

Feed ingredients and fertilizers for farmed aquatic animals

Sources and composition



Cover photographs:

Left top to bottom: Feed ingredients (groundnut cake, rice bran and maize flour) for preparation of farm-made feed in a carp farm near Thanjavur district, Tamil Nadu, India (courtesy of P.E. Vijay Anand). Commonly used feed ingredients for preparation of farm-made aquafeed, Dhaka, Bangladesh (courtesy of FAO/Benoy Barman). Cooked maize used as feed for Chinese mitten crab, Suzhou city, Jiangsu province, China (courtesy of FAO/M. Weimin).

Right top to bottom: Harvest of striped catfish (*Pangasianodon hypophthalmus*) from a pond, Mymensingh, Bangladesh, 2009 (courtesy of FAO/Jayanta Saha). Pellet feed used for feeding of rainbow trout, Forel Farm, Wahdat, Tajikistan, 2009 (courtesy of FAO/Mohammad R. Hasan).

Feed ingredients and fertilizers for farmed aquatic animals

Sources and composition

by

Albert G.J. Tacon

FAO Consultant

Hawaii, United States of America

Marc Metian

Hawaii Institute of Marine Biology

University of Hawaii

Hawaii, United States of America

and

Mohammad R. Hasan

Aquaculture Management and Conservation Service

FAO Fisheries and Aquaculture Department

Rome, Italy

The designations employed and the presentation of material in this information product do not imply the expression of any opinion whatsoever on the part of the Food and Agriculture Organization of the United Nations (FAO) concerning the legal or development status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. The mention of specific companies or products of manufacturers, whether or not these have been patented, does not imply that these have been endorsed or recommended by FAO in preference to others of a similar nature that are not mentioned.

The views expressed in this information product are those of the author(s) and do not necessarily reflect the views of FAO.

ISBN 978-92-5-106421-4

All rights reserved. Reproduction and dissemination of material in this information product for educational or other non-commercial purposes are authorized without any prior written permission from the copyright holders provided the source is fully acknowledged. Reproduction of material in this information product for resale or other commercial purposes is prohibited without written permission of the copyright holders. Applications for such permission should be addressed to:

Chief

Electronic Publishing Policy and Support Branch

Communication Division

FAO

Viale delle Terme di Caracalla, 00153 Rome, Italy

or by e-mail to:

copyright@fao.org

© FAO 2009

Preparation of this document

This document was prepared as part of the FAO Aquaculture Management and Conservation Service's (FIMA) ongoing regular work programme on "Study and analysis of feed and nutrients (including fertilizers) for sustainable aquaculture development" programme entity "Monitoring, Management and Conservation of Resources for Aquaculture Development".

As part of the FIMA work programme, a targeted workshop on "Use of feeds and fertilizers for sustainable aquaculture development" was held in Wuxi, Jiangsu Province, China, on 18–21 March 2006. The workshop was organized by FIMA of FAO in collaboration with the Freshwater Fisheries Research Centre (FFRC) of China and the Network of Aquaculture Centres in Asia-Pacific (NACA). The working groups focused on the important role of farm-made aquafeeds in Asia and the need to develop and promote the use of farm-made feeds in sub-Saharan Africa, considered issues pertaining to the production and safe use of aquafeeds and deliberated on the constraints faced by industrial and small-scale aquafeed producers. Several key issues and constraints were identified, categorized and prioritized and appropriate actions were recommended. The workshop recommended FAO to undertake a number of actions to assist regional organizations and member country governments to address a number of identified issues and constraints pertaining to feeds and fertilizers for sustainable aquaculture development from a regional and global perspective. The full report of the workshop has been published in an FAO Fisheries Technical Paper "Study and analysis of feeds and fertilizers for sustainable aquaculture development" (www.fao.org/docrep/011/a1444e/a1444e00.htm). One of the recommended actions was to compile synopses of the nutritional requirements of major cultured fish species and the feed ingredients currently used in compound/farm-made aquafeeds, including national/regional feed ingredient source books containing information on nutrient composition, quality control criteria, seasonal availability and market price. The present review has been undertaken as part of the above recommendation.

The manuscript was reviewed for linguistic quality and FAO house style by Mr Michael Martin. For consistency and conformity, scientific and English common names of fish species were used from FishBase (www.fishbase.org/search.php).

We acknowledge Ms Tina Farmer and Ms Françoise Schatto for their assistance in quality control and FAO house style and Mr José Luis Castilla Civit for layout design. The publishing and distribution of the document were undertaken by FAO, Rome. Finally, Mr Jiansan Jia, Chief, Aquaculture Management and Conservation Service of the FAO Fisheries and Aquaculture Department, is acknowledged for providing necessary support to initiate the study and to complete the publication.

Abstract

Farmed fish and crustaceans are no different from terrestrial livestock in that their nutritional well-being and health is based on the ingestion and digestion of food containing 40 or so essential dietary nutrients, including specific proteins and amino acids, lipids and fatty acids, carbohydrates and sugars, minerals, vitamins, energy, and water.

The present technical paper presents an up-to-date overview of the major feed ingredient sources and feed additives commonly used within industrially compounded aquafeeds, including feed ingredient sources commonly used within farm-made aquafeeds, and major fertilizers and manures used in aquaculture for live food production. Information is provided concerning the proximate and essential amino acid composition of common feed ingredient sources, as well as recommended quality criteria (when available) and relative nutritional merits and limitations (if any), together with a bibliography of published feeding studies for major feed ingredient sources by cultured species.

The technical paper is divided into five main sections. Section 1 deals with principles of feed ingredient and fertilizer analysis, including official methods of proximate chemical analysis, the analysis of amino acids, non-protein nitrogen, fatty acids, phospholipids, sterols, carbohydrates, sugars, energy, vitamins, minerals, the presence of anti-nutritional factors and contaminants, and the analysis of the physical properties of feed ingredients and feed microscopy. This is followed by a second section dealing with methods of analysis for fertilizers and manures, and a third section presenting a glossary of major feed and feed milling terms, including methods for ingredient classification and description in numerical terms.

The main body of the technical paper (section 4) deals with the nutritional composition and usage of major feed ingredient sources in compound aquafeeds, as well as the use of fertilizers and manures in aquaculture operations. Major feed ingredient and fertilizer groupings discussed include: animal protein sources (includes: fishery products, terrestrial livestock products, terrestrial invertebrate products), plant protein sources (includes: cereal products, oilseed products, pulse and grain legume seed products, miscellaneous plant protein sources), single cell protein sources (includes: algae, bacteria, yeast), lipid sources (includes: marine oils, livestock fats, vegetable oils), other plant ingredients (includes: terrestrial plant products, aquatic plant products), feed additives (includes: amino acids and related products, mineral products, vitamins, and chemical preservatives and antioxidants), and fertilizers and manures (includes: chemical fertilizers, organic manures). The feed ingredient section is followed by a summary of the major published studies dealing with potential feed and fertilizer contaminants, including metals and mineral salts, mycotoxins, persistent organic pollutants, Salmonellae and other microbes, veterinary drug residues, other agricultural chemicals and solvent residues, and transmissible spongiform encephalopathies.

The last section of the technical paper undertakes a comparative analysis of the essential amino acid profiles of the major reported feed ingredient sources for cultured finfish and crustaceans, and presents average reported dietary inclusion levels of major feed ingredient sources used within practical feeds, including their major attributes and limitations. Finally, the importance of feed safety, traceability, and use of good feed manufacturing practices is stressed, together with the importance of considering the long term sustainability of feed ingredient supplies and the need to maximize the use of locally available feed ingredient sources whenever economically possible.

Tacon, A.G.J.; Metian, M.; Hasan, M.R.

Feed ingredients and fertilizers for farmed aquatic animals: sources and composition.
FAO Fisheries and Aquaculture Technical Paper. No. 540. Rome, FAO. 2009. 209p.

Contents

Preparation of this document	iii
Abstract	iv
Contributors	vii
Abbreviations and acronyms	viii
1. Introduction	1
2. Principles of feed ingredient and fertilizer analysis	3
2.1 Feed ingredient analysis	3
2.1.1 Official methods of chemical analysis	3
2.1.2 Proximate analysis	3
2.1.3 Amino acids and non-protein compounds	7
2.1.4 Fatty acids, phospholipids and sterols	7
2.1.5 Carbohydrates and sugars	8
2.1.6 Energy	8
2.1.7 Vitamins	8
2.1.8 Minerals	9
2.1.9 Anti-nutritional factors and contaminants	9
2.1.10 Physical properties and feed microscopy	11
2.2 Fertilizer analysis	11
2.2.1 Major nutrient classes	11
2.2.2 Methods of nutrient analysis	11
3. Feed terms and ingredient classification	13
3.1 Glossary of major feed and feed milling terms	13
3.2 Ingredient classification and international feed number	26
4. Ingredient sources, composition and reported usage	29
4.1 Animal protein sources	29
4.1.1 Fishery products	29
4.1.2 Terrestrial livestock products	37
4.1.3 Terrestrial invertebrate products	42
4.2 Plant protein sources	44
4.2.1 Cereal protein products	44
4.2.2 Oilseed protein products	49
4.2.3 Pulse and grain legume seed products	63
4.2.4 Miscellaneous plant protein sources	69
4.3 Single cell protein sources	72
4.4 Lipid sources	77
4.4.1 Marine oils	77
4.4.2 Livestock fats	81
4.4.3 Vegetable oils	83
4.5 Other plant ingredients	87
4.5.1 Terrestrial plant products	87
4.5.2 Aquatic plant products	106
4.6 Feed additives	109
4.6.1 Amino acids and related products	110
4.6.2 Mineral products	112
4.6.3 Vitamins	121
4.6.4 Chemical preservatives and antioxidants	122
4.6.5 Others	124

4.7 Fertilizers and manures	125
4.7.1 Chemical fertilizers	126
4.7.2 Organic manures	126
4.7.3 Use of fertilizers and manures	127
5. Contaminants	131
6. Ingredient profiles and dietary inclusion levels	133
6.1 Ingredient essential amino acid profiles: comparative analysis	133
6.2 Dietary ingredient inclusion levels and major attributes and limitations	134
7. Conclusion	141
8. References	143

Contributors

Mohammad R. Hasan, Aquaculture Management and Conservation Service, FAO Fisheries and Aquaculture Department, Rome, Italy. E-mail: Mohammad.Hasan@fao.org

Marc Metian, Hawaii Institute of Marine Biology, University of Hawaii, PO Box 1346, Kaneohe, Hawaii, 96744, United States of America. E-mail: metian@hawaii.edu

Albert G.J. Tacon, FAO Consultant, Aquatic Farms Ltd, 49-139 Kamehameha Hwy, Kaneohe, Hawaii, 96744, United States of America. E-mail: agjtacon@aol.com

Abbreviations and acronyms

AOAC	Association of Analytical Communities (previously Association of Official Analytical Chemists; previously Association of Official Agricultural Chemists)
AAFCO	Association of American Feed Control Officials
AV	Anisidine value
B	Boron
C	Carbon
C	Chymotrypsin
Ca	Calcium
CF	Crude fibre
CP	Crude protein
Cu	Copper
DDG	Distillers dried grains
DDGS	Distillers dried grains with solubles
DDS	Distillers dried solubles
DHA	Docosahexaenoic acid
DPL	Dried poultry litter
DPW	Dried poultry waste
DRW	Dried ruminant waste
DSW	Dried swine waste
E	Elastin
EAA	Essential amino acid
EE	Ether extract
EFA	Essential fatty acids
En	Endopeptidase
EPA	Eicosapentaenoic acid
FAC	Fat Analysis Committee
FDA	US Food and Drug Administration
Fe	Iron
FFA	Free fatty acid
GLC	Gas-liquid chromatography
HPLC method	High-performance liquid chromatography method
IFN	International feed number
In	Insect Proteases
K ₂ O	Potash
lcPUFA	Long chain polyunsaturated fatty acids
Mc	Microbial proteases
Mg	Magnesium
MIU	Moisture, impurities, unsaponifiables
Mn	Manganese
Mo	Molybdenum
MUFA	Monounsaturated fatty acids
N	Nitrogen
NFE	Nitrogen-free extractives
NPN	Non-protein nitrogen
NRC	National Research Council
P	Phosphorus
P ₂ O ₅	Phosphate

Pa	Papain
Pl	Plasmin
ppm	parts per million
Pr	Pronase
PUFA	Polyunsaturated Fatty Acids
PV	Peroxide Value
S	Subtilisin
S	Sulphur
SCP	Single Cell Protein
SFA	Saturated Fatty Acids
T	Trypsin
TBA	Thiobarbituric acid number
TBARs	Thiobarbituric acid reactive compound concentration
Th	Thrombin
TVN	Total volatile nitrogen
US\$	US dollar
Zn	Zinc

1. Introduction

Farmed fish and crustaceans are no different from terrestrial livestock in that their nutritional well-being and health is based on the ingestion and digestion of food containing 40 or so essential dietary nutrients; depending on the species and developmental status, these nutrients may include specific proteins and amino acids, lipids and fatty acids, carbohydrates and sugars, minerals and vitamins. The form in which the essential nutrients are supplied to the cultured species in turn depends upon its feeding habit and position in the aquatic food chain, with filter feeding species usually only requiring the fertilization of the water body for the *in situ* production of live planktonic food organisms; herbivorous species usually consuming plant-based food items; omnivorous species usually consuming a mixture of plant and animal-based food items; and carnivorous species usually only consuming animal or fish-based food items.

