Chemical, Physiological and other Properties

Chemical Properties

The chemical composition of whey powder is determined by the type of liquid whey used and the type of coagulation of the cow milk. Whey powder from rennin whey has the highest crude protein content and the lowest ash content (Table 51-01). There are no significant differences in the chemical composition between drum-drying and spray-drying⁽²⁶⁾.

The thermo-labile amino acids such as cystine, lysine, histidine and arginine may be damaged by the temperature used for the dehydration of the whey (Table 51-02)⁽²⁶⁾.

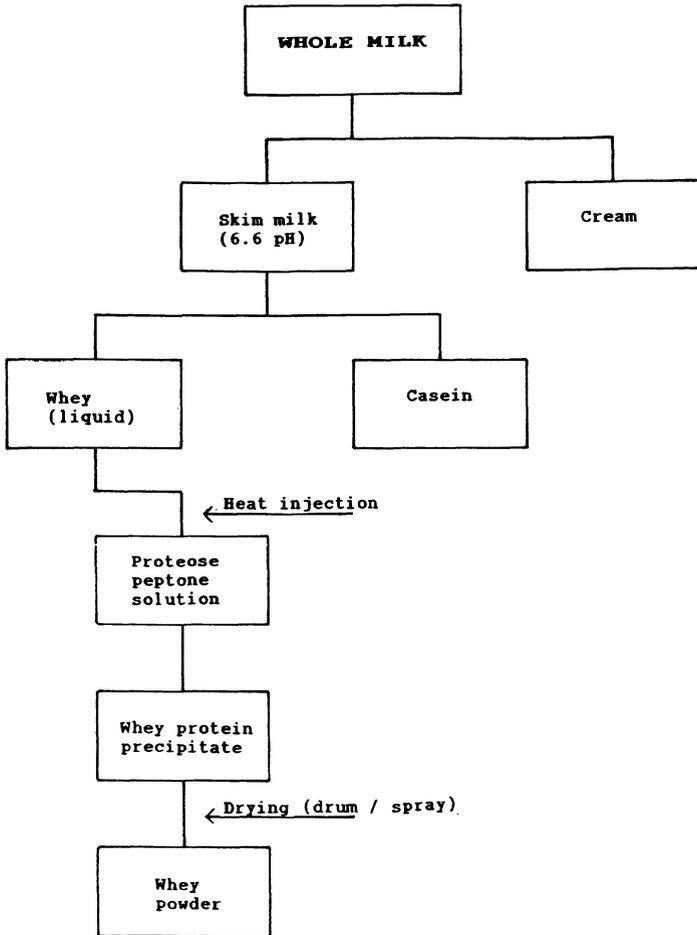


Figure 51-01. From whole milk to whey powder.

Table 51-01: The influence of the type of coagulation of cow milk on the chemical composition of whey powder (% in dry matter)^(9, 26)

	Rennin whey powder	Lactic acid whey powder	Acetic acid whey powder
Crude protein	3.5	12.4	11.0
Fat	0.8	0.6	0.7
Ash	8.1	11.9	11.7
N-free extract	77.6	75.1	76.6
Lactose	75.1	66.1	73.2

Table 51-02: Profile of essential amino acid of whey powder (g/16 g N)^(2, 7, 17, 21, 26)

	Mean	Variation
Arginine	2.7	2.2 - 3.1
Histidine	1.6	1.2 - 1.8
Isoleucine	5.7	5.2 - 6.8
Leucine	9.2	8.2 - 9.8
Lysine	7.3	5.6 - 8.4
Methionine	1.8	1.3 - 2.5
Phenylalanine	3.1	2.5 - 3.7
Threonine	6.5	5.7 - 6.9
Tryptophan	1.7	1.3 - 2.6
Valine	5.2	4.8 - 5.6

Rennin whey powder has a lower calcium and phosphorus content than lactic acid whey powder (Table 51-03)⁽²⁶⁾. The phosphorus is fully available⁽⁷⁾. Whey powder has reasonable levels of vitamins (Table 51-03). However, the vitamins of whey powder may be damaged by the drying temperature.

Table 51-03: Mineral and vitamin contents of whey powder

Minerals ^(4, 7, 16, 17, 26)			Vitamins (per 1,000 g) ^(3, 7, 17, 26)		
Calcium	%	0.63	Vitamin B ₁	mg	3.20
Phosphorus	%	0.68	Vitamin B ₂	mg	29.42
Sodium	%	0.82	Vitamin B ₆	mg	3.20
Potassium	%	2.43	Vitamin B ₁₂	mcg	16.70
Magnesium	%	0.18	Biotin	mg	0.24
Chlorine	%	3.67	Folic acid	mg	0.64
Manganese	mg/kg	2.7	Pantothenic acid	mg	42.25
Iron	mg/kg	260.0	Nicotinic acid	mg	27.10
Zinc	mg/kg	6.5	Choline	g	1.84
Copper	mg/kg	5.0			
Aluminium	mg/kg	1.4			
Boron	mg/kg	4.8			

Physiological Properties

The digestible energy of whey powder for fish amounts to 2,784 kcal/kg (11.6 MJ/kg) (Table 51-04). Protein digestibility may be affected by the drying process (Table 51-05) particularly, if high drying temperature is used⁽²⁶⁾. The digestibility of whey powder in animals has hardly been studied but is generally high (Table 51-06).

Table 51-04: Energy values of whey powder per kg

Species	Gross energy		Metabolisable energy		Digestible energy		Reference
	kcal	MJ	kcal	MJ	kcal	MJ	
Fish ¹	-	-	-	-	2,784	11.6	(16)
Chicken	-	-	2,326	9.8	3,420	14.3	(7,9)

¹ Unspecified species

Table 51-05: The effect of spray-drying and drum-drying on the protein digestibility (%) and the biological value of whey powder⁽²⁶⁾

	Spray-dried whey powder		Drum-dried whey powder	
	Mean	Variation	Mean	Variation
Protein digestibility	96.0	93.1 - 99.3	78.2	74.9 - 81.3
Biological Value	91.7	91.0 - 93.9	82.7	81.8 - 83.5

Table 51-06: Digestibility (%) of whey powder

Species	Digestibility					References
	Organic matter	Crude protein	Fat	Crude fibre	Carbo-hydrates	
Salmonids	-	87.8	91.8	-	-	84.5 (10)
Pigs	95.0	95.0	-	-	-	- (9)
Chicken	91.0	-	-	-	-	- (9)

Whey powder is quite consistent in its effectiveness as indicated by the relatively low standard deviation of the biological values (Table 51-07). The biological value of spray-dried whey powder is superior to the drum-dried material (Table 51-05).

Table 51-07: Biological values of whey powder⁽²⁶⁾

		Mean	Standard deviation
Biological value	BV	93	3.0
Protein efficiency ratio	ER	3.02	0.53
Net protein utilisation	NPU	86.0	6.9
Net protein retention	NPR	66.0	8.4

Other Properties

Whey powder has been presumed by some research workers to contain an unidentified growth factor (UGF) known as the “whey factor”^(8, 26) (see chapter 44).

Higher inclusion rates of whey powder may affect the pellet stability of aquaculture feed. The pelletising ability of whey powder is low but the abrasiveness is considered high^(11, 16).

51.4 Feeding Value

Whey powder is a carbohydrate feedstuff containing a low level of protein but of high quality. The use of whey powder in diets for land animals is common. The inclusion rates have to be limited to 2.0 to 5.0% for poultry feeds and 10.0% for pigs. Higher levels may cause wet droppings due to a high lactose content of whey powder unless its lactose content is low^(8, 26).

Fishes

At low level whey powder in diets for rainbow trout (*Salmo gairdneri*) did not affect weight gain and feed conversion when compared to the control. But at higher levels growth of the trout was reduced and feed conversion was poorer. There was no difference between rennin whey powder and acid whey powder (Table 51-08)⁽²³⁾. Rennin and acid whey powder can replace up to 15% fish meal in the diet for rainbow trouts, if supplemented with arginine^(13, 19).

Table 51-08: Whey powder in diets for rainbow trout (*Salmo gairdneri*)⁽²³⁾

Fish meal	%	34.6	17.3	-	-
Feather meal	%	13.5	6.7	-	-
Poultry by-product meal	%	17.9	9.0	-	-
Soya protein concentrate	%	-	21.1	42.2	42.7
Rennin whey powder	%	-	5.4	10.7	-
Acid whey powder	%	-	-	-	10.7
Crude protein	%	45.0	45.0	45.0	45.0
Fat	%	10.0	9.8	9.6	9.6
Arginine	%	2.70	2.72	2.73	2.73

Weight gain	g	179.4	178.6	149.3	159.5
	rel.	100	100	83	89
Feed conversion	1:	1.23	1.24	1.54	1.50
	rel.	100	101	125	122

Diets for carps (*Cyprinus carpio*) containing 12.5% whey powder were more efficient than the traditional diet of rice and groundnut cake⁽²⁰⁾. The European catfish (*Silurus glanis*) grew better when 50% of a fish meal-feather meal-poultry by-product meal mixture was replaced by whey powder⁽¹²⁾.

Crustaceans

Screening tests for high density culturing of brine shrimp showed that whey powder, soybean meal and rice bran supported good growth although specific precautions have to be considered to avoid water pollution problems⁽⁵⁾.

Molluscs

The dissolved protein in soluble whey protein concentrate was not sufficiently utilised by the Australian oyster (*Saccostrea commercialis*)⁽¹⁵⁾. Whey was also not a good substitute in diets for the American oyster (*Crassostrea virginica*) when compared with the growths of oysters fed on algae/yeast diets alone⁽²⁴⁾.

51.5 Recommended Inclusion Rates

Whey powder contains 50% to 70% lactose. High levels of lactose in diets for mono-gastric land animals can easily cause diarrhoea^(7, 14).

Practical feed formulations for channel catfish (*Ictalurus punctatus*) of the Texas A&M University contain 2.5% whey powder (low lactose)⁽⁶⁾. Up to 10% whey powder has been used in diets for salmonids⁽¹⁶⁾.

For practical aquaculture diets inclusion rates of 2.5 to 5.0% whey powder are recommended. When higher levels are used, the amino acid profile of the diet has to be checked in order to avoid amino acid deficiencies due to the limiting amino acids of whey powder.

51.6 Legal Aspects

Whey powder has to be free of any contamination with pathogenic germs. The use of preservatives is not allowed but whey powder may contain a maximum of 5.0% skim-milk powder⁽¹⁸⁾. EU-Directive 92/87/EEC of 26 October, 1992, differentiate between three different whey powder products. These are⁽²⁵⁾:

- Whey powder EU-No. 8.03
- Whey powder (low lactose) EU-No. 8.04
- Whey protein powder EU-No. 8.05

The requirements by the German feedstuff law for whey powder products are given in Table 51-09. *AAFCO*⁽¹⁾ demands that whey powder should not have less than 11% crude protein and not less than 61% lactose.

Table 51-09: Quality requirements (%) for whey products according to German feedstuffs legislation⁽²⁵⁾

Whey product	Crude protein min.	Lactose min.	Ash max.	Moisture max.
Whey powder	11.0	60.0	0.5	8.0
Whey powder (low lactose)	18.0	30.0	0.5	8.0
Whey powder (high protein)	33.0	-	0.5	8.0
Whey protein powder	70.0	-	0.5	12.0

51.7 References

1. *AAFCO* (1995): Official publication 1995. Ass. of American Feed Control Officials (Publisher), Sacramento, CA/USA.
2. *Anonymous* (1993): Alacen™ 312. New Zealand Dairy Board, Wellington, GD28 2/93.
3. *Anonymous* (w/o year): A vitamin guide for the ALA range of milk protein products. New Zealand Dairy Board, Wellington, EZ10. - 12
4. *Bath, D., Dunbar, J., King, J., Berry, S., Leonhard, R.O., Olbrich, S.* (w/o year): Composition of by-products and unusual feedstuffs (Mimeograph).
5. *Dobbelier, J.; Adams, N.; Bossuyt, E.; Bruggeman, E.; Sorgeloos, P.* (1979): New aspects of the use of inert diets for high density culturing of brine shrimps. Proc. Intern. Symp. on Brine Shrimp Artemina, 20-23 August, Salina Corpus Christi, Texas/U.S.A, 165-174.
6. *Dupree, H.K.; Huner, J.V.* (1984): Third report to the fish farmers. Publ. U.S. Fish and Wildlife Service, Washington, D.C.
7. *Evans, M.* (1985): Nutrient composition of feedstuffs for pigs and poultry. Queensland Dept. Primary Ind., Brisbane/ Australia (Series Q 185001).
8. *Feltwell, R.; Fox, S.* (1978): Practical poultry feeding. Faber and Faber, London and Boston.
9. *Friesecke, H.* (1984): Handbuch der praktischen Fütterung von Rind, Schaf, Pferd, Schwein, Geflügel und Süßwasserfischen. BLV Verlagsges., München/Germany.
10. *Hepher, B.* (1988): Nutrition of pond fishes. Cambridge University Press, Cambridge/U.K.
11. *Hertrampf, J.W.* (1992c): On the water durability of aquaculture feed pellets - A review. Advances in Feed Techn., (7), 18-38. -14-13
12. *Hilge, V.* (1984): Entwicklung von vollwertigen Mischfuttern für Warmwasserfische in der deutschen Aquakultur. Veröffl. Inst. Küst. Binnenfisch., Hamburg, 86., 66.
13. *Koops, H.; Tiews, K.; Gropp, J.; Schwalb-Böhling, A.* (1982): Further results on the replacement of fish meal by other protein feedstuffs in pellet feeds for rainbow trout (*Salmo gairdneri*). Arch. Fischereiwiss., 32., (1/3), 59-73.
14. *Meyer, H.* (1990): Ernährung des Hundes. Verlag Eugen Ulmer, Stuttgart/Germany (2nd ed.).
15. *Nell, J.A.; Wisely, B.* (1983): Experimental feeding of Sydney rock oysters (*Saccostrea commercialis*). II. Protein supplementation of artificial diets for adult oysters. Aquaculture, 32., 1-9.
16. *New, M.B.* (1987): Feed and feeding of fish and shrimps - A manual on the preparation and presentation of compound feeds for shrimps and fish in aquaculture. UNDP/FAO/ADCP/REP/87/26, Rome/Italy.
17. *NRC* (1983): Nutrient requirements of warmwater fishes and shellfishes. National Academy Press. Washington, D.C.
18. *Roeder, G.* (1954): Grundzüge der Milchwirtschaft und des Molkereiwesens. Verlag Paul Parey, Hamburg und Berlin/Germany.
19. *Rumsey, G.L.; Cacace, M.; Zall, R.R.; Lisk, D.J.* (1981): Dairy-processing waste as a replacement protein source in diets of rainbow trout. Prog. Fish. Cult., 43., 86-88.
20. *Sehgal, H.S.; Thomas, J.* (1985): Efficacy of two newly formulated supplementary diets for carp, *Cyprinus carpio, va. communis* (Linn.). 1. Effects on survival, growth and yield. Ann. Biology, 1., 46-55.
21. *Tacon, A.G.J.* (1987): The nutrition and feeding of farmed fish and shrimp - A training manual. 2. Nutrient sources and composition. FAO Field Document 5/E, Brasilia.
22. *Täufel, A.; Ternes, W.; Tunger, Liselotte, Zobel, M.* (1993): Lebensmittel-Lexikon. Behr's Verlag, Hamburg/Germany.
23. *Tiews, K.; Koops, H.; Beck, H.; Schwalb-Bühling, A.; Gropp, J.* (1981): Entwicklung von Ersatzfutter

- für die Regenbogenforelle. Bundesforschungsanstalt für Fischerei, Veröffentl. des Inst. für Küsten- und Binnenfischerei, Hamburg/Germany, Publ. No. 75.
24. Urban, E.R., jr.; Landon, C.J. (1984): Reduction on cost of diets for the American oyster, *Crassostrea virginica* (Gmelin), by the use of non-algal supplements. *Aquaculture*, 38., 277-292.
 25. Weinreich, O.; Koch, V.; Knippel, J. (1994): Futtermittelrechtliche Vorschriften. Buchedition Agrimedia, Hamburg/Germany.
 26. Wöhlbier, W.; Jager, F. (1977): Futtermittel aus Meerestieren. In: Kling, M.; Wöhlbier, W.: Handelsfuttermittel. Verlag Eugen Ulmer, Stuttgart/Germany.

52. YUCCA SCHIDIGERA EXTRACT

52.1 Rationale

All of the nitrogenous wastes from animals are degraded sooner or later to ammonia (NH_3), a colourless, pungent gas, which in its free form is toxic, irritant and corrosive. Aquatic organisms are fed diets of high quality protein. Considerable wastage of food occurs and undergoes microbial degradation to ammonia. Apart from organic nitrogenous residues in the faeces, fish eliminate their end products of nitrogen metabolism mainly as ammonia which pollutes the water. A concentration of $400 \mu\text{M}$ (about 7.0 ppm) of ammonia accumulating in water is highly toxic to the fish⁽¹²⁾.

In ponds, particularly when overstocked, toxic ammonia levels are quickly reached, especially when the nitrogen cycle has not been established, has been interrupted or suddenly become overloaded (Figure 52-01)⁽¹²⁾. Normally, ammonia is oxidised to nitrite and nitrate by autotrophic nitrifying bacteria. However, in intensive aquaculture operations the natural balanced system does not exist and ammonia accumulation is hazardous to aquaculture production.

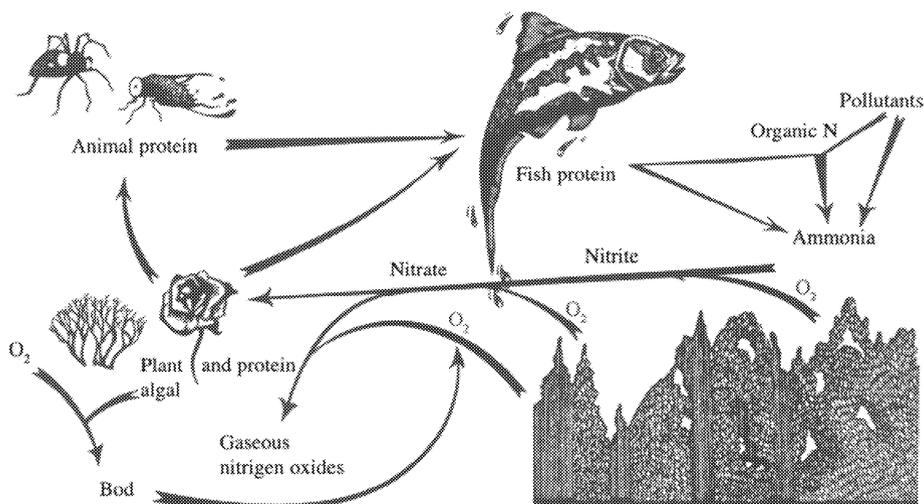


Figure 52-01. The environmental nitrogen cycle of aquatic animals^(re-designed from: 12).