Although the above statement may appear very simplistic, the importance of considering and understanding the natural feeding habits and position of the species in the aquatic food chain cannot be understated; the metabolism and physiology of the target species in the wild having been fine-tuned over millennia to a particular dietary food and nutrient pattern. It follows therefore that the natural food preferences of a species will usually point the way to indicating those food items which are most nutritious and preferred by the cultured species – and open the door for the aquaculture nutritionist to better understand and elucidate the dietary nutrient requirements and feeding preferences of the target species, and by so doing, formulate aquaculture diets or compound aquafeeds, targeted to species needs, which are nutritionally sound, palatable, digestible, elicit maximum growth with minimum wastage, and are cost-effective.

The present technical paper presents an up-to-date overview of the major conventional feed ingredient sources and feed additives commonly used within industrially compounded aquafeeds, including feed ingredient sources commonly used within farm-made aquafeeds, and major fertilizers and manures used in aquaculture for live food production. Information will also be provided on the nutrient composition of common feed ingredient sources, as well as reported usage within industrially compounded and farm-made aquafeeds, and relative nutritional merits and limitations if any. For other useful scientific reviews on aquaculture feed ingredient sources and composition, see Galano, Villarreal-Colmenares and Fenucci (2007), Hasan *et al.* (2007) and Hertrampf and Pascual (2000).

2. Principles of feed ingredient and fertilizer analysis

The appraisal and evaluation of a feed ingredient or fertilizer as a direct or indirect source of dietary nutrients for a farmed aquatic species necessitates information on the following (in addition to cost at source and delivered to the farm or feed plant):

- product description, including common feed name and classification or registration number;
- origin and supplier of the material and how it was produced, processed and/or stabilized;
- date of manufacture, method of transportation and storage, including declared shelf life;
- physical properties, including visual appearance, particle size, colour, smell and bulk density;
- chemical composition, including nutrient levels and toxicological/microbial safety;
- past experience concerning usage as an aquaculture feed ingredient or fertilizer; and
- biological evaluation, including nutrient digestibility and availability for the target species.

2.1 FEED INGREDIENT ANALYSIS

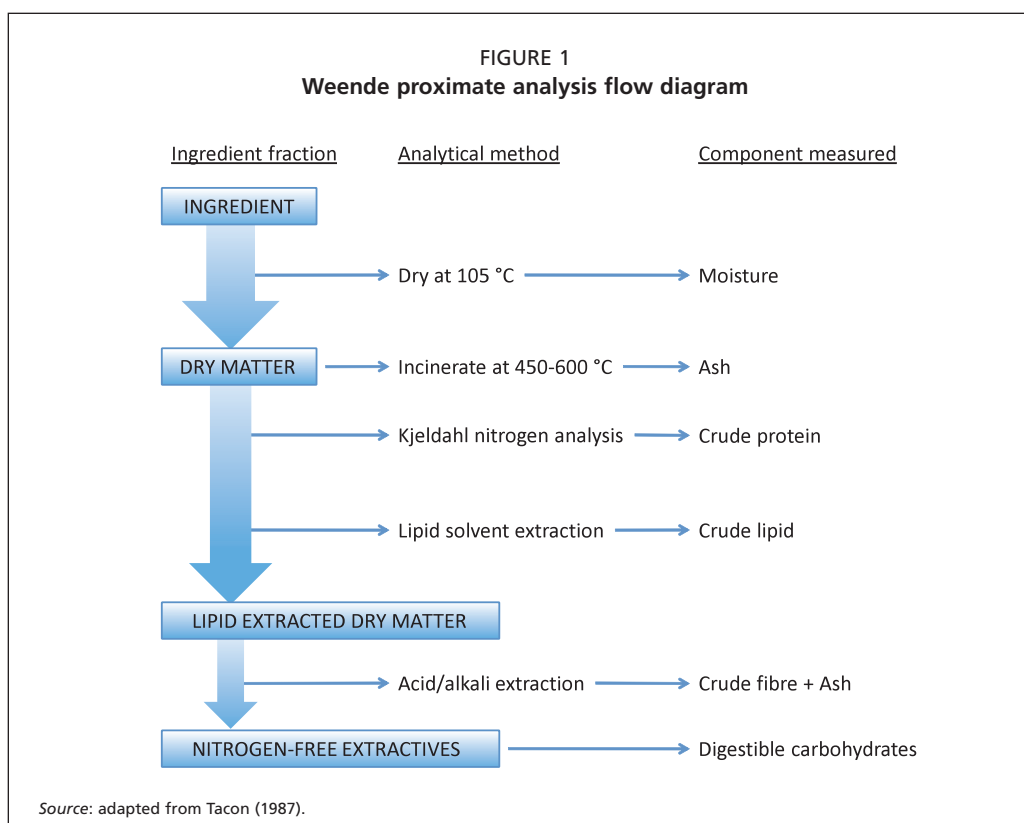
2.1.1 Official methods of chemical analysis

The chemical composition of feed ingredients and fertilizers is usually determined using validated analytical methods such as those published by the Association of Analytical Communities International (AOAC, 2005), formerly known as the Association of Official Analytical Chemists, and before that the Association of Official Agricultural Chemists. AOAC International is an association comprised of nearly 4 000 individuals and 300 organizational members from more than 90 countries. Individual members include laboratory managers, analytical chemists, microbiologists, toxicologists, forensic scientists and management executives working in industry, government and academia. Organizational members are corporations, commercial laboratories, government agencies and universities.

AOAC International is a unique, non-profit scientific organization whose primary purpose is to serve the needs of government, industry and academic laboratories for analytical methods and quality measurement systems. The AOAC Official Methods Program is designed to provide methods of analysis with known performance characteristics, such as accuracy, precision, sensitivity, range, specificity, limit of measurement and similar attributes. A prerequisite of AOAC adoption is validation through interlaboratory collaborative study in independent laboratories under identical conditions (for further information see www.aoac.org).

2.1.2 Proximate analysis

The first step in the chemical evaluation of a feed ingredient is usually the Weende or proximate analysis, where the material is subjected to a series of relatively simple chemical tests so as to determine the content of moisture, crude protein, lipid, crude fibre, ash and digestible carbohydrate. A diagrammatic representation of the Weende proximate feed analysis scheme is shown in Figure 1. However, the proximate composition of an ingredient is a general index as to its potential nutritive value, as it



does not deal with the analysis of specific nutrients but rather with groups of nutrients, including protein, lipid, ash or minerals, and carbohydrates (Campos, 1994; Divakaran, 1999; Lazo and Davis, 2000; Olvera-Novoa, Martinez-Palacios and de Leon, 1994; Teruel, 2002).

Crude protein

The crude protein content of a feedstuff is almost always determined using the Kjeldahl method by measuring the total nitrogen content within the sample and then converting this figure to a total crude protein value by multiplication with the empirical factor 6.25 (AOAC Official Method 954.01, 976.05, 984.13, 990.02, 2001.11 – Table 1; see also Miller *et al.*, 2007). This conversion factor is based on the assumption that the average protein contains about 16 percent nitrogen by weight ($6.25 \times 16 = 100$), although in practice a variation of between 12 and 19 percent nitrogen is possible between individual proteins. In such cases, the use of the 6.25 nitrogen-to-protein conversion factor can lead to a 15-20 percent error in the estimation of crude protein content (Mariotti, Tome and Mirand, 2008). For example, Table 2 shows the revised nitrogen-to-protein conversion factors for different protein sources; an average default factor of 5.60 being more appropriate than 6.25 (Mariotti, Tome and Mirand, 2008).

The other major disadvantage of the Kjeldahl method is that it does not differentiate between protein and non-protein nitrogen (NPN) sources, including nucleic acids, amines (i.e. such as N-acetyl hexosamines or chitin), uric acid, urea, ammonia, nitrates,

TABLE 1
AOAC Official Methods for determining crude protein

Method number and description
0954.01 - Protein (crude) in animal feed and pet food – Kjeldahl method
0976.05 - Protein (crude) in animal feed and pet food – automated Kjeldahl method
0984.13 - Protein (crude) in animal feed – semi-automated method – alternative system
0990.02 - Protein (crude) in animal feed and pet food – copper catalyst Kjeldahl method
2001.11 - Protein (crude) in animal feed, forage, grain and oilseeds – copper catalyst method

Source: AOAC (2005).

TABLE 2
Mean nitrogen conversion factors recommended for different protein sources

Protein sources	Conversion factor
Casein	6.15
Milk and other products	5.85
Millet (foxtail)	5.80
Egg (white)	5.74
Egg (whole)	5.68
Sorghum	5.67
Corn	5.62
Fish	5.58
Gelatin	5.55
Chicken	5.53
Wheat flour and derived products	5.52
Other meat and animal tissues	5.51
Soybean or soybean meal	5.50
Other cereals	5.50
Triticale	5.49
Wheat	5.49
Beef	5.48
Millet (pearl)	5.47
Barley	5.45
Lupin	5.44
Other legumes	5.40
Pea	5.36
Rapeseed	5.35
Rice	5.34
Oats	5.34
Sunflower (hulled)	5.29
Dry bean	5.28
Buckwheat	5.24
Wheat germ	4.99
Wheat bran	4.96
Average default factor – mixed proteins,	5.60

Source: data compiled from Mariotti, Tome and Mirand (2008).

nitrites, nitrogenous glycosides, melamine, etc. In view of the very limited ability of most monogastric animals to utilize NPN (including most farmed finfish and crustacean species) and the variability of NPN content within plant and animal protein sources (depending upon the production and processing method employed), it is strongly recommended that a more direct analysis of true amino acid protein nitrogen be developed, and that crude protein be dispensed with as an analytical tool. Sadly, the majority of feed compounders and nutritionists alike still determine crude protein using the conventional Kjeldahl method using the 6.25 conversion factor, with all its associated limitations and scientific inaccuracy.

Crude lipid

The crude lipid content of feed ingredients is usually determined by solvent extraction with ether (AOAC Official Method 920.39, 954.02, 2003.05, 2003.06 – Table 3).

Other solvents which have also been successfully used for lipid extraction include chloroform: methanol (2:1 vol/vol; Bligh and Dyer, 1959; Folch *et al.*, 1957; AOAC Official Method 983.23 – Appendix 1) and hexane: methanol (4:1 vol/vol; Nematipour and Gatlin, 1993; AOAC Official Method 2003.06 – Table 3).

Although the lipid fraction or 'ether extract' of conventional animal and plant feed ingredients is predominantly composed of triglyceride fats and oils, within some meals (such as microbial single cell proteins, including bacteria, yeast and algae) and other heat-treated processed meals a significant proportion of the total lipid present may be in a bound form (including within phospholipids) which may necessitate acid

TABLE 3
AOAC Official Methods for determining crude lipid

Method number and description
0920.39 - Fat (crude) or ether extract in animal feed
0948.15 - Fat (crude) in seafood – acid hydrolysis method
0954.02 - Fat (crude) or other extract in pet food – gravimetric method
0983.23 - Fat in foods – chloroform-methanol extraction method
0996.06 - Fat hydrolytic extraction – gas chromatographic method
2003.05 - Crude fat in feeds – Randall/Soxtec/ether extraction-submersion method
2003.06 - Crude fat in feeds – Randall/Soxtec/hexane extraction-submersion method

Source: AOAC (2005).

TABLE 4
AOAC Official Methods for determining crude fibre

Method number and description
0948.15 - Total dietary fibre – gas chromatographic-colorimetric-gravimetric method
0962.09 - Fibre (crude) in animal feed and pet food – ceramic fibre filter method
0973.18 - Fibre (acid detergent) and lignin (H ₂ SO ₄) in animal feed
0978.10 - Fibre (crude) in animal feed and pet food – fritted glass crucible method
0985.29 - Total dietary fibre in foods – enzymatic-gravimetric method
0993.19 - Soluble dietary fibre in food and food products – enzymatic-gravimetric method
2002.04 - Amylase-treated neutral detergent fibre in feeds – refluxing in beakers or crucible method

Source: AOAC (2005).

hydrolysis prior to solvent extraction for full lipid liberation (Salo, 1977; Halverson and Alstin, 1981; Limsuwan and Lovell, 1985; see also AOAC Official Method 948.15, 996.06 – Table 3).