The extract of the *Yucca schidigera* plant is an ammonia binding agent which can buffer the imbalance of ammonia in the environment of aquatic animals.

Yucca schidigera is a species of the genus *Yucca*, which belongs to the *Agave* family and is related to *Agave sisalana*, the source of sisal fibre. *Yucca schidigera* has stiff, sword-shaped leaves and achieve heights of 3.0 to 4.0 m (Figure 52-02). The plant is native to south-western deserts of U.S.A., Central America and the Caribbees.

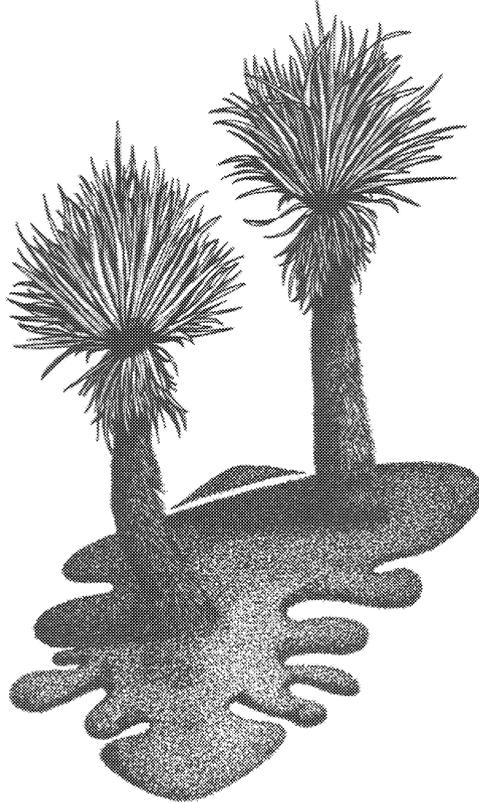


Figure 52-02. *Yucca schidigera* plants.

Another plant with similar properties is *Quillaja saponaria* which is native to Chile and Peru⁽²⁾.

Extracts and preparations from *Yucca schidigera* are used in the soft drink industry as flavouring and foaming agents, and in cosmetics for their surfactant properties⁽¹⁰⁾. The extract is also used as an ingredient in antiarthritic and antistress preparations⁽¹⁾.

52.2 Manufacture and Processing

The leaves and rhizomes of *Yucca schidigera* plants are crushed into pulp. The pulp is centrifuged at high revolution speed and the “juice” obtained is purified and standardised.

The liquid extract is incorporated into a carrier to produce a product in powder form. Saponin-free *Yucca schidigera* extract is obtained by butanol extraction of the plant material^(8, 18).

52.3 Chemical Properties and Mode of Action

Chemical Properties

Yucca schidigera extract contains the following steroidal saponins⁽¹⁾:

- Sarsasapogenin
- Smilagenin
- Hecogenin
- Markogenin
- Samogenin
- Gitogenin
- Neogitogenin.

The differences in the various saponins is due to the combination of the type of sugars. It is presumed that Sarsasaponin, Smilonin and Heconin are the most important saponins of *Yucca schidigera*⁽¹¹⁾. Sarsasapogenin, smilagenin and hecogenin are the respective glycosides⁽³⁾.

The specifications of commercial *Yucca schidigera* products are in Table 52-01. Heat treatment of *Yucca schidigera* at 121°C for 20 minutes does not reduce the ammonia binding capacity⁽¹⁰⁾.

Table 52-01: Specification and chemical composition of commercial *Yucca schidigera* products

	Liquid %	Powder %
Appearance	dark brown	light tan colour
Carrier	-	wheat bran
Heat stability	excellent	excellent
pH	3.9	-
Specific gravity	1.09	-
Shelf-life (min. month)	15	18

Moisture	48.6	5.8
Crude fibre	1.1	8.2
Fat	2.4	3.4
Crude fibre	0.3	22.7
Ash	1.9	11.1
Sugars	28.1	6.2
N-free extract (others)	17.6	42.6

Mode of Action

The capacity of *Yucca schidigera* to survive and grow in the desert is due to its ability to bind the volatile ammonia from the air. It is retained by the plant in a non-toxic form at a high concentration. The ammonia is made available for synthesis of various nitrogenous compounds as required in order to support rapid growth of this desert plant⁽¹⁰⁾.

It is presumed that the three steroid saponins of *Yucca schidigera* extract prevents the accumulation of ammonia by the inhibition of the enzyme urease^(6, 7, 11, 13). But it is more likely that *Yucca schidigera* extract binds ammonia directly^(10, 15). The extraction with butanol, which removes the saponins, shows that the ammonia binding properties are not associated with the saponins⁽¹⁰⁾.

52.4 Feeding Value

In aquatic studies it was found that the concentrations of *Yucca schidigera* extract which can reduce aqueous ammonia levels were toxic to fish^(15, 17). The saponins of *Yucca schidigera* can alter cell wall permeability and cause hemolysis and, therefore, can severely impair gill function⁽⁵⁾. Butanol fractioned, saponin-free *Yucca schidigera* extract is non-toxic to fish. At levels of 0.33 ml saponin-free *Yucca schidigera* extract per litre of water reduced the ammonia and nitrate concentration of the water^(12, 14), which means a better water quality for the fish. In terrestrial farm animals it was found that *Yucca schidigera* extract not only reduces atmospheric ammonia levels in confinement houses as well as to bind other noxious gases but also had a positive effect on the animals' performances^(4, 9, 19, 16).

52.5 Recommended Inclusion Rates and Legal Aspects

Recommended Inclusion Rates

Only saponin-free *Yucca schidigera* extract can be used for aquaculture purposes. Saponin-containing preparations are fatal to aquatic organisms.

For better water quality the liquid saponin-free *Yucca schidigera* extract has to be added to the water at a level of 3.0 to 5.0 ppm. To the feed saponin-free *Yucca schidigera* powder is used at a level of 100 to 150 ppm.

Legal Aspects

Yucca schidigera is non-toxic to man and land animals, but toxic to aquatic animals. However, aquatic animals can tolerate saponin-free preparations. No withdrawal periods have to be observed. *Yucca schidigera* extract has the GRAS-status from the U.S. Food and Drug Administration (FDA Registration No. 172.510).

52.6 References

1. *Anonymous* (1990): Yucca extracts in products for humans. Nor-Feed Product Information Norponin XI (December).
2. *Anonymous* (1993): Data sheet "Quiponin 200 liquid. Nor-Feed, Hvidovre, Denmark.
3. *Anonymous* (1993): Saponins and sapogenins. Nor-Feed Product information Norponin V (August).
4. *Bastien, R.W.* (1987): Effects of *Yucca schidigera* extract on shell strength and ammonia production in poultry manure. Proc. 78th Ann. Meeting Poultry Res. Ass., 10-13 August.
5. *Basu, N.; Rastogi, R.P.* (1967): Triterpenoid saponins and sapogenins. *Phytochemistry*, 6., 1249-1270.
6. *Ellenburger, M.A.; Rumpfer, M.V.; Johnson, D.E.; Goodall, S.R.* (1985): Evaluation of the extent of ruminal urease inhibition by sarsaponin and sarsaponin fractions. *J. Anim. Sci.*, 61. (Suppl.), 491.
7. *Gibson, M.L.; Preston, R.L.; Pritchard, R.H.; Goodall, S.R.* (1985): Effect of sarsaponin and monensin on ruminal ammonia levels and in vitro dry matter digestibilities. *J. Anim. Sci.*, 61. (Suppl.), 492.
8. *Headon, D.R.* (1992): Biotechnology: A case study in identifying glycocomponents and enzymes to assist in reducing pollution. Proc. Alltech's 6th Ann. Europ. Lecture Tour, 24 February to 13 March.
9. *Headon, D.R.; Dawson, K.A.* (1990): Yucca extract controls atmospheric ammonia levels. *Feedstuff*, 62., (29), 2-6.
10. *Headon, D.R.; Bugge, K.; Nelson, A.; Killeen, G.* (1991): Glycofractions of the Yucca plant and the role in ammonia control. In: *Lyons, T.P.* (Ed.): Biotechnology in the Feed Industry. Proc. 7th Ann. Alltech's Symp., 95-108.
11. *Kaneda N.; Nakanishi, H.; Staba, E.J.* (1987): Steroidal constituents of *Yucca schidigera* plants and tissue culture. *Phytochemistry*, 26., 1425-1429.
12. *Leek, B.F.* (1992): The problem of nitrogen waste products in animal production: Investigation into the mode of action of certain glycocomponents capable of manipulating nitrogen. In: *Lyons, T.P.* (Ed.): Biotechnology in the Feed Industry. Proc. 8th Ann. Alltech's Symp., 307-329.
13. *Preston, R.L.; Bartle, S.J.; May, T.; Goodall, S.R.* (1987): Influence of sarsaponin on growth, feed and nitrogen utilization in growing male rats fed diets with added urea or protein. *J. Anim. Sci.*, 65., 481-487.
14. *Quinn, T.; Leek, B.F.* (1992): Effect of saponin-free De-Odorase on fish, ammonia levels and bacterial nitrification in aquaria and its mechanism of action in reducing ammonia and nitrate levels. Alltech Res. Report: 1991-1992 (Sept.).
15. *Ryan, J.; Quinn, T.; Leek, B.F.* (1991): The effects of De-Odorase and its mechanism of action (I) on rumen function and (II) in reducing ammonium levels in a biological filtered environment. Alltech Res. Report (September).
16. *Rowland, L.D.; Plyer, J.E.; Bradley, J.W.* (1979): *Yucca schidigera* extract effect on egg production and house ammonia levels. *Poultry Sci.*, 55. (Abstr.), 2086.
17. *Tidwell, J.H.; Webster, C.D.; Clark, J.A.; Yance, D.H.* (1991): Effects of *Yucca schidigera* extract on water quality and fish growth in recirculating aquaculture systems. *Progressive Fish Cult.* (in press).
18. *Wall, M.E.; Krider, M.M.; Rothman, E.S.; Eddy, C.R.* (1952): Steroidal sapogenins: I. Extraction, isolation and identification. *J. Biol. Chem.*, 198., 533-543.

LIST OF SCIENTIFIC NAMES OF AQUATIC ORGANISMS USED IN THIS BOOK

<i>Acartia</i>	Zooplankton
<i>Acartia clause</i>	Zooplankton
<i>Acartia tonsa</i>	Calanoid copepod
<i>Acetes</i> spp.	
<i>Achatina</i> spp.	Edible land snails
<i>Achatina fulica</i>	African giant snail
<i>Acipenser oxyrhynchus</i>	Atlantic sturgeon
<i>Acipenser transmontanus</i>	White sturgeon
<i>Agriolimax reticulatus</i>	Common field slug
<i>Alligator mississippiensis</i>	Alligator
<i>Allolobophora longa</i>	Terrestrial worm
<i>Ammodytidae</i> spp.	Sand eel
<i>Amusium balloti</i>	Scallops
<i>Anguilla anguilla</i>	European eel
<i>Anguilla japonica</i>	Japanese eel
<i>Aplysia dactylomela</i>	Tropical sea hare
<i>Aplysia kurodai</i>	Japanese sea hare
<i>Arctica islandica</i>	Icelandic bivalve
<i>Argopectan irradians</i>	Argopecten bay scallop
<i>Arion ater</i>	Slug
<i>Aristichtus nobilis</i>	Big head carp
<i>Artemia salina</i>	Brine shrimp
<i>Artemia nauplii</i>	Brine shrimp nauplii
<i>Articulata</i>	Class of gill-breathing
<i>Bacillariophyta</i>	Phylum of diatoms
<i>Bivalvia</i>	Class of oysters, mussels, clams, scallops
<i>Boleophthalmus chinensis</i>	Mud skipper
<i>Brachionus plicatilis</i>	Rotifer
<i>Branchiura sowerby</i>	Tubificid worm
<i>Brevoortia</i> spp.	Menhaden
<i>Calanus</i>	Genus of <i>Copepod</i>
<i>Calanus finmarchicus</i>	Copepod
<i>Callinectes sapidus</i>	Blue crab
<i>Cancer irroratus</i>	Rock crab
<i>Cancer magister</i>	Dungeness crab

<i>Caranx delicatissimus</i>	Striped jack
<i>Carassius auratus</i>	Goldfish
<i>Cardium</i> spp.	Cockle
<i>Catla catla</i>	Indian major carp
<i>Caulerpales</i>	Order of seaweed
<i>Centropages</i>	Zooplankton
<i>Cephalopoda</i>	Class of squid
<i>Ceramiales</i>	Class of seaweed
<i>Ceriodaphnia cornuta</i>	Zooplankton
<i>Cerithium</i> sp.	Pest snails in ponds
<i>Cerithium tenellum</i>	Pest snail in ponds
<i>Chaetoceros</i> spp.	Diatoms
<i>Chaetoceros calcitrans</i>	Algae
<i>Chanos chanos</i>	Milkfish
<i>Channa maculatus</i>	Formosan snakehead
<i>Channa micropeltes</i>	Indonesian snakehead
<i>Channa striatus</i>	Snakehead
<i>Cherax tenuimanus</i>	Freshwater crayfish
<i>Chionoectes opilio</i>	Snow crab
<i>Chlamydomonas</i>	Flagellate
<i>Chlorella vulgaris</i>	Green micro-algae
<i>Chlorophyceae</i>	Class of seaweed
<i>Chlorophyta</i>	Phylum of green micro-algae
<i>Chrysophrys auratus</i>	Gilthead sea bream
<i>Chrysophrys major</i>	Red (Japanese) seabream
<i>Cichlasoma urophthalmus</i>	Mexican native cichlid
<i>Cirrhinus mrigala</i>	Indian major carp
<i>Cirrhinus molitorella</i>	Mud carp
<i>Cladophorales</i>	Order of green algae seaweed
<i>Clarias anguillaris</i>	Mudfish
<i>Clarias batrachus</i>	Catfish
<i>Clarias fuscus</i>	Formosan catfish
<i>Clarias garipepinus</i>	African catfish
<i>Clarias isheriensis</i>	African catfish
<i>Clarias lazera</i>	African catfish
<i>Clarias macrocephalus</i>	Catfish
<i>Clarias mossambicus</i>	African airbreathing catfish
<i>Clupea harengus</i>	Herring
<i>Clupea harengus harengus</i>	Atlantic herring
<i>Clupea harengus pallasii</i>	Pacific herring
<i>Colossoma macropomum</i>	Tambagui
<i>Conger conger</i>	Conger
<i>Coregonus albula</i>	Coldwater vendace
<i>Crangonidae</i>	Shrimp family
<i>Crassostrea</i> spp.	Oyster

<i>Crassostrea gigas</i>	Pacific oyster, blue print oyster
<i>Crassostrea virginica</i>	American oyster
<i>Ctenopharyngodon idellus</i>	Grass carp
<i>Cyanobacteria</i>	Phylum of micro-algae
<i>Cyprinidae</i>	Carp family
<i>Cyprinus carpio</i>	Common carp, mirror carp
Daphnia	Micro-crustacea, water flea
<i>Daphnia pulex</i>	Micro-crustacea
<i>Daphnia similis</i>	Micro-crustacea
<i>Decapoda</i>	Order of crabs
<i>Decapterus</i> spp.	Horse mackerel
<i>Dendrodrilus subrubicundus</i>	Terrestrial worm
<i>Dicentrachus labrax</i>	European sea bass
<i>Dictyotales</i>	Order of seaweed
<i>Dinophyta</i>	Phylum of dinoflagellates
<i>Dosidicus gigas</i>	Jumbo flying squid
<i>Dunaliella salina</i>	Astaxanthin producing algae
Eisenia foetida	Terrestrial worm
<i>Elliptio complanatus</i>	Mussel
<i>Emerita analoga</i>	Sand crab
<i>Engraulidae</i> spp.	Anchovy (true)
<i>Engraulis mordax</i>	Northern anchovy
<i>Eriocheir sinensis</i>	Chinese crab
<i>Epinephelus</i> spp.	Grouper
<i>Eudrilus eugeniae</i>	African night crawler
<i>Euphausia</i>	Genus of small, shrimp-like phosphorescent crustaceans
<i>Euphausia superba</i>	Antarctic krill species
<i>Euphausiidae</i>	Family of Antarctic krill
<i>Evynnis japonica</i>	Crimson sea bream
Fugu rubripes	Puffer fish
<i>Fugu vermicularis</i>	Puffer fish
Gadus morhua	Cod
<i>Geryon quinquedens</i>	Red crab
<i>Gigartinales</i>	Class of seaweed, order of red algae
<i>Girella punctata</i>	Nibbler
<i>Glycera dibranchiata</i>	Blood worm
<i>Gobio gobio</i>	Gudgeon
<i>Gonyaulax catenella</i>	Phytoplankton
<i>Gonyaulax tarenensis</i>	Phytoplankton
<i>Gymnodium breve</i>	Marine dinoflagellate

<i>Haematococcus</i>	Green micro-algae
<i>Haematococcus pluvialis</i>	Micro-algae
<i>Haliotis</i> spp.	Abalone
<i>Haliotis discus</i>	Ezo abalone
<i>Haliotis fulgens</i>	Pink abalone, southern green abalone
<i>Haliotis sieboldi</i>	Japanese abalone
<i>Haliotis tuberculata</i>	Ormer abalone
<i>Haptophyta</i>	Phylum of micro-algae
<i>Heliantis</i> spp.	Snail abalone
<i>Helix</i> spp.	Edible land snails
<i>Helix aspersa maxima</i>	Giant edible land snail
<i>Heterobranchus longifilis</i>	African catfish
<i>Heteropneustes fossilis</i>	Catfish
<i>Hexagrammos otakii</i>	Greenling
<i>Hippoglossus hippoglossus</i>	Halibut
<i>Homarus americanus</i>	Spiny lobster, American lobster
<i>Homarus gammarus</i>	European lobster
<i>Hypothalmichthys molitrix</i>	Silver carp
<i>Ictalurus furcatus</i>	Blue catfish
<i>Ictalurus punctatus</i>	Channel catfish
<i>Ictiobus cyprinellus</i>	Buffalo fish
<i>Illex illecebrosus</i>	Short finned squid
<i>Isochrysis galbana</i>	Algae
<i>Labeo rohita</i>	Rohu (Indian carp)
<i>Labidocera</i>	Zooplankton
<i>Lamellibranchiata</i>	Class of oysters, mussels, clams, scallops
<i>Laminaria</i>	Long leafed kelp
<i>Laminariales</i>	Order of seaweed
<i>Lates calcarifer</i>	Seabass
<i>Lebistes reticulatus</i>	Common guppy
<i>Lepomis chanelus</i>	Green sunfish
<i>Lepomis macrochirus</i>	Bluegill sunfish
<i>Lepomis microlophas</i>	Longear sunfish
<i>Leptobarbus hoevenii</i>	Hoven's carp
<i>Liza macrolepis</i>	Mullet
<i>Liza parsia</i>	Mullet
<i>Loligo loligo</i>	Squid (largest species)
<i>Loligo pealei</i>	Long fin squid
<i>Loligo vulgaris</i>	Common squid
<i>Loliginidae</i>	Family of cephalopods
<i>Lumbricus</i>	Genus of earthworm
<i>Lumbricus terrestris</i>	Earthworm
<i>Lycera dibranchiata</i>	Blood worm