Crude fibre

Various chemical techniques are available for the estimation of carbohydrates in plant and animal feed ingredients. The method most commonly employed for proximate analysis divides the carbohydrates into two fractions, namely crude fibre and nitrogen-free extractives (NFE; Figure 1). Crude fibre is the insoluble organic residue remaining after extracting a lipid extracted ingredient with dilute acid (0.255 N H₂SO₄) and alkali (0.312 N NaOH) under controlled conditions (see AOAC Official Method 962.09, 973.18, 978.10, 2002.04 – Table 4). Crude fibre is generally regarded as the non-digestible carbohydrate component of a feed ingredient; within plant materials it is usually composed of a mixture of cellulose, hemicellulose and lignin (the latter not being a carbohydrate, but rather a complex aromatic compound), and within certain animal feed ingredients it is composed of varying proportions of glucans, mannans and amino sugars.

Nitrogen-free extractives (NFE) on the other hand is an indirect measure of the potential 'soluble' or 'digestible' carbohydrate present within a feed ingredient, and is obtained by adding the percentage values determined for moisture, crude protein, lipid, crude fibre and ash, and subtracting the total from 100. Within plant-based feeds this fraction is composed primarily of free sugars, starch and other digestible carbohydrates.

Moisture and ash

The moisture and ash content of a feed ingredient is usually determined by (1) heating a sample in a drying oven at a temperature above the boiling point of water (100 to 105 °C) to constant weight (the loss in weight being calculated as percent moisture); and (2) by oxidative combustion in a muffle furnace at 550 to 600 °C (the inorganic residue remaining being calculated as percent ash: AOAC Official Method 925.04, 934.01, 938.08, 942.05 – Table 5).

As mentioned previously, proximate analysis is only a crude estimate of the major classes of nutrients present and as such should be only used as a general guide to the potential nutritional merits of a feed ingredient. It follows therefore that the next step is to conduct chemical analyses for specific dietary nutrients and/or potential contaminants.

TABLE 5

AOAC Official Methods for determining moisture and ash

Method number and description
0925.04 - Moisture in animal feed – distillation with toluene
0930.15 - Loss on drying (moisture) for feeds at 135 °C for 2 hours
0934.01 - Loss on drying (moisture) at 95–100 °C for feeds
0938.08 - Ash of seafood
0942.05 - Ash of animal feed

Source: AOAC (2005).

2.1.3 Amino acids and non-protein compounds

In contrast to the Kjeldahl method of estimating protein quality, the amino acid composition of a feed ingredient provides one of the best indicators of its potential nutritive value. Amino acids are generally measured individually by chromatography (AOAC Official Method 985.28, 988.15, 994.12, 999.12, 999.13 – Table 6).

However, it must be remembered that the amino acid levels obtained from such analyses do not give any indication of their chemical form within the feedstuff (i.e. free, bound, unbound, state of oxidation) or availability during digestion. Consequently, an estimate of amino acid availability within the feedstuff is often warranted. The most commonly used method for estimating amino acid availability is the available lysine test (AOAC Official Method 0975.44 – Table 6).

In addition to amino acids, other non-protein components that might warrant analysis (depending on the ingredient), include urea, nucleic acids (Albrecht-Ruiz *et al.*, 1999; Broughton, 1970; Keer and Birch, 2008), specific biological amines (including the amino acid degradation products histamine, putrescine, cadaverine), indole (tryptophan degradation product), melamine (FDA, 2007; Vail, Jones, and Sparkman, 2007; AOAC Official Method 941.04, 957.07, 948.17, 967.07, 977.13, 982.20, 984.33, 996.07 – Table 7).

2.1.4 Fatty acids, phospholipids and sterols

The fatty acid composition of a lipid is usually determined by gas-liquid chromatography (GLC) after lipid extraction and transesterification (Christie, 2003; AOAC Official Method 963.22, 965.49, 969.33, 991.39 – Table 8).

TABLE 6

AOAC Official Methods for determining amino acids

Method number and description
0975.44 - Lysine (available) in nutritional supplements – automated method
0985.28 - Sulfur amino acids in food, feed ingredients and processed foods – ion exchange chromatographic method
0988.15 - Tryptophan in foods and feed ingredients – ion exchange chromatographic method
0994.12 - Amino acids in feeds – performic oxidation with acid hydrolysis – sodium meta bisulfite method
0999.12 - Taurine in pet food – liquid chromatographic method
0999.13 - Lysine, methionine and threonine in pure amino acids (feed grade) and premixes – HPLC post-column derivatization method

Source: AOAC (2005).

TABLE 7

AOAC Official Methods for determining non-protein nitrogen compounds

Method number and description
0941.04 - Urea and ammoniacal nitrogen in animal feeds – Kjeldahl method
0948.17 - Indole in crabmeat, oysters and shrimp – calorimetric method
0957.07 - Histamine in seafood – chemical method
0967.07 - Urea in animal feed – colorimetric method
0977.13 - Histamine in seafood – flurometric method
0982.20 - Indole in shrimp – gas chromatographic method
0984.33 - Urea in feeds – urease method, colorimetric method
0996.07 - Putrescine in canned tuna and cadaverine in canned tuna and common dolphinfish – gas chromatographic method

Source: AOAC (2005).

TABLE 8

AOAC Official Methods for determining fatty acids

Method number and description
0963.22 - Methyl esters of fatty acids in oils and fats – gas chromatographic method
0965.49 - Fatty acids in oils and fats – preparation of methyl esters
0969.33 - Fatty acids in oils and fats – preparation of methyl esters – boron trifluoride method
0991.39 - Fatty acids in encapsulated fish oils and fish oil – methyl and ethyl esters

Source: AOAC (2005).

TABLE 9

AOAC Official Methods for determining fat quality and cholesterol

Method number and description
0940.28 - Fatty acids (free) in crude and refined oils – titration method
0941.09 - Cholesterol in eggs – titrimetric method
0965.33 - Peroxide value of oils and fats – titration method
0969.33 - Fatty acids in oils and fats – preparation of methyl esters – boron trifluoride method
0970.51 - Fats (animal) in vegetable fats and oils (determination of cholesterol) – gas chromatographic method
0976.26 - Cholesterol in multicomponent foods – gas chromatographic method
0991.39 - Fatty acids in encapsulated fish oils and fish oil – methyl and ethyl esters
0994.10 - Cholesterol in foods – direct saponification – gas chromatographic method

Source: AOAC (2005).

Since ingredients and aquaculture feeds rich in polyunsaturated fatty acids (PUFA) are highly prone to oxidative damage, numerous chemical methods are available for determining the degree of oxidation or oxidative rancidity, including free fatty acid value (FFA), peroxide value (PV), and thiobarbituric acid number (TBA – Hardy and Roley, 2000; Teruel, 2002; AOAC Official Method 940.28, 965.33 – Table 9).

In addition to fatty acids and their oxidation products, other lipid components that might warrant analysis (depending on the ingredient) include cholesterol and phospholipids (Carnevale de Almeida, Perassolo, Camargo, Bragagnolo and Gross, 2006; Cheng, Du and Lai, 1998; Fraser, Tocher and Sargent, 1985; AOAC Official Method 941.09, 970.51, 976.26, 994.10 – Table 9).

2.1.5 Carbohydrates and sugars

In addition to crude fibre and NFE, other specific carbohydrate and sugars that might warrant analysis (depending on the ingredient) include starch, sucrose and total sugars (AOAC Official Method 920.40, 925.05, 974.06 – Table 10).

2.1.6 Energy

The chemical energy content of feed ingredients is usually expressed in terms of heat units (since all forms of energy are convertible into heat energy) and determined either directly using a bomb calorimeter (the ingredient being oxidized by combustion and the liberated heat energy measured) or calculated indirectly using mean gross energy values for lipid, protein and carbohydrate of 9.5 kcal/g (39.8 kJ/g), 5.6 kcal/g (23.4 kJ/g) and 4.1 kcal/g (17.2 kJ/g), respectively (Cho, Slinger and Bayley, 1982).

2.1.7 Vitamins

Vitamin levels within feed ingredients can be measured individually, including Vitamin A (AOAC Official Method 960.46, 974.29, 2001.13); Carotenes and Xanthophylls (AOAC Official Method 970.64); Thiamine (AOAC Official Method 942.23, 953.17, 957.17); Riboflavin (AOAC Official Method 940.33, 970.65); Niacin (AOAC Official Method 944.13, 961.14, 968.32); Pantothenic acid (AOAC Official Method 945.73,

TABLE 10

AOAC Official Methods for determining starch and sugars

Method number and description
0920.40 - Starch in animal feed
0925.05 - Sucrose in animal feed
0974.06 - Sugars (total) in animal feed – modified Fehling solution method

Source: AOAC (2005).

945.74); Vitamin B₆ (AOAC Official Method 961.15); Folic acid (AOAC Official Method 944.12, 2004.05); Vitamin B₁₂ (AOAC Official Method 952.20); Vitamin K₃ (AOAC Official Method 974.30); Vitamin C (AOAC Official Method 967.21, 967.22); Vitamin D (AOAC Official Method 975.42, 979.24, 980.26, 982.29, 2002.05); and Vitamin E (AOAC Official Method 948.26, 971.30, 972.31 – Table 11).

2.1.8 Minerals

The mineral composition of ash obtained by oxidative combustion (using a muffle furnace) is not necessarily the same as that originally present in the feed material as some elements are volatile and lost at ashing temperatures above 450 °C, and in particular the elements mercury, arsenic, selenium, phosphorus, chromium and cadmium (Katz, Jenniss and Mount, 1981). Consequently, for trace mineral analysis feed samples are usually solubilized by a wet-acid oxidation technique prior to analysis by atomic absorption spectrophotometry. Table 12 shows the recommended AOAC methods for individual minerals in feed ingredients.

2.1.9 Anti-nutritional factors and contaminants

The presence of endogenous anti-nutritional factors within plant feedstuffs is believed to be a one of the major factors limiting their use within animal feeds, including aquaculture feeds (Dong, Hardy and Higgs, 2000; Francis, Makkar and Becker, 2001;

TABLE 11

AOAC Official Methods for determining vitamins

Method number and description
0974.29 - Vitamin A in mixed feeds, premixes, human and pet foods – calorimetric method
2001.13 - Vitamin A (Retinol) in foods – liquid chromatography method
0970.64 - Carotenes and Xanthohpylls – plants and mixed feeds – spectrophotometric method
0942.23 - Thiamine (Vitamin B ₁) in human and pet foods – fluometric method
0953.17 - Thiamine (Vitamin B ₁) in grain products – fluometric (rapid) method
0957.17 - Thiamine (Vitamin B ₁) – fluometric method
0940.33 - Riboflavin (Vitamin B ₂) in vitamin preparations – microbiological method
0970.65 - Riboflavin (Vitamin B ₂) in foods and vitamin preparations – fluometric method
0944.13 - Niacin and nicotinamide (nicotinic acid and nicotinamide) in vitamin preparations – microbiological method
0961.14 - Niacin and nicotinamide in drugs, foods and feeds – colorimetric method
0968.32 - Niacin amide in multivitamin preparations – spectrophotometric method
0945.73 - Calcium pantothenate in vitamin preparations – spectrophotometric method
0945.74 - Pantothenic acid in vitamin preparations – microbiological method
0961.15 - Vitamin B ₆ (pyridoxine, pyridoxal, pyridoxamine) in food extracts – microbiological method
0944.12 - Folic acid (pteroylglutamic acid) in vitamin preparations – microbiological method
2004.05 - Total folates in cereals and cereal foods – micro assay – trienzyme procedure
0952.20 - Cobalamin (Vitamin B ₁₂ activity) in vitamin preparations – microbiological method
0974.30 - Menadione sodium bisulfate (water-soluble vitamin K ₃) – gas chromatographic method
0967.21 - Ascorbic acid in vitamin preparations and juices – 2,6-dichloroindophenol method
0967.22 - Vitamin C (total) in vitamin preparations – microfluometric method
0975.42 - Vitamin D in vitamin preparations – colorimetric method
0979.24 - Vitamin D in vitamin preparations – liquid chromatographic method
0980.26 - Vitamin D in multivitamin preparations – liquid chromatographic method
0982.29 - Vitamin D in mixed feeds, premixes and pet foods – liquid chromatographic method
2002.05 - Cholecalciferol (vitamin D ₃) in selected foods – liquid chromatographic method
0948.26 - α -tocopherol acetate (supplement) in foods and feeds – colorimetric method
0971.30 - α -tocopherol and α -tocopherol acetate in foods and feeds – colorimetric method
0972.31 - Nomenclature rules for Vitamin E

Source: AOAC (2005).