M	
<i>Macrobrachium</i>	Freshwater prawn sub-family
<i>Macrobrachium nobilis</i>	Fresh water prawn
<i>Macrobrachium rosenbergii</i>	Giant freshwater prawn
<i>Macrocystis</i>	Giant kelp
<i>Macrocystis pyrifera</i>	Seaweed
<i>Macroramphosus scolopax</i>	Snipefish
<i>Mallotus villosus</i>	Capelin
<i>Menidia beryllina</i>	Silverside
<i>Mercenaria mercenaria</i>	Hard clam
<i>Merluccius geyi</i>	Chilean hake
<i>Metapenaeus monoceros</i>	Speckled shrimp, ginger prawn
<i>Micaractinum</i>	Sewage-green algae
<i>Micropogonias undulatus</i>	Atlantic croaker
<i>Micropterus dolomieu</i>	Small-mouth bass
<i>Monochrysis</i>	Genus of micro-algae
<i>Modulus metcalfei</i>	Brown mussel
<i>Morone chrysops</i>	Striped bass
<i>Morone saxatilis</i>	Sunshine bass
<i>Meganyctiphanes norvegica</i>	Norwegian krill
<i>Melanogrammus aeglefinus</i>	Haddock
<i>Menidia menidia</i>	Atlantic silverside
<i>Merlangus merlangus</i>	Whiting
<i>Micropterus salmoides</i>	Largemouth
<i>Misgurnus anguillicaudatus</i>	Oriental weatherfish
<i>Modiolus modiolus</i>	New Zealand green mussel
<i>Modulus metcalfei</i>	Brown mussel
<i>Moina macrocopa</i>	Water flea
<i>Moina notabile</i>	Water flea
<i>Mollusca</i>	Phylum of oysters, mussels, clams, scallops
<i>Monochrysis</i>	Genus of micro-algae
<i>Mugil auratus</i>	Golden mullet
<i>Mugil cephalus</i>	Grey mullet, Pacific mullet
<i>Mylio macrocephalus</i>	Black sea bream
<i>Mylopharyngodon piceus</i>	Black carp
<i>Mysidopsis bahia</i>	Mysid
<i>Mystus nemurus</i>	Tropical catfish
<i>Mytilidae</i>	Family of mussels
<i>Mytilus californianus</i>	California sea mussel, common mussel
<i>Mytilus edulis</i>	Blue mussel
N	
<i>Natantia</i>	Suborder of decapode crustaceans
<i>Neomysis integer</i>	Crayfish
<i>Neries</i> sp.	Marine annelids
<i>Nitocra spinipes</i>	Harpacticoid copepod
<i>Nototodarus sloanii</i>	Wellington flying squid, New Zealand arrow squid

<i>Oithona</i>	Zooplankton
<i>Oligochaeta</i>	Class of earthworm
<i>Omnastrephidae</i>	Family of Cephalopods
<i>Oncorhynchus</i> spp.	Pacific salmon
<i>Oncorhynchus gorbusha</i>	Pink salmon
<i>Oncorhynchus keta</i>	Chum salmon
<i>Oncorhynchus kisutch</i>	Coho salmon
<i>Oncorhynchus mykiss</i>	Rainbow trout
<i>Oncorhynchus nerka</i>	Sockeye salmon
<i>Oncorhynchus tshawytscha</i>	Chinook salmon
<i>Oplegnathus fasciatus</i>	Striped knifejaw
<i>Oplegnathus punctatus</i>	Spotted parrot fish
<i>Oreochromis aureus</i>	Blue tilapia
<i>Oreochromis mossambicus</i>	Mozambique tilapia
<i>Oreochromis niloticus</i>	Nile tilapia
<i>Osphronemus gourami</i>	Gourami
<i>Ostrea</i> spp.	Flat oysters
<i>Ostreidae</i>	Family of oysters
<i>Oxyelotris marmoratus</i>	Marble goby
<i>Pacificastus leniusculus</i>	Freshwater crayfish
<i>Pagrus major</i>	Red seabream
<i>Pagurus ehrenborgi</i>	Common crab
<i>Palaemon elegans</i>	Caribbean shrimp
<i>Palaemon serratus</i>	Common prawn, pink shrimp
<i>Palaemonidae</i>	Freshwater prawn family
<i>Palmaria palmata</i>	Red algae
<i>Pandalidae</i>	Shrimp family
<i>Pandalus borealis</i>	Deepwater prawn
<i>Pangasius sutchi</i>	Catfish
<i>Paralichthys olivaceus</i>	Japanese flounder
<i>Paraealanus dabryanus</i>	Chinese loach
<i>Pavlova</i>	Genus of micro-algae
<i>Pecten maximus</i>	Scallop
<i>Pectinidae</i>	Family of scallops
<i>Penaeus aztecus</i>	Brown shrimp
<i>Penaeidae</i>	Shrimp family
<i>Penaeus californiensis</i>	Yellow leg shrimp
<i>Penaeus chinensis</i>	Chinese shrimp
<i>Penaeus duorarum</i>	Pink shrimp
<i>Penaeus indicus</i>	Indian prawn
<i>Penaeus japonicus</i>	Kuruma prawn
<i>Penaeus kerathurus</i>	Caramote prawn
<i>Penaeus merguensis</i>	Banana prawn
<i>Penaeus monodon</i>	Tiger prawn

<i>Penaeus orientalis</i>	Chinese shrimp
<i>Penaeus paulensis</i>	Sao Paulo shrimp
<i>Penaeus penicillatus</i>	Red tail shrimp
<i>Penaeus schmittii</i>	Southern white shrimp
<i>Penaeus semisulcatus</i>	Green tiger prawn, bamboo node prawn
<i>Penaeus setiferus</i>	White shrimp
<i>Penaeus stylirostris</i>	Blue shrimp
<i>Penaeus vannamei</i>	White leg shrimp
<i>Perca</i> spp.	Perch
<i>Perca fluviatilis</i>	European perch
<i>Perna canaliculus</i>	New Zealand green mussel
<i>Perna viridis</i>	Green mussel
<i>Phaeophyceae</i>	Order of seaweed
<i>Phoxinus laevis</i>	Minnow
<i>Pimephales promelas</i>	Fathead minnow
<i>Placuna placenta</i>	Window-pane oyster
<i>Platymonas suecica</i>	Phytoplankton
<i>Plecoglossus altivelis</i>	Ayu sweetfish
<i>Pleuronectes plannipes</i>	Red crab
<i>Pleuronectes platessa</i>	Plaice
<i>Pluerobena cordatum</i>	Big toe mussel
<i>Poecilia reticulata</i>	Guppy
<i>Poecilis latipinna</i>	Molly
<i>Poecilla sphenops</i>	Molly
<i>Pollachius virens</i>	Coalfish, saithe
<i>Pollachius pollachius</i>	Pollack
<i>Polydon spathula</i>	Paddlefish
<i>Pomacea caniculata</i>	Golden apple snail
<i>Procambarus clarkii</i>	Red swamp crayfish
<i>Procambarus zonangulus</i>	Swamp crayfish
<i>Pseudocaranx dentex</i>	Striped jack
<i>Pseudopleuronectis americanus</i>	Winter flounder
<i>Puntius gonionotus</i>	Puntius carp, silver barb
<i>Puntius javanicus</i>	Javanese carp, Java barb
<i>Pyraminontas virginica</i>	Algae
<i>Rana catesbeiana</i>	Bullfrog
<i>Rana perezi</i>	Frog
<i>Ratatoria</i>	Phylum of Rotifer
<i>Rhinalanus</i>	Zooplankton
<i>Rhithropanoperus harrisii</i>	Mudcrab
<i>Rhodophyceae</i>	Class of seaweed
<i>Rhodophyta</i>	Unicellular micro-algae
<i>Rhodotorula aurantica</i>	Seaweed
<i>Rhodymeniales</i>	Class of seaweed

<i>Saccostrea commercialis</i>	Australian oyster
<i>Salmo gairdneri</i>	Rainbow trout
<i>Salmo salar</i>	Atlantic salmon
<i>Salmo trutta</i>	Brown trout, sea trout
<i>Salvelinus alpinus</i>	Arctic cohar
<i>Salvelinus fontinalis</i>	Brook trout
<i>Salvelinus namaycush</i>	Lake trout
<i>Sardina pilchardus</i>	Sardine, pilchard
<i>Sardinops melanostictus</i>	Sardine
<i>Sarotherodon aureus</i>	Blue tilapia
<i>Sarotherodon melanotheron</i>	African Tilapia
<i>Sarotherodon mossambicus</i>	Mozambiqueian tilapia
<i>Sarotherodon niloticus</i>	Nile tilapia
<i>Sciaenidae</i> spp.	Croaker
<i>Sciaenops ocellatus</i>	Red drum
<i>Scomber</i> spp.	Mackerel
<i>Scomber japonicus</i>	Chub mackerel
<i>Scomber scombrus</i>	Atlantic mackerel
<i>Scomberomorus cavalla</i>	King mackerel
<i>Scophthalmus maximus</i>	Turbot
<i>Scorpoma ustulata</i>	Fish
<i>Scylla serrata</i>	Mud crab
<i>Sebastes</i> spp.	Bream, redfish
<i>Sebastes marinus</i>	Redfish
<i>Sebastes thompsoni</i>	Rock fish
<i>Sebastes viviparus</i>	Redfish
<i>Seriola quinqueradiata</i>	Yellowtail
<i>Serratia liquefaciens</i>	Pathogenic bacteria
<i>Siganus canaliculatus</i>	Rabbitfish
<i>Siganus guttatus</i>	Rabbitfish
<i>Silurus glanis</i>	European catfish
<i>Simocephalus vetulus</i>	Cladocera
<i>Skeletonema costatum</i>	Diatom phytoplankton
<i>Solea solea</i>	Sole
<i>Solemya reidi</i>	Gutless bivalve
<i>Sparus aurata</i>	Gilthead seabream
<i>Spirulina</i> sp.	Diatoms
<i>Spratus spratus</i>	Sprat
<i>Squalidae</i>	Family of dogfish
<i>Squaliformes</i>	Order of shark
<i>Squalus acanthias</i>	Dogfish
<i>Sterolepsis gigas</i>	Sea bass
<i>Stizostedion vitreum</i>	Walleyes
<i>Stolephorus commersonii</i>	Anchovy (false)
<i>Sunneta scripta</i>	Clam

<i>Tapes</i> spp.	Short-necked clam
<i>Telescopium telescopium</i>	Pest snail in ponds
<i>Tenebrio</i>	Genus of mealworm
<i>Tenebrio molitor</i>	Mealworm
<i>Tetraselmis</i> sp.	Algae
<i>Thalassiosira pseudonana</i>	Cultured algae
<i>Thunnidae</i>	Family of tuna
<i>Thunnus</i> spp.	Tuna
<i>Thysandoessa inermis</i>	Krill species
<i>Tigriopus</i> spp.	Marine copepods
<i>Tilapia aurea</i>	Blue tilapia
<i>Tilapia discolor</i>	Tilapia
<i>Tilapia mossambica</i>	Mozambique tilapia
<i>Tilapia nilotica (niloticus)</i>	Nile tilapia
<i>ilapia randalli</i>	Tropical cichlid
<i>Tilapia zillii</i>	Tilapia
<i>Tinca tinca</i>	Tench
<i>Tracheata</i>	Sub-phylum of articulated animals
<i>Trachurus japonicus</i>	Horse mackerel
<i>Trachinotus carolinus</i>	Florida pompano
<i>Trichogaster leerii</i>	Pearl gourami
<i>Trichagaster pectoralis</i>	Siamese gourami
<i>Trisopterus esmarkii</i>	Norway pout
<i>Trisopterus luscus</i>	Pout
<i>Tubifex</i>	Freshwater oligochaete worms
<i>Ulvales</i>	Order of green algae
<i>Undaria</i>	Brown kelp
<i>Venerupis philippinarum</i>	Short-necked clam
<i>Xiphophorus helleri</i>	Ornamental swordtail

INDEX

- Abalone (*Haliotis discus*), 428
Abalone (*Haliotis tuberculata*), 428
Abrasive, 471
Acacia, 232
Acartia, 244, 250, 252
Acetes, 365, 367
Acetic acid whey powder, 544
Achatina spp, 379
Acid fish silage, 198, 199
Acid treated blood, 76
Acid value, 55
Active or live yeast, 158, 169, 170
Active yeast culture, 169
Acute toxicities in dogs, rats, mice, 144
Aflatoxin, 98, 422, 481, 495
African giant snail (*Achatina fulica*), 379
African night crawler, 511
Algae, 383
Algal astaxanthin, 146, 151, 152
Alkaline silage, 199
Alkaloids, 487
Alkane yeast, 158, 159, 160, 161, 163, 164, 165
Allolobophora longa, 510, 511
Allyl isothiocyanate, 465
Ammonia binding agent, 551
Ammoniac amines, 200
Amphipods, 245, 430
Amylase inhibitor, 534
Animal fat, 44, 54, 55
Antinutritional substances, 417
Antioxidants, 205
Antioxidative property, 386
Anti-vitamins, 342, 462
Apparent digestibility, 89, 101, 164, 184, 194, 203, 204, 251, 267, 285, 297, 367, 398, 434, 460, 464, 479
Apparent protein digestibility, 405, 526
Appetite stimulants, 374
Approved pigments, 154
Aquatic animals, 4
Arachis nut, 455
Argentine rape-seed (*Brassica napus*), 472
Arginine inhibitors, 495
Artemia, 244, 245, 246, 247, 537
Arthropoda, 244
Ascomycetes, 157
Aspergillus niger, 326
Astaxanthin, 142, 144, 146, 147, 148, 150, 151
Asteraceae, 498
Autolysis, 199
Autoxidation, 374
Avocado oil, 415
Babassu, oil, 415
Bacillariophyta, 243
Bacteria, 383
Bacterial fermentation, 133
Baker's yeast, 157, 218
Barley, 80
B-carotene, 236
Betaine, 406
Bile, 60
Bile acid, 60, 61
Bile salts, 60
Biogenic amines, 200
Biological properties, 144, 145
Biological value, 10, 89, 304, 399, 519, 520, 546
Bivalves, 9
Black gram (*Phaseolus mungo*), 338, 339
Bleaching earth, 65
Blood, 69, 70
Blood collection, 69
Blood composition dried, fresh, 70
Blood meal, 74
Blood preservation, 70
Blood worms (*Glycera dibranchiata*), 319
Blue disease, 145
Blue mussel (*Mytilus edulis*), 314, 315, 317
Bohemeria nivea, 267
Brachionus plicatilis, 243, 245, 246, 247
Brain, 383
Bran, 263, 264, 272, 276, 531
Brewer's grains, 80
Brewer's yeast, 149, 158
Brine shrimp (*Artemia salina*), 244, 245, 246, 356
Bristles, 322
Broken back syndrome, 515, 516
Broken rice, 351, 353, 356, 357
Brown rice, 351
Bulk density, 83
Cadaverine, 202
Calanus, 244
Ca-L-ascorbyl-2-monophosphate (AAP-Ca), 518
Candida, 172
Candida utilis, 165
Canola meal, 472
Cantaxanthin, 142, 145, 146, 147, 148, 149
Carbohydrates, 13
Carcass composition, 286
Carcass quality, 287

- Carnivores, 5
 Carotenes/carotenoids, 142, 143, 144, 145
 Cassava, 200
 Castor oil, 415
 Cataract, 235
 Catla-rohu hybrid, 375
Centropages, 244, 246
Cephalopoda, 403
 Cereals, 169
Chaetoceros, 368
 Cheese loaf, 98
 Cheese rind, 98
Cheese scrap, 96
 Chelated mineral, 310
 Chemoattractant properties, 185, 317, 367, 386, 406, 511
 Chick pea (*Cicer arietinum*), 338
 Chicken egg, 125
 Chinese nuts, 455
 Chitin, 201, 373, 367
Chlorella, 250
 Chlorophyta, 243
 Cholesterol, 405
 Choline, 390
 Chromium content, 229
Chroococcus, 250
Cladocerans, 244
 Clams, 8, 314
Clostridium perfringens, 299
 Cocoa beans/berries/pods/shells, 100, 101
 Cocoa butter, 415
 Coconut meal, 446
 Coconut oil, 419
 Cocoon, 372
 Collagen, 229
 Colza, 472
 Common field slug (*Agriolimax meticulatus*), 379
 Congealing point, 54
 Contaminants in mineral ingredients, 308, 309, 311
 Contour feathers, 131
 Copepods (*Arcaïta tonsa*), 244, 356
 Corn, 262
Corpus luteum, 142
 Cotton-seed meal, corticated/decorticated, 450, 454
 Cotton-seed oil, 415, 422
 Cow pea (*Vigna catiãg*, *Vigna unguiculata*), 338, 345
 Crab meal, 109, 110, 111
 Crab protein concentrate, 109, 110, 111
 Cresole red dye-binding, 486
 Crucifer oil, 415
 Crustacean wastes, 152, 153
 Crustaceans, 6, 15
Cryptococaceae, 172
 Cuttlefish, 403
 Cyanogenic glycoside, 424
 Cyanogens, 342
 Cyclopropenoids, 453

 Danish fish meal, 178
Daphnia, 244, 245, 250
 De-hulled rice, 352
 Dehydrated fish solubles, 411, 453, 457, 458, 461, 464, 465, 474, 481, 486, 495
 Deleterious substances, 422, 431, 433, 453, 461, 462, 464, 465, 474, 475, 478, 531, 553
Dendrodrilus subrubicundus meal, 511
 De-oiled rice bran, 352
 Dextrin, 266, 274, 276
 Detritus feeders, 5
 Diatoms, 243
 Digestible energy, 13, 102, 135, 162, 170, 183, 194, 203, 213, 223, 259, 284, 296, 327, 332, 341, 366, 374, 420, 449, 452, 457, 460, 464, 469, 470, 474, 480, 484, 485, 495, 526, 534, 545, 546,
 Digestibility of feed ingredients, 14, 82, 135, 136, 213, 230, 234, 405, 421, 451, 457, 461, 471, 477, 480, 485, 486, 495, 511, 526, 535, 546
 Dinoglagellates, 243
Dinophyta, 243
 Distillers dried grains, 115
 Distillers dried solubles, 115
 Distillers feeds, 411
 Distillery by-products, 115
Down feathers, 131
 Dried feed microbials, 169
 Dry extrusion technology, 133
 Dry roasting, 445
 Duck egg, 125