TABLE 12
AOAC Official Methods for determining minerals

Method number and description
0957.22 - Arsenic (total) in feeds – colorimetric test
0964.06 - Phosphorus in animal feed – alkalimetric ammonium molybdophosphate method
0965.17 - Phosphorus in animal feed and pet food – photometric method
0968.08 - Minerals in animal feed/pet food – atomic absorption method (Ca, Cu, Fe, Mn, Zn)
0971.21 - Mercury in food – flameless atomic absorption spectrophotometric method
0995.11 - Phosphorus (total) in foods – colorimetric method
0996.16 - Selenium in feeds and premixes
0986.15 - Arsenic, cadmium, lead, selenium and zinc in human and pet foods

Source: AOAC (2005).

Gatlin *et al.*, 2007; Olvera-Novoa, Martinez-Palacios and de Leon, 1994; Tacon, 1997). For example, Table 13 shows the reported anti-nutritional factors present in some commonly used plant feed ingredient sources.

Analytical methods for measuring anti-nutritional factors are numerous and varied, with examples including: Protease inhibitors (Bergmeyer, 1965; Clarke and Wiseman, 1998; Sandholm, Shih and Scott, 1976); Phytate (AOAC Official Method 986.11 – AOAC, 2005; Olvera-Novoa, Martinez-Palacios and de Leon, 1994); Erucic acid (AOAC Official Method 985.20 – AOAC, 2005); Cyanogenetic glycosides (AOAC Official Method 936.11 – AOAC, 2005); Hydrocyanic acid (AOAC Official Method 915.03 – AOAC, 2005); Glycoalkaloids (AOAC Official Method 997.13 – AOAC, 2005); Urease activity, Gossypol, Thioglucides, Mimosine, Canavanne, Chlorhydric acid, Tannins, and Saponins (Clarke and Wiseman, 1998; Olvera-Novoa, Martinez-Palacios and de Leon, 1994).

In addition to the presence of endogenous anti-nutritional factors, feed ingredients may also contain exogenous contaminants (depending on their origin and/or processing), including: solvent residues (within solvent extracted plant oilseeds – methylene chloride, ethylene dichloride, trichloroethylene, hexane, acetone, isopropyl alcohol), fungal or mycotoxins (i.e. Aflatoxins, Trichothecenes, Zearalenone, Fumonisin, Ochratoxins, Slaframmine, etc.), Salmonellae and other microbes (including microbial toxins – botulinum toxin), therapeutic drugs (antibiotics, sulphonamides, nitrofurans, arsenilic

TABLE 13
Endogenous anti-nutritional factors present in some common feed ingredients used in aquaculture feeds

	Reported anti-nutritional factors ¹
Cereals	
Rice <i>Oryza sativum</i>	1,2,5,8,13
Wheat <i>Triticum vulgare</i>	1,2,5,8,11,18,22
Corn/maize <i>Zea mays</i>	1,5,8,19
Root tubers	
Potato <i>Solanum tuberosum</i>	1,2,4,8,18,19
Legumes	
Cow pea <i>Vigna unguiculata</i>	1 (T,C),2,5,11
Lentil <i>Lens culinaris</i>	1 (T),2,6,28
Lupin <i>Lupinus albus</i>	1 (T,C),2,4,5,7,28
Field pea <i>Pisum sativum</i>	1 (T),2,4,5,6,12
Oilseeds	
Rapeseed <i>Brassica campestris napus</i>	1 (T),3,5,7,28,29
Indian mustard <i>Brassica juncea</i>	1 (T),3,5,7,13,28,29
Soybean <i>Glycine max</i>	1 (T,E,C,Pa,In),2,3,5,6,8,11,12,14,16,17,27, 28

Source: adapted from Gatlin *et al.* (2007); Liener (1980, 1989); Tacon (1992).

¹ 1 – Protease inhibitors (T-trypsin, C-chymotrypsin, Pl-plasmin, Pr-pronase, Th-thrombin, S-subtilisin, En-endopeptidase, In-insect proteases, Pa-papain, E-elasticin, Mc-microbial proteases), 2 – Phyto-haemagglutinins, 3 – Glucosinolates, 4 – Cyanogens, 5 – Phytic acid, 6 – Saponins, 7 – Tannins, 8 – Estrogenic factors, 9 – Lathyragens, 10 – Gossypol, 11 – Flatulence factor, 12 – Anti-vitamin E factor, 13 – Anti-thiamine factor, 14 – Anti-vitamin A factor, 15 – Anti-pyridoxine factor, 16 – Anti-vitamin D factor, 17 – Anti-vitamin B₁₂ factor, 18 – Amylase inhibitor, 19 – Invertase inhibitor, 20 – Arginase inhibitor, 21 – Cholinesterase inhibitor, 22 – Dihydroxyphenylalanine, 23 – Mimosine, 24 – Cyclopropenoic acid, 25 – Alkaloids, 26 – Canavanine, 27 – Allergens, 28 – Non-starch polysaccharides – oligosaccharides, 29 – Erucic acid

acid), pesticide residues (chlorinated hydrocarbons), organochlorine compounds (polychlorinated biphenyls), petroleum hydrocarbons (n-paraffins), heavy metals, and transmissible spongiform encephalopathies contaminants.

As with anti-nutritional factors, analytical methods for measuring contaminants vary widely, and include: mycotoxins (AOAC Official Method 970.43, 970.44, 971.22, 975.36, 975.35, 976.22, 977.16, 986.18, 990.34, 991.44, 995.15, 2001.06 – AOAC, 2005; Binder, Tan, Chin, Handl and Richard, 2007; Chu, 1992), Salmonellae and other microbes (AOAC Official Method 966.23, 966.24, 967.25, 967.26, 976.30, 977.27, 983.25, 986.32, 987.09, 988.18, 990.11, 995.21, 997.02, 2000.15, 2002.07, veterinary drugs (Stolker, Zuidema and Nielen, 2007), halogenated hydrocarbons or persistent organic pollutants (includes pesticides, dioxins, polychlorinated biphenyls [PCBs], polybrominated biphenyls [PBBs] and polybrominated diphenyls ethers [PBDEs]) (Jaouen-Madoulet, Abarnou, Le Guellec, Loizeau and Leboulenger, 2000; Maule, Gannam and Davis, 2007; Padula, Daughtry and Nowak, 2008).

2.1.10 Physical properties and feed microscopy

Apart from a biochemical profile of the major nutrients and potential contaminants present, important information is also required on the physical characteristics of the feed ingredient in question, including particle size range (screen analysis – and consequent possible requirement for further grinding prior to usage – for most aquatic species, the smaller the particle size and narrower the particle size range the better), bulk density (important when transporting large volumes and when formulating nutrient dense feeds), physical appearance and texture (homogenous free flowing products being preferred, with no visible lumps or cakes), colour (in general, darker ingredients usually being indicative of animal protein sources), and smell (fresh, not musty, and not sour or burned – the more fishy the smell the better).

From a feed manufacturer's perspective, the physical characteristics and consequent handling/processing requirements of a product are more often than not as important as the nutritional characteristics of the product itself. Moreover, simple microscopic examination will quickly indicate the purity of an ingredient and the presence or not of unwanted foreign materials. For standard methods of measuring the bulk density of feed ingredients and microscopic characteristics of different plant and animal feed ingredient sources, see Bates, Akiyama and Shing (1995), Khajarern and Khajarern (1999), and AOAC Official Methods 964.07, 970.08, 970.09 (AOAC, 2005).

2.2 FERTILIZER ANALYSIS

2.2.1 Major nutrient classes

The chemical analysis of chemical fertilizers and organic manures (includes animal manures, plant manures and composts) is normally restricted to three nutrient classes. With the exception of water, these include:

- primary or major nutrients: nitrogen (N), phosphate (P_2O_5), potash (K_2O) and carbon (C);
- secondary nutrients: sulphur (S), magnesium (Mg) and calcium (Ca); and
- micro-nutrients: iron (Fe), copper (Cu), zinc (Zn), manganese (Mn), boron (B) and molybdenum (Mo).

2.2.2 Methods of nutrient analysis

Fertilizer primary nutrient levels are usually expressed as percent N: P_2O_5 : K_2O . For example, a chemical fertilizer labeled as 15:20:10 will contain 15 percent nitrogen (N), 20 percent phosphate (P_2O_5) and 10 percent potash (K_2O). Although the terms ' P_2O_5 ' and ' K_2O ' are normally used to express the fertilizer nutrients 'phosphate' and 'potash', there is now a trend to express fertilizer nutrient levels as the single element and not as the oxide. The conversion factors used are as follows: to convert oxides to elements

multiply P_2O_5 value by 0.4364 and K_2O value by 0.8302, and to convert elements to oxides multiply P value by 2.2914 and K value by 1.2046.

Table 14 shows the methods commonly employed for the nutrient analysis of fertilizers and manures commonly used in aquaculture. As with feed ingredients, there is sometimes a possibility that fertilizers may be contaminated with toxic mineral elements, pesticides, herbicides, growth promotants and pathogenic micro-organisms (ie. animal manures). For details of major contaminants and analytical methods see section 2.1.9.

TABLE 14
AOAC Official Methods for fertilizer nutrient analysis

Method number and description
0920.01 - Nitrates in fertilizers – detection method
0929.01 - Sampling of solid fertilizers
0955.04 - Nitrogen (total) in fertilizers – Kjeldahl method
0957.02 - Phosphorus (total) in fertilizers – preparation of test solution
0958.01 - Phosphorus (total) in fertilizers – spectrophotometric method
0958.02 - Potassium in fertilizers – volumetric sodium tetraphenylboron method I
0960.03 - Phosphorus (available) in fertilizers
0962.02 - Phosphorus (total) in fertilizers – gravimetric quinolinium molybdophosphate method
0962.03 - Phosphorus (water-soluble) in fertilizers – quinolinium molybdophosphate method
0962.04 - Phosphorus (water-soluble) in fertilizer – alkaline quinolinium molybdophosphate method
0964.06 - Sampling of fluid fertilizers
0965.09 - Nutrients (minor) in fertilizers – atomic absorption spectrophotometric method
0969.04 - Potassium in fertilizers – volumetric sodium tetraphenylboron method II
0970.01 - Phosphorus (water-soluble) in fertilizer – spectrophotometric molybdophosphate method
0977.01 - Phosphorus (water-soluble) in fertilizers – preparation of test solution
0978.01 - Phosphorus (total) in fertilizers – automated method
0983.02 - Potassium in fertilizers – flame photometric method
0993.13 - Nitrogen (total) in fertilizers – combustion method
0993.31 - Phosphorus (available) in fertilizers – direct extraction method

Source: AOAC (2005).

3. Feed terms and ingredient classification

Prior to listing individual feed ingredient sources and their nutrient content it is important here to first provide a glossary of nutrient and feed milling terms which are commonly used to describe individual feed ingredients. For a complete listing of official feed terms, readers should consult with the Official Publication of the Association of American Feed Control Officials (AAFCO, 2008a) and the publications of Millamena, Coloso and Pascual (2002).

3.1 GLOSSARY OF MAJOR FEED AND FEED MILLING TERMS

Additive: An ingredient or combination of ingredients added to the basic feed mix or parts thereof to fulfill a specific need. Usually used in micro quantities and requires careful handling and mixing (AAFCO, 2008a).

Ad libitum feeding: Providing unlimited amount of feed until satiation (Millamena, Coloso and Pascual, 2002).

Amino acid: A carboxylic acid that includes an amino group as part of its structure; any one class of organic compounds which contain both the amino (NH₂) group and the carboxyl (COOH) group (Millamena, Coloso and Pascual, 2002).

Amino acid antagonism: Occurs when some amino acids are fed in excess of required levels causing an increase in the requirement for another amino acid of similar structure, e.g. arginine-lysine antagonism (Millamena, Coloso and Pascual, 2002).

Anaerobic: A condition or chemical reaction where gaseous oxygen is not present or not required, e.g. decomposition of organic wastes by microorganisms, releasing toxic hydrogen sulfide and methane gas (Millamena, Coloso and Pascual, 2002).

Animal waste: Means a material composed of excreta, with or without bedding materials, and collected from poultry, ruminants or other animals except humans (AAFCO, 2008a).

Antibiotics: A class of drug. They are usually synthesized by a living microorganism and in proper concentration inhibit the growth of other microorganisms (AAFCO, 2008a).

Antinutritional factors: Substances in the feedstuff which can reduce nutritional value (Millamena, Coloso and Pascual, 2002).

Antioxidant: A strong reducing agent, which is easily oxidized and thus prevents the oxidation of other substances (Millamena, Coloso and Pascual, 2002).

Aquafeeds: Feeds that are intended for aquaculture species (Millamena, Coloso and Pascual, 2002).

Arachidonic acid: A 20-carbon unsaturated fatty acid having four double bonds (Millamena, Coloso and Pascual, 2002).

Artificially dried: (Process) Moisture having been removed by other than natural means (AAFCO, 2008a).

Aspirated, Aspirating: Having removed chaff, dust or other light materials by use of air (AAFCO, 2008a).

Attractant: Substances added to feeds for fast consumption especially by crustacean species (Millamena, Coloso and Pascual, 2002).

Bagasse: (Part) Pulp from sugar cane (AAFCO, 2008a).

Balanced: A term that may be applied to a diet, ration or feed having all known required nutrients in proper amount and proportion based on recommendations of recognized authorities in the field of animal nutrition, such as the National Research Council, for a given set of physiological animal requirements. The species for which it is intended and the functions such as maintenance or maintenance plus production (growth, foetus, fat, milk, eggs, wool, feathers or work) shall be specified (AAFCO, 2008a).

Barn-cured: (Process) Forage material dried with forced ventilation in an enclosure (AAFCO, 2008a).

Beans: Seed of leguminous plants especially of the genera *Phaseolus*, *Dalmanella* and *Vigna* (AAFCO, 2008a).

Benthos: Organisms that live on or in the sediment of aquatic environments (Millamena, Coloso and Pascual, 2002).

Binder: Substances added to feeds to make it stable in the water, usually a carbohydrate (Millamena, Coloso and Pascual, 2002).

Blending: (Process) To mingle or combine two or more ingredients of feed. It does not imply a uniformity of dispersion (AAFCO, 2008a).

Blood: (Part) Vascular fluid of animals (AAFCO, 2008a).

Blood albumin: (Part) One of the blood proteins (AAFCO, 2008a).

Bone: (Part) Skeletal parts of vertebrates (AAFCO, 2008a).

Boneless: (Process) The flesh resulting from removal of bone from accompanying flesh by means of knife separation (AAFCO, 2008a).

Bran: (Part) Pericarp of grain (AAFCO, 2008a).

Buttermilk: (Part) A residue from churning cream (AAFCO, 2008a).

By-product: (Part) Secondary products produced in addition to the principal product (AAFCO, 2008a).

Cake: (Physical form) The mass resulting from the pressing of seeds, meat or fish in order to remove oils, fats or other liquids (AAFCO, 2008a).

Calorie: A unit of heat or energy; the amount of heat required to raise 1 g of water to 1°C. Nutritionally, the kcal is sometimes used; 1 kcal = 1 000 cal, 1 cal = 4.186 joules, 1 joule = 0.239 cal (Millamena, Coloso and Pascual, 2002).

Canned: (Process) a term applied to a feed which has been processed, packaged, sealed and sterilized for preservation in cans or similar containers (AAFCO, 2008a).

Cannery residue: (Part) Residue suitable for feeding obtained in preparing a product for canning (AAFCO, 2008a).

Carbohydrate: A large group of organic compounds common in plants which include simple sugars, starches, celluloses, gums and related substances (Millamena, Coloso and Pascual, 2002).

Carcass meat trimmings: (Part) Clean flesh obtained from slaughtered animals. It is limited to striated, skeletal and cardiac muscles, but may include the accompanying and overlaying fat and the portion of skin, sinew, nerve and blood vessels which normally accompany the flesh (AAFCO, 2008a).

Carcass residue, mammals: (Part) Residues from animal tissues including bones and exclusive of hair, hoofs, horns and contents of the digestive tract (AAFCO, 2008a).

Carriers: An edible material to which ingredients are added to facilitate uniform incorporation of the latter into feeds. The active particles are absorbed, impregnated or coated into or onto the edible material in such a way as to physically carry the active ingredient (AAFCO, 2008a).

Casein: The colloidal protein in milk (Millamena, Coloso and Pascual, 2002).

Cellulose: A polymer of glucose, an important structural material in plants; major structural component of plant cell wall (Millamena, Coloso and Pascual, 2002).

Chaff: (Part) Glumes, husks or other seed covering together with other plant parts separated from seed during threshing or processing (AAFCO, 2008a).

Charcoal: Dark-coloured porous forms of carbon made from the organic parts of vegetable or animal substances, by their incomplete combustion (AAFCO, 2008a).

Chipped, chipping: (Process) Cut or broken into fragments; also meaning prepared into small thin slices (AAFCO, 2008a).

Chitin: Major structural component of the rigid exoskeleton of invertebrates (Millamena, Coloso and Pascual, 2002).

Cholesterol: A physiologically important sterol which is widespread in the biomembrane (Millamena, Coloso and Pascual, 2002).

Chopped, chopping: (Process) Reduced in particle size by cutting with knives or other edged instruments (AAFCO, 2008a).

Cleaned, cleaning: (Process) Removal of material by such methods as scalping, aspirating, magnetic separation, or by any other method (AAFCO, 2008a).

Cleanings: (Part) Chaff, weed seeds, dust and other foreign matter removed from cereal grain (AAFCO, 2008a).

Cobs with grain: (Part) The ears of maize without the husks, but consisting of the entire cobs and adhering grain (AAFCO, 2008a).

Cobs with husks: (Part) Kernel-free fibrous inner portion of the ear of maize with enveloping leaves (AAFCO, 2008a).

Coenzyme: A nonprotein substance that takes part in an enzymatic reaction and is regenerated at the end of the reaction; a partner required by some enzymes to produce enzymatic activity (Millamena, Coloso and Pascual, 2002).

Cofactor: An inorganic ion or coenzyme required for enzymatic activity (Millamena, Coloso and Pascual, 2002).

Complete feed: A nutritionally adequate feed for animals other than man; by specific formula is compounded to be fed as the sole ration and is capable of maintaining life and/or promoting production without any additional substance being consumed except water (AAFCO, 2008a).

Complete diet: Feed that contains all the essential nutrients (protein, lipid, carbohydrate, vitamins, minerals) required by the animal for maintenance and growth (Millamena, Coloso and Pascual, 2002).

Compound feed: A feed composed of several ingredients (Millamena, Coloso and Pascual, 2002).

Concentrate: A feed used with another to improve the nutritive balance of the total and intended to be further diluted and mixed to produce a supplement or a complete feed (AAFCO, 2008a).

Condensed, condensing: (Process) Reduced to denser form by removal of moisture (AAFCO, 2008a).

Conditioned, conditioning: (Process) Having achieved predetermined moisture characteristics and/or temperature of ingredients or a mixture of ingredients prior to further processing (AAFCO, 2008a).

Cooked, cooking: (Process) Heated in the presence of moisture to alter chemical and/or physical characteristics or to sterilize (AAFCO, 2008a).

Cracked, cracking: (Process) Particle size reduced by a combined breaking and crushing action (AAFCO, 2008a).

Cracklings: (Part) Residue after removal of fat from adipose tissue or skin of animals by dry heat (AAFCO, 2008).

Crimped, crimping: (Process) Rolled by use of corrugated rollers. It may curtail tempering or conditioning and cooling (AAFCO, 2008a).

Crumbled, crumbling: (Process) Pellets reduced to granular form (AAFCO, 2008a).

Crumbles: (Physical form) Pelleted feed reduced to granular form (AAFCO, 2008a).

Crushed, crushing: (Process) See rolled, rolling (AAFCO, 2008a).

Cull: Material rejected as inferior to the process of grading or separating (AAFCO, 2008a).

Culture: Nutrient medium inoculated with specific microorganisms which may be in a live or dormant condition (AAFCO, 2008a).

Cultured, culturing: (Process) Biological material multiplied or produced in a nutrient media (AAFCO, 2008a).

Cure, curing, cured: (Process) To prepare for keeping for use, or to use, or to preserve. The process may be by drying, use of chemical preservatives, smoking, salting, or by use of other processes and/or materials for preserving (AAFCO, 2008a).

Customer-formula feed: Consists of a mixture of commercial feeds and/or feed ingredients each batch of which is manufactured according to the specific instructions of the final purchaser (AAFCO, 2008a).

Cut, cutting: (Process) See chopped, chopping (AAFCO, 2008a).

D-activated, D-activating: Plant or animal sterol fractions which have been Vitamin D activated by ultraviolet light or by other means (AAFCO, 2008a).

Deboned: (Process) The flesh resulting from removal of bones from accompanying flesh by mechanical deboning (AAFCO, 2008a).

Defluorinated, defluorinating: (Process) Having had fluorine removed (AAFCO, 2008a).

Degermed: (Process) Having had the embryo of seeds wholly or partially separated from the starch endosperm (AAFCO, 2008a).

Dehulled, dehulling: (Process) Having removed the outer covering from grains or other seeds (AAFCO, 2008a).

Dehydrating, dehydrated: (Process) Having been freed of moisture by thermal means (AAFCO, 2008a).

Diatom: A single-celled plant (phytoplankton) covered with two overlapping porous shells of silica (Millamena, Coloso and Pascual, 2002).

Diet: Feed ingredients or mixture of ingredients including water which are consumed by animals (AAFCO, 2008a).

Digested, digesting: (Process) Subjected to prolonged heat and moisture, or to chemicals or enzymes with a resultant change of decomposition of the physical or chemical nature (AAFCO, 2008a).

Diluent: (Physical form) An edible substance used to mix with and reduce the concentration of nutrients and or additives to make them more acceptable to animals, safer to use, and more capable of being mixed uniformly in a feed (it may also be a carrier) (AAFCO, 2008).

Distillation soluble: (Part) Stillage filtrate (AAFCO, 2008a).

Docosahexaenoic acid (DHA): A 22-carbon unsaturated fatty acid having six double bonds, an essential fatty acid in fish (Millamena, Coloso and Pascual, 2002).

Dressed, dressing: (Process) Made uniform in texture by breaking or screening of lumps from feed and/or the application of liquid(s) (AAFCO, 2008a).

Dried, drying: (Process) Materials from which water or other liquid has been removed (AAFCO, 2008a).

Drug: (as defined by FDA as applied to feed) A substance (a) intended for use in the diagnosis, cure, mitigation, treatment or prevention of disease in man or other animals or (b) a substance other than food intended to affect the structure or any function of the body of man or other animals (AAFCO, 2008a).

Dry-milled: (Process) Tempered with a small amount of water or steam to facilitate the separation of the various component parts of the kernel in the absence of any significant amount of free water (AAFCO, 2008a).

Dry-rendered, dry-rendering: (Process) Residues of animal tissue cooked in open steam-jacketed vessels until the water has evaporated. Fat is removed by draining and pressing the solid residue (AAFCO, 2008a).

Dust: (Part) Fine, dry pulverized particles of matter usually resulting from the cleaning or grinding of grain (AAFCO, 2008a).

Ears: (Part) Fruiting heads of *Zea mays*, including only the cob and grain (AAFCO, 2008a).

Egg albumin: (Part) Whites of eggs of poultry (AAFCO, 2008a).

Eicosapentaenoic acid (EPA): A 20-carbon unsaturated fatty acid having five double bonds, an essential fatty acid in fish (Millamena, Coloso and Pascual, 2002).

Environmental nutrition: The role of nutritional factors in altering animal impacts on the environment (AAFCO, 2008a).

Enzymatic activity: the catalytic activity required to convert a given amount of assay substrate to a given amount of product per unit time under the standard conditions set forth in the assay procedure (AAFCO, 2008a).

Enzyme: A protein made up of amino acids or their derivatives, which catalyzes a defined chemical reaction. Required cofactors should be considered an integral part of the enzyme (AAFCO, 2008a).

Enzyme product: A processed, standardized enzyme-containing material which has been produced with the intention of being sold for use in animal feed and feed ingredients (AAFCO, 2008a).

Emulsifier: A material capable of causing fat or oils to remain in liquid suspension (AAFCO, 2008a).

Endosperm: (Part) Starchy portion of seed (AAFCO, 2008a).

Ensiled: (Process) Aerial parts of plants which have been preserved by ensiling. Normally the original material is finely cut and placed in an airtight chamber such as a silo, where it is pressed to exclude air and where it undergoes an acid fermentation that retards spoilage (AAFCO, 2008a).

Etiolated: (Process) A material grown in the absence of sunlight, blanched, bleached, colourless or pale (AAFCO, 2008).

Evaporated, evaporating: (Process) Reduced to a denser form; concentrated as by evaporation or distillation (AAFCO, 2008a).

Eviscerated: (Process) Having had all the organs in the great cavity of the body removed (AAFCO, 2008a).