 Earth nuts, 455
 Edible snails/meal, 379
 Efficiency index of binders, 34, 35
 Egg powder, 125, 129
 Egg protein ratio, 128
 Egg spray-dried, 127
 Egg white proteins, 127
 Egg yolk, 142
Eichhornia crassipes, 525
Eisenia foetida, 509, 510, 511, 512
Endomycetaceae, 172
Endomycopsis fibuliger, 165
 Ensiling, 364

- Enzyme inhibitors, 130
- Erucic acid, 431, 474
- Escherichia coli*, 171
- Essential amino acid index, 10
- Essential amino acid profile, 12, 81, 87, 97, 106, 118, 128, 133, 134, 160, 170, 181, 184, 201, 202, 213, 222, 230, 233, 247, 256, 264, 294, 323, 326, 331, 340, 365, 372, 373, 380, 396, 398, 405, 412, 448, 451, 456, 460, 464, 470, 473, 477, 479, 483, 494, 510, 532, 543, 544, 545, 553
- Estrogen, 487
- Eudrilus eugeniae*, 510, 511, 512
- Euphasia pacifica*, 221
- Euphasia superba*, 221
- Euphasia*, 221
- Euphausiidae*, 221
- Faba bean (*Vicia faba*), 338, 343, 344
- Fat composition, 105
- Fat soluble, 20
- Fatty acid groups, 18
- Fatty acid profile, 44, 55, 417, 418
- Fatty acids, 100, 117, 128, 182, 193, 201, 223, 246, 247, 282, 283, 316, 332, 366, 372, 373, 385, 405, 409, 510
- Fatty acids, systematic and common name, 50
- Fatty liver syndrome, 21
- Faunal order, 241
- Feather meal (hydrolysed), 131
- Feed conversion, 224, 225, 259, 323, 375
- Feed organisms, 241
- Feed yeast, 157
- Feeding habit, 6
- Feeding value in:
- Abalone (*Heliantis* spp.), 270, 298, 492
- Alligator (*Alligator mississippiensis*), 275
- Crustaceans, 48, 51, 52, 68, 75, 91, 112, 120, 129, 138, 147, 151, 152, 155, 186, 196, 207, 214, 226, 237, 250, 259, 260, 270, 275, 317, 345, 356, 368, 376, 381, 389, 406, 421, 425, 428, 436, 454, 458, 466, 490, 491, 492, 512, 521, 537, 538, 548
- Fishes, 46, 51, 52, 53, 54, 62, 67, 74, 75, 83, 90, 98, 102, 106, 119, 129, 136, 146, 150, 163, 164, 171, 185, 195, 205, 219, 224, 230, 235, 250, 258, 267, 269, 271, 273, 275, 286, 297, 322, 333, 343, 345, 346, 347, 355, 357, 358, 367, 375, 388, 400, 406, 421, 422, 423, 424, 426, 427, 429, 430, 431, 432, 433, 434, 435, 437, 453, 458, 462, 468, 471, 475, 478, 481, 488, 489, 490, 495, 496, 511, 519, 527, 528, 529, 536, 537, 547, 554
- Frogs (*Rana* sp., *Rana perizi*), 492
- Live food organisms, 356
- Lobster (*Halifax*), 389
- Mollusc, 91, 129, 139, 167, 187, 251, 428, 548
- Oyster, 150, 168, 251, 260, 548, 554
- Snail (*Hermisenda*), 538
- Terrestrial animals, 554
- Tubificid worms, 466
- Zooplanktons (*Brachionus plicatilis*), 167
- Fermentation factor, 411
- Fermented silage, 199, 200, 202
- Field bean (*Phaseolus vulgaris*), 338, 343, 344
- Filoplume, 131
- Fish catch, 179
- Fish extract, 411
- Fish liver oil, 281
- Fish meal, 177, 178, 179, 199, 180, 181, 182, 411
- Fish meal analog, 136, 137
- Fish oil, 281, 283
- Fish protein concentrate (hydrolysed), 192
- Fish silage, 198, 199
- Fish solubles, 211, 411
- Fishes, 4, 14
- Flax (*Linum usitatissimum*), 459
- Flesh oils, 415, 416
- Floral order, 241
- Flour, 263
- Fluorescence test, 486
- Food attractants, 374
- Formaldehyde tritration, 486
- Freshwater fish, 18
- Fungi, 383
- Galactomannan gums, 235
- Gastropod molluscs, 379
- "Gischt", 157
- Gitogenin, 553
- Gliadin, 531
- Glucans, 218, 219
- Gluco-brassicinapin, 474
- Glucosinapin, 474
- Glucose, 275
- Glucosinolates, 464, 465, 474
- Gluten feed, 263, 270, 271, 272, 276
- Gluten meal, 263, 264, 265, 266, 270, 271, 272, 273, 276
- Glutenin, 531
- Glycerphospholipids, 384
- Glycine betaine concentration, 28
- Glycine, 406
- Glycoalkaloid, 327
- Glycoside, 487
- Goitrogens, 342
- Golden apple snail (*Pomacea caniculata*), 379
- Gonyaulax catenella*, 317

- Gonyaulax tarenensis*, 317
 Goober peas, 455
 Goose egg, 125
 Gossypol, 422, 453
 GRAS, 173
 Green gram (*Phaseolus aureus*), 343
 Grits, 263
 Gross energy, 102, 194, 203, 249, 266, 284, 296,
 317, 327, 332, 341, 355, 374, 381, 420, 452,
 457, 461, 464, 468, 470, 474, 485, 485, 534,
 546
 Ground nut expeller/meal, 455, 456
 Ground-nut oil, 415, 423
Gymnodinium breve, 317

 Haptophyta, 243
 Harpacticoid copepod, 537
 Heavy metal, 7, 223, 527
 Hecogenin, 553
Helianthus annuus, 493
 Herbivores, 5, 185, 202
 Histamine, 185, 202
Hominy, 264
 Hops and dreg, 80
 Hydrogenated fish oil, 285
 Hydrolysed feather meal, 134
 Hygienic aspects, 73

Illex illecebrosus, 404
 Immunostimulatory effect, 217
 Immunostimulatory substances, 217
 Inactive or dead yeast, 158, 160, 162
 Inositol, 390
 Invertebrates, 509
 Iodine value, 55, 419
 Ipil-ipil, 232
Isochrysis galbana, 251
 Isothiocyanate, 465

 Jack bean (*Canavalia ensiformis*), 338, 346, 347
 Jet-sploding, 445

 Keratin, 322
 Koa-haole, 232
 Krill meal, 221

Labidocera, 244
 Lactic acid whey powder, 544
 Lactic yeast (*Kluyveromyces fragilis*), 158, 159,
 160, 161, 165, 166, 167
 Lamtoro, 232
 Land snails (*Helix* spp), 379
 Lard, 50, 51
 Larval movement, 242

 L-ascorbic acid, 515
 L-ascorbic acid-2-sulphate (AAS), 518
 L-ascorbyl-2-monophosphate (AAP), 518
 L-ascorbyl-2-polyphosphate (AAP), 518
 Lathrogens, 342
 Leather meal (hydrolysed), 229
 Leather scrap (fleshings), 229
 Leather waste (trimmings), 229
 Lecithin (crude de-oiled), 383, 384, 385, 386
 Lectins (phytohemagglutinins), 343, 487
 Legume oil, 415
Leguminosae, 232, 338
 Lentils (*Lens esculenta*), 338, 346
Leucaena leaf meal, 234
Leucaena leucocephala, 232
 L-gulono-t-lactone oxidase, 515
 Limiting amino acids, 81
 Linamarine, 461
 Linatine, 461, 462
 Linseed expeller/meal, 459, 460
 Linseed oil, 415, 424
 Lipids, 16
 Lipochromes, 143
 Live cell yeast culture, 169
 Live food, 241
 Live food organisms, 356
 Live yeast feed, 169
 Liver, 255
 Liver meal, 256
 Liver residue, 411
Loligo pealeii/*Loliquinidae*, 403, 404
 Lucerne, 411
Lumbricus terrestris, 509, 510, 511
 Lupins, 338, 344, 346, 346
 Lutein, 234

 Macrominerals, 23, 24, 302
Macroramphosus scolopax, 207
 Maize distillers dried grains, 116
 Maize germ cake, 273, 276
 Maize oil, 263
 Maize products, 262
 Maize starch, 264, 268
 Maize-germ oil, 415, 425
 Malt, 80
 Malvalic acid, 453
 Manilla nuts, 455
 Marine fish, 18
 Marine oil, 281
 Marine silage, 198
 Markogenin, 553
 Mass culture, 245
 Matairesinol-B-glucoside, 478
 Mealworm, 509