Expanded, expanding: (Process) Subjected to moisture, pressure and temperature to gelatinize the starch portion. During extrusion, volume is increased because of abrupt reduction in pressure (AAFCO, 2008a).

Extracted, mechanical: (Process) Having removed fat or oil from materials by heat and mechanical pressure. Similar terms: expeller extracted, hydraulic extracted, "oil process" (AAFCO, 2008a).

Extracted, solvent: (Process) Having removed fat or oil from materials by organic solvents. Similar term: "new process" (AAFCO, 2008a).

Extruded: (Process) A process by which feed has been pressed, pushed or protruded through orifices under pressure (AAFCO, 2008a).

Farm-made aquafeeds: Feeds in pellet or other forms, consisting of one or more artificial and/or natural feedstuff, produced for the exclusive use of a particular farming activity, not for commercial sale or profit (New, Tacon and Csavas, 1995).

Fat: (Part) A substance composed chiefly of triglycerides of fatty acids, and solid or plastic at room temperature (AAFCO, 2008a).

Fatty acids: (Part) Aliphatic monobasic acids containing only the elements carbon, hydrogen and oxygen (AAFCO, 2008a).

Feathers: (Part) The light, horny epidermal outgrowths that form the external coverings of birds (AAFCO, 2008a).

Feed(s): Edible material(s) which are consumed by animals and contribute energy and/or nutrients to the animals' diet (AAFCO, 2008a). (Usually refers to animals rather than to man.)

Feed grade: Suitable for animal consumption (AAFCO, 2008a).

Feed mixture: See formula feed.

Feedstuff: One or a mixture of substances which form the nutrients – protein, carbohydrate, fat, vitamins, minerals and water – that are eaten by an animal as part of its daily ration (Millamena, Coloso and Pascual, 2002).

Fermentation aid: A substance added to assist in providing proper conditions which result in action by yeasts, molds or bacteria in a controlled aerobic or anaerobic process used for the manufacture of certain products (AAFCO, 2008a).

Fermented, fermenting: (Process) Acted upon by yeasts, molds or bacteria in a controlled aerobic or anaerobic process in the manufacture of such products as alcohols, acids, vitamins of the B-complex group, or antibiotics (AAFCO, 2008a).

Fibre: (Part) Any of a large class of plant carbohydrates that resist digestion hydrolysis (AAFCO, 2008a).

Filler: A substance added in the feed to complete the feed formula (Millamena, Coloso and Pascual, 2002).

Fines: (Physical form) Any materials which will pass through a screen whose openings are immediately smaller than the specified minimum crumble size or pellet diameter (AAFCO, 2008a).

Flaked, flaking: (Process) See rolled.

Flakes: (Physical form) An ingredient rolled or cut into flat pieces with or without prior steam conditioning (AAFCO, 2008a).

Floating feed: Produced by an extrusion process through which feed materials are moistened, pre-cooked, expanded (higher moisture, temperature and pressure than ordinary pelleting) and dried, resulting in low density feed particles (Millamena, Coloso and Pascual, 2002).

Flour: (Part) Soft, finely ground and bolted meal obtained from the milling of cereal grains, other seeds, or products. It consists essentially of the starch and gluten of the endosperm (AAFCO, 2008a).

Fodder: (Part) The green or cured plant, containing all the ears or seed heads, if any, grown primarily for forage (it has been applied more specifically to corn and sorghum) (AAFCO, 2008a).

Food(s): When used in reference to animals, it is synonymous with feed(s). See feed(s) (AAFCO, 2008a).

Formula feed: Two or more ingredients proportioned, mixed and processed according to specifications (AAFCO, 2008a).

Free choice: A feeding system by which animals are given unlimited access to the separate components or groups of components constituting the diet (AAFCO, 2008a).

Fresh: (Process) Ingredient(s) having not been subject to freezing, to treatment by cooking, drying, rendering, hydrolysis, or similar process, to the addition of salt, curing agents, natural or synthetic chemical preservatives or other processing aids, or to preservation by means other than refrigeration (AAFCO, 2008a).

Fused, fusing: (Process) Melted by heat (AAFCO, 2008a).

Gelatinized, gelatinizing: (Process) Having had the starch granules completely ruptured by a combination of moisture, heat and pressure, and in some instances, by mechanical shear (AAFCO, 2008a).

Germ: (Part) The embryo found in seeds and frequently separated from the bran and starch endosperm during the milling process (AAFCO, 2008a).

Glucose: A monosaccharide; a hexose (six-carbon) sugar, of empirical formula $C_6H_{12}O_6$ basic molecule for the synthesis of starch and cellulose (Millamena, Coloso and Pascual, 2002).

Gluten: (Part) The tough, viscid nitrogenous substance remaining when the flour of wheat or other grain is washed to remove the starch (AAFCO, 2008a).

Glycerol: A trihydric alcohol to which three fatty acid molecules are esterified in the formation of triacylglycerols (fats and oils) (Millamena, Coloso and Pascual, 2002).

Glycogen: A branched chain polymer of glucose, linked by alpha 1-6 links; the storage form of carbohydrate in animals, as starch is in plants (Millamena, Coloso and Pascual, 2002).

Gossypol: (Part) A phenolic pigment in cottonseed that is toxic to some animals (AAFCO, 2008a).

Grain: (Part) Seed from cereal plants (AAFCO, 2008a).

GRAS: Abbreviation for the phrase “Generally Recognized as Safe”. A substance which is generally recognized as safe by experts qualified to evaluate the safety of the substance for its intended use (AAFCO, 2008a).

Grease: Animal fats with a titre below 40 °C (AAFCO, 2008a).

Grit: Coarse ground, insoluble, non-nutritive material (e.g. granite rock) for the *in vivo* mechanical grinding of feed by avian species (AAFCO, 2008a).

Grits: (Part) Coarsely ground grain from which the bran and germ have been removed, usually screened to uniform particle size (AAFCO, 2008a).

Groats: (Part) Grain from which the hulls have been removed (AAFCO, 2008a).

Ground, grinding: (Process) Reduced in particle size by impact, shearing or attrition (AAFCO, 2008a).

Hay: (Part) The aerial portion of grass or herbage especially cut and cured for animal feeding (AAFCO, 2008a).

Heads: (Part) The seed or grain-containing portions of a plant (AAFCO, 2008a).

Heat-processed, heat-processing: (Process) Subjected to a method of preparation involving the use of elevated temperatures with or without pressure (AAFCO, 2008a).

Heat rendered, heat rendering: (Process) Melted, extracted or clarified through use of heat. Usually, water and fat are removed (AAFCO, 2008a).

Hemicellulose: Composed of a mixture of hexose and pentose units; any of various polysaccharides that accompany cellulose and lignin in the skeletal substances of wood and green plants. Unlike cellulose, it can be hydrolyzed in relatively mild acids (Millamena, Coloso and Pascual, 2002).

Hexose: A monosaccharide with six carbon atoms, and hence the empirical formula C₆H₁₂O₆. The nutritionally important hexoses are glucose, galactose and fructose (Millamena, Coloso and Pascual, 2002).

Highly unsaturated fatty acids (HUFA): Fatty acids that contain four or more double bonds (Millamena, Coloso and Pascual, 2002).

Homogenized, homogenizing: (Process) Particles broken down into evenly distributed globules small enough to remain emulsified for long periods of time (AAFCO, 2008a).

Hulls: (Part) Outer covering of grain or other seed (AAFCO, 2008a).

Husks: (Part) Leaves enveloping an ear of maize; or the outer coverings of kernels or seeds, especially when dry and membranous (AAFCO, 2008a).

Hydrolyzed, hydrolyzing: (Process) Complex molecules having been split to simpler units by chemical reaction with water, usually by catalysis (AAFCO, 2008a).

Ingredient, feed ingredient: Means a component part or constituent of any combination or mixture making up a commercial feed (AAFCO, 2008a).

Irradiated, irradiating: (Process) Treated, prepared or altered by exposure to a specific radiation (AAFCO, 2008a).

Juice: (Part) The aqueous substance obtainable from biological tissue by pressing or filtering with or without addition of water (AAFCO, 2008a).

Keratin: A sulfur-containing protein which is the primary component of epidermis, hair, wool, hoof, horn and the organic matrix of the teeth (Millamena, Coloso and Pascual, 2002).

Kernel: (Part) A whole grain. For other species, dehulled seed (AAFCO, 2008a).

Kibbled, kibbling: (Process) Cracked or crushed baked dough, or extruded feed that has been cooked prior to or during the extrusion process (AAFCO, 2008a).

Lablab: Natural food in ponds, composed of complex of blue-green and green algae, diatoms, rotifers, crustaceans, insects, roundworms, detritus and plankton (Millamena, Coloso and Pascual, 2002).

Lactose: The sugar of milk; a disaccharide composed of glucose and galactose (Millamena, Coloso and Pascual, 2002).

Laboratory method: A technique or procedure of conducting scientific experiment, test, investigation or observation according to a definite established logical or systematic plan (AAFCO, 2008a).

Lard: (Part) Rendered fat of swine (AAFCO, 2008a).

Leached: (Process) The condition of a product following subjection of the material to the action of percolating water or other liquid (AAFCO, 2008a).

Leaves: (Part) Lateral outgrowths of stems that constitute part of the foliage of a plant, typically a flattened green blade which primarily functions in photosynthesis (AAFCO, 2008a).

Lecithin: (Part) A specific phospholipid. The principal constituent of crude phosphatides derived from oil-bearing seeds (AAFCO, 2008a).

Lignin: A polymer of coniferyl alcohol; a structural material found in woody plants (Millamena, Coloso and Pascual, 2002).

Linolenic acid: A 18-carbon unsaturated fatty acid having three double bonds (Millamena, Coloso and Pascual, 2002).

Lipids: A broad term for fats and fat-like substances including phospholipids, waxes, steroids and sphingomyelins (Millamena, Coloso and Pascual, 2002).

Liver: (Part) The hepatic gland (AAFCO, 2008a).

Macronutrients: Nutrients needed in large amounts such as proteins, carbohydrates or lipids (Millamena, Coloso and Pascual, 2002).

Malt: (Part) Sprouted and steamed whole grain from which the radicle has been removed (AAFCO, 2008a).

Malted, malting: (Process) Converted into malt or treated with malt or malt extract (AAFCO, 2008a).

Maltose: A disaccharide composed of two molecules of glucose (Millamena, Coloso and Pascual, 2002).

Mash: (Physical form) A mixture of ingredients in meal form. Similar term: mash feed (AAFCO, 2008a).

Meal: (Physical form) An ingredient which has been ground or otherwise reduced in particle size (AAFCO, 2008a).

Medicated feed: Any feed which contains drug ingredients intended or presented for the cure, mitigation, treatment or prevention of diseases of animals other than man or which contains drug ingredients intended to affect the structure or any function of the body of animals other than man. Antibiotics included in a feed for growth promotion and/or efficiency levels are drug additives and feeds containing such antibiotics are included in the foregoing definition of “Medicated feed.” (AAFCO, 2008a).

Metal (mineral) salt: An ionic substance containing a metal cation and either an inorganic or an organic anion. The water soluble portion of a metal (mineral) salt dissociates in water to give the hydrated metal cation and the free anion (or its hydrolysis product) in solution (AAFCO, 2008a).

Metal (mineral) complex: A substance in which a metal cation (electron pair acceptor) accepts an electron pair from one or more anionic or neutral bonding partners (ligands, electron pair donors) to form chemical bonds. The water soluble portion of the complex remains as the intact complex in aqueous solution (AAFCO, 2008a).

Metal (mineral) chelate: A metal complex (see preceding term) in which at least one ligand (electron pair donor) forms two or more bonds to the central metal ion through different atoms of the ligand. A distinctive feature of a metal chelate is the presence of a heterocyclic ring(s) in which the metal is a member of the ring. In the water soluble portion of the chelate, the heterocyclic ring(s) remains intact (AAFCO, 2008a).

Microencapsulated feed: A larval feed made by encapsulating a solution, colloid or suspension of feed ingredient mixture within a membrane or capsule; these particles can be designed to have a slow release of the material inside the capsule, or to totally prevent leaching of the water-soluble nutrients (Millamena, Coloso and Pascual, 2002).

Micro-ingredients: Vitamins, minerals, antibiotics, drugs and other materials normally required in small amounts and measured in milligrams, micrograms or parts per million (ppm) (AAFCO, 2008a).

Middlings: (Part) A by-product of flour milling comprising several grades of granular particles containing different proportions of endosperm, bran, germ, each of which contains different levels of crude fibre (AAFCO, 2008a).

Milk: Total lacteal secretion from the mammary gland (AAFCO, 2008a).

Mill by-product: (Part) A secondary product obtained in addition to the principal product in milling practice (AAFCO, 2008a).

Mill dust: (Part) Fine feed particles of undetermined origin resulting from handling and processing feed and feed ingredients (AAFCO, 2008a).

Mill run: (Part) The state in which a material comes from the mill, ungraded and usually uninspected (AAFCO, 2008a).

Mineralize, mineralized: (Process) To supply, impregnate or add inorganic mineral compounds to a feed ingredient or mixture (AAFCO, 2008a).

Mixing: (Process) To combine by agitation two or more materials to a specific degree of dispersion (AAFCO, 2008a).

Molasses: (Part) The thick, viscous by-product resulting from refined sugar production or the concentrated, partially dehydrated juices from fruits (AAFCO, 2008a).

Mold inhibitor: Substances added to feeds that inhibit mold growth (Millamena, Coloso and Pascual, 2002).

Monosaccharide: A simple sugar, the basic units from which disaccharides and polysaccharides are composed. The nutritionally important monosaccharides are the pentoses (five-carbon sugars) and the hexoses (six-carbon sugars) (Millamena, Coloso and Pascual, 2002).

Natural: A feed or ingredient derived solely from plant, animal or mined sources, either in its unprocessed state or having been subject to physical processing, heat processing, rendering, purification, extraction, hydrolysis, enzymolysis or fermentation, but not having been produced by or subject to a chemically synthetic process and not containing any additives or processing aids that are chemically synthetic except in amounts as might occur unavoidably in good manufacturing practices (AAFCO, 2008a).

Nutrient: A feed constituent in a form and at a level that will help support the life of an animal. The chief classes of feed nutrients are proteins, fats, carbohydrates, minerals and vitamins (AAFCO, 2008a).

Nutrition: The science of nourishing an organism; the sum of the processes by which an animal or plant absorbs and utilizes food substances. It involves the ingestion, digestion, absorption and transport of food nutrients into body cells and release of waste products of metabolism (Millamena, Coloso and Pascual, 2002).

Offal: (Part) Material left as a by-product from the preparation of some specific product, less valuable portions and the by-products of milling (AAFCO, 2008a).

Oil: (Part) A substance composed chiefly of triglycerides of fatty acids and liquid at room temperature (AAFCO, 2008a).

Oligosaccharides: A general term for polymers containing about 3-10 monosaccharides (Millamena, Coloso and Pascual, 2002).

Organic: (process) A formula feed or a specific ingredient within a formula feed that has been produced and handled in compliance with the requirements of the FDA National Organic Program (AAFCO, 2008a).

Parboiling: A hydrothermal process in which the crystalline form of starch is changed into the amorphous form, due to the irreversible swelling and fusion of starch. This is accomplished by soaking, steaming, drying and milling to produce physical and chemical modifications (AAFCO, 2008a).

Pearled, pearling: (Process) Dehulled grains reduced by machine brushing into smaller smooth particles (AAFCO, 2008a).

Peel: (Part) See skin.

Pellets: (Physical form) Agglomerated feed formed by compacting and forcing through die openings by a mechanical process. Similar terms: pelleted feed, hard pellet (AAFCO, 2008a).

Pellets, soft: (Physical form) Similar term: High molasses pellets. Pellets containing sufficient liquid to require immediate dusting and cooling (AAFCO, 2008a).

Pelleted, pelleting: (Process) Having agglomerated feed by compaction and forced through die openings (AAFCO, 2008a).

Peptide bond: The link between amino acids in a protein; formed by condensation between the carboxylic acid group (-COOH) of one amino acid and the amino group (NH₂) of another to give a -CO- NH- link between the amino acids (Millamena, Coloso and Pascual, 2002).

Phospholipid: A lipid in which glycerol is esterified to two fatty acids, but the third hydroxyl group is esterified to phosphate, and through the phosphate to one of a variety of other compounds; esters of fatty acid, glycerol and phosphatidic acid (Millamena, Coloso and Pascual, 2002).

Phytoplankton: Microscopic aquatic plants suspended in the water column; major oxygen-producing organisms in a pond (Millamena, Coloso and Pascual, 2002).

Plankton: The microscopic plant and animal life in the water including bacteria (Millamena, Coloso and Pascual, 2002).

Plant gums: Complex, highly branched residues containing D-glucuronic and D-galacturonic acids along with other simple sugars such as arabinose and shambose (Millamena, Coloso and Pascual, 2002).

Polished, polishing: (Process) Having a smooth surface produced by mechanical process usually by friction (AAFCO, 2008a).

Polysaccharides: Formed by the combination of hexoses or other monosaccharides (Millamena, Coloso and Pascual, 2002).

Polyunsaturated fatty acids (PUFA): Fatty acids with two or more carbon-carbon double bonds in the molecule, separated by a methylene (-CH₂) group (Millamena, Coloso and Pascual, 2002).

Pomace: (Part) Pulp from fruit or vegetables. See pulp (AAFCO, 2008a).

Precipitated, precipitating: (Process) Separated from suspension or a solution as a result of some chemical or physical change brought about by a chemical reaction, by cold or by any other means (AAFCO, 2008a).

Premix: A uniform mixture of one or more micro-ingredients with diluent and/or carrier. Premixes are used to facilitate uniform dispersion of the micro-ingredients in a large mix (AAFCO, 2008a).

Premixing: (Process) The preliminary mixing of ingredients with diluents and/or carriers (AAFCO, 2008a).

Preservative: A substance added to protect, prevent or retard decay, discoloration or spoilage under conditions of use or storage (AAFCO, 2008a).

Pressed, pressing: (Process) Compacted or molded by pressure; also meaning having fat, oil or juices extracted under pressure (AAFCO, 2008a).

Presswater: The aqueous extract of fish or meat free from the fats and/or oils. Presswater is the result of hydraulic pressing of the fish or meat followed by separation of the oil by centrifuging or other means (AAFCO, 2008a).

Product: (Part) A substance produced from one or more other substances as a result of chemical or physical change (AAFCO, 2008a).

Protein: (Part) Any of a large class of naturally occurring complex combinations of amino acids (AAFCO, 2008a).

Processed animal waste: Animal waste that has been artificially dried, dry stacked, ensiled, oxidized, chemically treated, micro-biologically digested, chemically or physically fractionated or otherwise treated to render the material suitable for feeding (AAFCO, 2008a).

Pulp: (Part) The solid residue remaining after extraction of juices from fruits, roots or stems. Similar terms: Bagasse and Pomace (AAFCO, 2008a).

Pulverized, pulverizing: (Process) See ground, grinding (AAFCO, 2008a).

Ration: The amount of the total feed which is provided to one animal over a 24-hour period (AAFCO, 2008a).

Raw: Food in its natural or crude state not having been subjected to heat in the course of preparation as food (AAFCO, 2008a).

Refuse: (Part) Damaged, defective or superfluous edible material produced during or left over from a manufacturing or industrial process (AAFCO, 2008a).

Residue: Part remaining after the removal of a portion of its original constituents (AAFCO, 2008a).

Rolled, rolling: (Process) Having changed the shape and/or size of particles by compressing between rollers. It may entail tempering or conditioning (AAFCO, 2008a).

Roots: (Part) Subterranean parts of plants (AAFCO, 2008a).

Rumen contents: Contents of the first two compartments of the stomach of a ruminant (AAFCO, 2008a).

Rumen protected: Refers to a nutrient(s) fed in such a form that provides an increase in the flow of that nutrient(s), unchanged, to the abomasum, yet is available to the animal in the intestine (AAFCO, 2008a).

Scalped, scalping: (Process) Having removed larger material by screening (AAFCO, 2008a).

Scratch: (Physical form) Whole, cracked or coarsely cut grain. Similar terms: scratch grain, scratch feed (AAFCO, 2008a).

Screened, screening: (Process) Having separated various sized particles by passing over and/or through screens (AAFCO, 2008a).

Seed: (Part) The fertilized and ripened ovule of a plant (AAFCO, 2008a).

Self fed: A feeding system where animals have continuous free access to some or all components of a ration, either individually or as mixtures (AAFCO, 2008a).

Separating: (Process) Classification of particles by size, shape and/or density (AAFCO, 2008a).

Separating, magnetic: (Process) Removing ferrous material by magnetic attraction (AAFCO, 2008a).

Shells: (Part) The hard, fibrous or calcareous covering of a plant or animal product, i.e. nut, egg, oyster (AAFCO, 2008a).

Shoots: (Part) The immature aerial parts of plants, stems with leaves and other appendages in contrast to the roots (AAFCO, 2008a).

Shorts: (Part) Fine particles of bran, germ, flour or offal from the tail of the mill from commercial flour milling (AAFCO, 2008a).

Sifted: (Process) Materials that have been passed through wire sieves to separate particles in different sizes. The separation of finer materials than would be done by screening (AAFCO, 2008a).

Sinking feed: Prepared through extrusion under fairly low temperature and pressure such that pellets produced sink when placed in water (Millamena, Coloso and Pascual, 2002).

Sizing: (Process) See screening (AAFCO, 2008a).

Skimmed: (Process) Material from which floating solid material has been removed. It is also applied to milk from which fat has been removed by centrifuging (AAFCO, 2008a).

Skin: (Part) Outer coverings of fruits or seeds, as the rinds, husks or peels. May also apply to dermal tissue of animals (AAFCO, 2008a).

Sludge: The suspended or dissolved solid matter resulting from the processing of animal or plant tissue for human food (AAFCO, 2008a).

Solubles: Liquid containing dissolved substances obtained from processing animal or plant materials. It may contain some fine suspended solids (AAFCO, 2008a).

Solvent extracted: (Process) A product from which oil has been removed by solvents (AAFCO, 2008a).

Spent: Exhausted of active or effective properties, i.e. absorbing activity (AAFCO, 2008a).

Spray dehydrated: (Process) Material which has been dried by spraying on the surface of a heated drum. It is recovered by scraping from the drum (AAFCO, 2008a).

Spray dried: Material which has been dried by spraying or atomizing into a draft of heated dry air (AAFCO, 2008a).

Stalk(s): (Part) The main stem of a herbaceous plant often with its dependent parts such as leaves, twigs and fruit (AAFCO, 2008a).

Starch: (Part) A white, granular polymer of plant origin. The principal part of seed endosperm (AAFCO, 2008a).

Starch: A polymer of glucose units; are usually polycyclic long-chain alcohols; principal storage form of carbohydrates in plants (Millamena, Coloso and Pascual, 2002).

Steamed, steaming: (Process) Having treated ingredients with steam to alter physical and/or chemical properties. Similar terms: steam cooked, steam rendered, tanked (AAFCO, 2008a).

Steep-extracted, steep-extracting: (Process) Soaked in water or other liquid (as in the wet milling of corn) to remove soluble materials (AAFCO, 2008a).

Steepwater: Water containing soluble materials extracted by steep-extraction, i.e. by soaking in water or other liquid (as in the wet milling of corn) (AAFCO, 2008a).

Stem: (Part) The coarse, aerial parts of plants which serve as supporting structures for leaves, buds, fruit, etc. (AAFCO, 2008a).

Sterols: (Part) Solid cyclic alcohols which are the major constituents of the unsaponifiable portion of animal and vegetable fats and oils (AAFCO, 2008a).

Stickwater, fish: (Part) The aqueous extract of cooked fish free from the fat. Stickwater contains the aqueous cell solutions of the fish and any water used in processing (AAFCO, 2008a).

Stickwater, meat: (Part) The aqueous extract of meat free from the fat. Meat stickwater is the result of the wet rendering of meat products and contains the aqueous cell solution, the soluble glue proteins, and the water condensed from steam used in wet rendering (AAFCO, 2008a).

Stillage: (Part) The mash from fermentation of grains after removal of alcohol by distillation (AAFCO, 2008a).

Stover: (Part) The stalks and leaves of maize after the ears, or sorghum after the heads have been harvested (AAFCO, 2008a).

Straw: (Part) The plant residue remaining after separation of the seeds in threshing. It includes chaff (AAFCO, 2008a).

Sugar: Chemically, a monosaccharide or small oligosaccharide. Cane or beet sugar is sucrose, a disaccharide of glucose and fructose (Millamena, Coloso and Pascual, 2002).

Sun-cured: (Process) Material dried by exposure in open air to the direct rays of the sun (AAFCO, 2008a).

Supplement: A feed used with another to improve the nutritive balance or performance of the total and intended to be: (1) fed undiluted as a supplement to other feeds; or (2) offered free choice with other parts of the ration separately available; or (3) further diluted and mixed to produce a complete feed (AAFCO, 2008a).

Supplemental feed: Feed supplied to meet the nutrient requirement of fish for maintenance and growth when natural food is inadequate (Millamena, Coloso and Pascual, 2002).