- Meat and bone meal, 291
Meganocytiphanes norvegica, 226
 Melting point, 17, 55, 285, 419
Mercenaria mercenaria, 319
 Metabolisable energy, 13, 102, 135, 163, 171, 183, 194, 203, 213, 266, 284, 296, 327, 332, 341, 355, 381, 420, 449, 451, 457, 460, 468, 470, 474, 477, 480, 484, 485, 495, 534, 546
 Metal-binding factors, 342
 Mg-L-ascorbyl-2-monophosphate (AAP-M), 518
 Micro-crustacea, 241, 243
 Micronisation, 445
 Milk, 86
 Mill run, 531
 Mimosine, 232, 235
 Mineral content in *Dosidicus gigas*, 405
 Mineral content, 82, 88, 97, 119, 129, 134, 161, 162, 170, 182, 194, 201, 213, 234, 248, 257, 265, 295, 316, 322, 327, 332, 340, 354, 366, 373, 385, 412, 425, 429, 449, 452, 456, 460, 470, 473, 477, 479, 484, 494, 533, 545
 Mineral feed ingredients, 302
Modiolus modiolus, 317
Moina, 250
 Molasses absorption capacity, 83
 Mold inhibitor, 199
 Molluscs, 8, 16
 Monkey nuts, 455
 Montmorillonite, 65
 Mulberry (*Morus alba*), 372
 Mulberry silkworm (*Bombyx mori*), 372
 Mung bean (*Vigna radiata*, *Vigna mungo*), 338, 343
 Mussels (*Mytilidae*), 8, 314, 315
 Mustard meal, 463, 464
 Mustard oil, 415
Mytilus edulis, 317
- Na-L-ascorbyl-2-monophosphate (Na), 518
 Na-L-ascorbyl-2-triphosphate (AAP-Na), 518
Naviculla, 250
 Nematodes, 245
 Neogitogenin, 553
Nereis sp., 510, 512
 Net protein utilisation, 10, 89, 251, 398
 Nitrifying bacteria, 551
 Nitrogen cycle, 551
 Nitrogen fraction of milk, 87
 Non-protein nitrogen, 202
 Nucleic acid, 164
- Oil of colza, 431
 Oil-bearing seeds, 445
Oithona, 252
- Oligochaeta*, 509
 Oligochaete worms, 245
 Olive by-products/cake/bagasse, 467
 Olive meal/pulp, 468
 Olive oil, 415, 428
 Omnivores, 5
Onmastrephidae, 403
 Ornamental fish, 154
 Ostrich egg, 125
 Ovoinhibitor, 128, 129, 130
 Ovomuroid, 129, 130
 Oxalates, 481
 Oxalic acid salts, 527
 Oxides, 308, 309
 Oxidised oils, 204
 Oysters (*Ostreidae*), 8, 317
- Palm oil/palm kernel oil, 415, 429
 Palm-kernel expeller/meal, 468, 469, 470
Paracalanus, 252
 Pea (*Pisum sativum*), 338, 346
 Peanuts, 455
 Pellet binder, 534
 Pellet quality, 471
 Pelletising ability, 83, 185, 343, 357, 487
 Pelletising temperature, 517, 518, 519
 Pepsin digestibility, 137
Pereskia aculeata, 267
Perna viridis, 317
 Peroxide value, 55
 Pesticide residues, 223
 Pesticides, 7
 Pests in:
 milkfish ponds (*Telescopium telescopium*), 379
 ricefield (*Ceritium tenellum*), 379
Phaffia rhodozyma, 149
 Phagostimulatory substances, 28
 Phenolic compounds, 342
 Phosphatidylcholine, 383, 384
 Phosphatidylethanolamine, 384
 Phosphatidylinositol, 384
 Phospholipids, sources, functions, 383, 387, 388
 Phosphorus, 390
 Phytates, 481
 Phytoplanktons, 241, 242, 243
Pichia pastoris yeast, 172
 Pig bristle meal (hydrolysed), 322
 Pigeon egg, 125
 Pigmented flesh, 144
 Pigmenter, 367
 Pindar, 455
 Pink flesh of salmonids, 142
 Pink plumage, 142

- Platymonas suecica*, 251
 Poaceae, 531
 Polar lipids, 384, 386
 Polish rape-seed (*Brassica campestris*), 472
 Potato juice, 325
 Potato products - starch, protein, pulp, 325
 Potato protein, 325
 Poultry fat, 53
 Poultry by-products meal, 330, 331
 Precautions, 84, 107, 108, 113, 154, 208, 252, 319
 Preservatives, 199, 201
 Preserved blood, 76
 Procyanidins, 235
 Productive protein value, 10
 Progoitrin, 474
 Protease inhibitor, 235, 342, 465, 495
 Proteins, 9
 Protein efficiency ratio, 10, 251
 Protein requirement, 10, 11, 12
 Protozoa, 245
 Putrescine, 202
- Rana* sp, 245
 Rape, 472
 Rape-seed (*Brassica* spp.) expeller/meal, 472
 Rape-seed meal, double low, 472
 Rape-seed oil, 415, 431
 Raps, 472
Rattatoria, 243
 Red algae, 242
 Red drum, 538
 Red earthworm, 509
 Red exoskeleton, 142
 Red tide, 243
 Rendering, 192, 292
 Residual oil, 449, 459, 462
Rhinalanus, 244
 Rice (*Oryza sativa*), 351
 Rice bran, 351, 352, 353, 354
 Rice bran oil, 352, 432
 Rice hulls, 351, 358
 Rice, polished, 352
 Rice pollard, 353
 Rock crab (*Cancer irroratus*), 109
 Rotifers, 243
- Saccharomyces cerevisiae*, 158, 167, 169
Saccharomycetaceae, 172
 Safflower expeller/meal, 476
 Safflower meal, corticated/decorticated, 476, 477
 Safflower oil, 432
 Salmonella
 Salmonids, 146
- Salmons, 154
 Samogenin, 553
 Saponification value, 55
 Saponin, 235, 487
 Sarafloxacin, 426
 Sarsapogenin, 553
 Scallops (*Pectinidae*), 8, 314, 315, 317
 Scurvy, 515
 Seed fats (solid and semi-solid), 418
 Seed oils, 415
 Sericulture, 372
Serraton liquefaciens, 251
 Sesame expeller/meal, 478
 Sesame oil, 415, 433
 Sesamin, 433
 Sesamolone, 433
 Sesbania (*Sesbania grandiflora*), 338, 346, 347
 Short-necked clam (*Venerupis philippinarum*), 314, 318
 Shrimp meal, 364, 365, 411
 Shrimp head meals/silage, 365
 Silkworm pupae meal, 372
 Sinalbine, 465
 Sinapine, 475
 Sinigrine, 465
 Slip point, 430
 Sludge, 385
 Smilagenin, 553
 Snail, 538
 Sodium hydroxide treatment, 133
 Solidification point, 419
 Solvent extraction, 445
 Soya lecithin, 383
 Soya protein concentrate/hydrolysate, 396, 397, 398
 Soya protein products/isolate, 396, 397, 398, 399
 Soybean meal, 482
 Soybean expeller/meal, 383, 396, 482, 484
 Soybean oil, 415, 434
 Sphingophospholipids, 384
Spirulina platensis, 250
Spyrogira, 250
 Squid meal, 403, 411
 Squid liver meal, 404
 Squid viscera fresh, 404
 Starch, 263, 264, 276
 Sterculic acid, 453
 Steroidal saponins, 553
 Sterols, 433
 Sterol content, 128
 Storage, 517, 518, 519
 Sucrose, 275
 Sulphates, 308, 309
 Sunflower expeller/meal/seeds, 493

- Sunflower oil, 415, 437
Sunnepta scripta, 317
 Surfactants, 7
- Tallow, 44, 47
 Tannins, 235, 457, 475, 487, 495
 Tapioca, 200
 Taste bud, 27
 Taurocholic acid, 61
Tenebrio, 509
Tetraselmis suecica, 251
Tetraselmis tetrahele, 252
Thalassiosera pseudonana, 251
 Theobromine, 99
 Thiaminase enzyme, 204
 Thiaminase, 465
 Torula yeast, 163
 Toxic algae, 317
 Toxicity, 120, 227
 Trace minerals 24, 308, 309
 Trassi-udang, 100
Trigriopus japonicus, 250
 Trimethylamine, 200
Triticum aestivum, 531
Triticum vulgare, 531
Triticum, 531
 True digestibility, 89, 398, 464, 479
 Trypsin inhibitors, 343, 458, 486, 487
Tubifex, 245
 Turkey egg, 125
 Tyramine, 202
 Undesirable substances, 187
 Unidentified growth factor (UGF), 119, 120, 135, 164, 204, 214, 258, 381, 406, 411
 Unpalatable factor, 381
 Unsaturated fatty acids, 281, 283
 Urea nitrogen, 202
 Urease activity, 486, 487
 Urease, 487
- Vegetable oils, 415
 Velvet bean (*Stizolobium* sp), 338
 Vermi meal, 509
 Vermiculture, 509
 Vetch (*Vicia sativa*), 338
Vibrio anguillarum, 251
Vibrio salmonicida, 251
 Vitamins, 19, 96
 Vitamin B₆ antagonist, 461
 Vitamin C products (see also ascorbic acid), 515, 516, 517, 518, 519
 Vitamin content, 82, 88, 119, 129, 134, 161, 162, 170, 183, 194, 201, 213, 234, 248, 257, 265, 295, 316, 332, 340, 354, 366, 373, 412, 425, 429, 430, 449, 452, 456, 460, 470, 473, 477, 479, 480, 484, 494, 533, 545
- Vitamin interactions, 22
 Vitamin toxicity, 24
 Volatile nitrogen, 200
- Water durability, 89
 Water flea, 244
 Water hyacinth, 525
 Wet process, 105, 179
 Wet rendering, 330
 Whale, 256
 Wheat by-products/berry/bran/germ, 531, 532
 Wheat distillers dried grains, 116
 Wheat germ agglutinin, 538
 Wheat gluten, 531, 532
 Wheat grain composition, 531, 532
 Wheat middlings, 531
 Wheat pollard, 531, 532
 Wheat protein, 531, 532
 Whey, 543, 544
 Whole egg 127, 128, 129
 Worm meal, 511
 Wort, 80
- Xanthophylls, 142, 143, 234, 235, 381
 Xeaxanthin, 234
- Yeast, 162, 383
Yucca schidigera extract, 551
Yucca schidigera plant, 552
- Zea mays*, 262
 Zeaxanthin, 145
 Zooplanktons, 241, 243