Syrup: (Part) Concentrated juice of a fruit or plant (AAFCO, 2008a).

Tallow: (Part) Animal fats with titre above 40 °C (AAFCO, 2008).

Tankage: (Part) See carcass residue (AAFCO, 2008a).

Tempered, tempering: (Process) See conditioned, conditioning (AAFCO, 2008a).

Titre: A property of fat determined by the solidification point of the fatty acids liberated by hydrolysis (AAFCO, 2008a).

Toasted: (Process) Browned, dried or parched by exposure to a fire, or to gas or electric heat (AAFCO, 2008a).

Trace minerals: Mineral nutrients required by animals in micro amounts only (measured in milligrams per pound or smaller units) (AAFCO, 2008a).

Trash fish: Fish that have a low commercial value by virtue of their low quality, small size or lack of consumer preference. They are either used for human consumption (often processed or preserved) or used for livestock/fish, either directly or through reduction to fishmeal/oil (Funge-Smith, Lindebo and Staples, 2005).

Triglycerides: Esters of fatty acid and glycerol, the major form of storage lipids (Millamena, Coloso and Pascual, 2002).

Tubers: (Part) Short, thickened fleshy stems or terminal portions of stems or rhizomes that are usually formed underground, bear minute scaled leaves, each with a bud capable, under suitable conditions, of developing into a new plant; constitute the resting stage of various plants (AAFCO, 2008a).

Uncleaned: (Physical form) Containing foreign material (AAFCO, 2008a).

Unaponifiable matter: (Part) Ether soluble material extractable after complete reaction with strong alkali (AAFCO, 2008a).

Unsaturated fatty acid: Any one of several fatty acids containing one or more double bonds, e.g. oleic, linoleic, linolenic and arachidonic (Millamena, Coloso and Pascual, 2002).

Viscera: (Part) All the organs in the great cavity of the body, excluding contents of the intestinal tract (AAFCO, 2008a).

Viscera, fish: (Part) All organs in the great cavity of the body; includes the guts, heart, liver, spleen, stomach and intestines (AAFCO, 2008a).

Viscera, mammals: (Part) All organs in the great cavity of the body; includes the oesophagus, heart, liver, spleen, stomach and intestines, but excludes the contents of the intestinal tract (AAFCO, 2008a).

Viscera, poultry: (Part) All organs in the great cavity of the body; includes the oesophagus, heart, liver, spleen, stomach, crop, gizzard, undeveloped eggs and intestines (AAFCO, 2008a).

Vitaminize, vitaminized: (Process) To provide or supplement with vitamins (AAFCO, 2008a).

Vitamins: Organic compounds that function as parts of enzyme systems essential for the transmission of energy and the regulation of metabolism of the body (AAFCO, 2008a).

Water extract: The aqueous phase containing dissolved materials resulting from the treatment (e.g. by mixing or boiling) of a solid with water. All or part of the solid matrix may be dissolved in the extract (AAFCO, 2008a).

Wet: (Physical form) Material containing liquid or which has been soaked or moistened with water or other liquid (AAFCO, 2008a).

Wet-milled: (Process) Steeped in water with or without sulfur dioxide to soften the kernel in order to facilitate the separation of the various component parts (AAFCO, 2008a).

Wet-rendered, wet-rendering: (Process) Cooked with steam under pressure in closed tanks (AAFCO, 2008a).

Whey: (Part) The watery part of milk separated from the curd (AAFCO, 2008a).

Whey solids: (Part) The solids of whey (proteins, fats, lactose, ash and lactic acid) (AAFCO, 2008a).

Whole: (Physical form) Complete, entire (AAFCO, 2008a).

Whole pressed, whole pressing: (Process) Having the entire seed to remove oil (AAFCO, 2008a).

Wort: (Part) The liquid portion of malted grain. It is a solution of malt sugar and other water-soluble extracts from malted mash (AAFCO, 2008a).

Zooplankton: Small animals in water making up the secondary production level which depend on the water movement for locomotion (Millamena, Coloso and Pascual, 2002).

3.2 INGREDIENT CLASSIFICATION AND INTERNATIONAL FEED NUMBER

Feed ingredients can be coded and classified according to the “International Feed Vocabulary” of Harris (1980). The vocabulary is designed to give a comprehensive name to each feed ingredient as concisely as possible so as to avoid unnecessary confusion in ingredient identification. The feed ingredient name consists of up to six facets, separated by commas, and written in linear form. The six facets are:

- Facet 1 - Origin consisting of scientific name (genus, species, variety) and common name (generic name, breed or kind, strain or chemical formula);
- Facet 2 - Part fed to animals as affected by process(es) (i.e. actual part of the parent material fed);
- Facet 3 - Process(es) and treatment(s) to which the part has been subjected;
- Facet 4 - Stage of maturity or development;
- Facet 5 - Cutting (applicable to forages); and
- Facet 6 - Grade (official grades with guarantees).

For example, using the above nomenclature, Dong and Hardy (2000) named soybean meal and anchovy meal as follows:

- Soybean, Glycine max, seeds without hulls, meal, solvent extracted
- Fish, anchovy, *Engraulis ringens*, meal, mechanically extracted

Feeds/feed ingredients can also be further classified into one of eight classes depending on their proximate chemical composition and intended dietary use (NRC, 1983), namely:

- Class 1 - Dry forages and roughages, including hay, straw, fodder (aerial part), stover, hulls, and other products with more than 18 percent crude fibre (i.e. rice bran, seed coats, pods, etc.);
- Class 2 - Pasture, range plants and forages fed green, including all forage feeds either not cut (including feeds cured on the stem) or cut and fed fresh;
- Class 3 - Silages, including only ensiled forages (i.e. maize, alfalfa, grass, etc.) and excluding ensiled fish, grain, roots and tubers;
- Class 4 - Energy feeds, including products with less than 20 percent protein (dry basis) and less than 18 percent crude fibre (i.e. grain, mill by-products);
- Class 5 - Protein supplements, including products containing 20 percent or more protein (dry basis) from animal origin (including ensiled products) as well as oil meals, gluten, etc.
- Class 6 - Mineral supplements;

Class 7 - Vitamin supplements, including ensiled yeast; and

Class 8 - Additives, including antibiotics, colouring materials, flavours, hormones and medicaments.

Finally, each feed ingredient name can be assigned a six-digit international feed number (IFN) so as to facilitate identification and computer handling, with the first digit of the IFN denoting the feed class number. For example, the IFN of solvent extracted soybean meal and mechanically extracted anchovy meal is 5-04-612 and 5-01-985, respectively (NRC, 1983). For further information concerning the feed name description and IFN of individual feed ingredient sources commonly used in animal feeds (including aquafeeds), see AAFCO (2008b), Galano, Villarreal-Colmenares and Fenucci (2007), Hertrampf and Pascual (2000), NRC (1982, 1983) and Tacon (1993a, 1993b, 1994).

Despite the simplicity of the above nomenclature and feed reporting scheme, the large majority of published data concerning feed ingredient usage within aquafeeds more often than not fails to give full ingredient names and descriptions, including IFN. For example, listing an ingredient within an aquafeed formulation just as “fishmeal” or “soybean meal” is totally meaningless as there are literally scores of different types and grades of fishmeal and to a lesser extent of soybean meal, depending on the species and origin of the raw fish or bean and processing method employed. Clearly, full ingredient descriptions and nutrient composition data must be given if any meaningful conclusions are to be drawn from the results of dietary feeding trials.

4. Ingredient sources, composition and reported usage

It must be stated at the outset that the current review of feed ingredient sources and reported usage within compound aquafeeds is based upon an analysis of published information and papers in the public domain. For the most part these are feeding studies conducted by university/government researchers usually under controlled laboratory conditions, typically with juvenile animals over a fixed 8- to 16-week time period. Apart from the difficulty of extrapolating the findings of these laboratory-based research studies to outdoor commercial farming conditions, the nutrient content and nutritional value of individual feed ingredient sources varies considerably between countries and ingredient processing facilities depending on local farming conditions and processing methods employed. Moreover, the ultimate performance of a feed ingredient within a formulated aquafeed will depend on the dietary formulation employed, including the nutrient profile of the diet fed and the level of the feed ingredient used and ambient rearing conditions, including natural food availability in the case of pond-reared animals (Tacon, 1995, 1996). Despite the above limitations, some generalizations can be made regarding the nutrient composition and reported usage of individual feedstuffs within compound aquafeeds. The current review covers information gained from feeding studies conducted after 1994; studies conducted prior to that date having been reviewed previously (see Tacon, 1993a, 1993b, 2004).

4.1 ANIMAL PROTEIN SOURCES

4.1.1 Fishery products

Official definitions (AAFCO, 2008b)

Condensed fish protein digest (IFN 5-17-779 Fish protein hydrolysed condensed) is the condensed enzymatic digest of clean undecomposed whole fish or fish cuttings using the enzyme hydrolysis process. The product must be free of bones, scales and undigested solids with or without the extraction of part of the oil. It must contain not less than 30 percent protein.

Condensed fish solubles is obtained by evaporating excess moisture from the stickwater, aqueous liquids, resulting from the wet rendering of fish into fishmeal, with or without removal of part of the oil. Minimum percent of solids, minimum percent of crude protein and minimum percent of crude fat must be guaranteed.

Crab meal (IFN 5-01-663 Crab process residue meal) is the undecomposed ground dried waste of the crab and contains the shell, viscera and part or all of the flesh. It must contain not less than 25 percent crude protein. If it contains more than 3 percent salt (NaCl), the amount of salt must constitute a part of the product name, although in no case must the salt content of this product exceed 7 percent.

Dried fish protein digest (IFN 5-18-778 Fish protein hydrolysed dehydrated) is the dried enzymatic digest of clean undecomposed whole fish or fish cuttings using the enzyme hydrolysis process. The product must be free of bones, scales and undigested solids with or without the extraction of part of the oil. It must contain not less than 80 percent protein and not more than 10 percent moisture. If the degree of fineness is stated, it must conform thereto.

Dried fish solubles (IFN 5-01-971 Fish solubles dehydrated) is obtained by dehydrating the stickwater. It must contain not less than 60 percent crude protein.

Dried shellfish digest is the dried enzymatic digest of clean, undecomposed shellfish (crustaceans and/or molluscs), using the enzyme hydrolysis process. The product may contain shells, viscera and part or all of the flesh, and must be free of undigested solids with or without the extraction of part of the oil. It must contain not less than 50 percent crude protein with not more than 10 percent moisture. If the degree of fineness is stated, it must conform thereto. If the product bears a name descriptive of its kind, composition or origin, it must correspond thereto.

Fish by-products (IFN 5-14-509 Fish process residue fresh) must consist of non-rendered, clean undecomposed portions of fish (such as, but not limited to, heads, fins, tails, ends, skin, bone and viscera) which result from the fish processing industry. If it bears a name descriptive of its kind, it must correspond thereto. Any single constituent used as such may be labeled according to the common or usual name of the particular portion used (such as fish heads, fish tails, etc.).

Fish digest residue (IFN 5-27-467 Fish protein residue hydrolyzed dehydrated) is the clean, dried, undecomposed residue (bones-scales-undigested solids) of the enzymatic digest resulting from the enzyme hydrolysis process of producing fish protein digest. It must be designated according to its protein, calcium and phosphorus content.

Fish liver and glandular meal (IFN 5-01-973 Fish viscera meal) is obtained by drying the complete viscera of the fish. At least 50 percent of the dry weight of the product must be derived from fish liver and must contain at least 18 milligrams of riboflavin per pound (Adopted 1944, Amended 1945; AAFCO, 2008b).

Fishmeal (IFN 5-01-977 Fishmeal mechanical extracted) is the clean, dried, ground tissue of undecomposed whole fish or fish cuttings, either or both, with or without the extraction of part of the oil. If it contains more than 3 percent salt (NaCl), the amount of salt must constitute a part of the product name, although in no case must the salt content of this product exceed 7 percent. The label shall include guarantees for minimum crude protein, minimum crude fat, maximum crude fibre, minimum phosphorus (P) and minimum and maximum calcium (Ca). If it bears a name descriptive of its kind, it must correspond thereto.

Fish protein concentrate – feed grade (IFN 5-09-334 Fish protein concentrate solvent extracted) is prepared from clean, undecomposed whole fish or fish cuttings using the solvent extraction process developed for the production of edible whole fish protein concentrate. It must contain not less than 70 percent protein and not more than 10 percent moisture. If the degree of fineness is stated, it must conform thereto. Solvent residues are not to exceed those established in Food Additive Regulations.

Fish residue meal (IFN 5-01-966 Fish glue residue meal) is the clean, dried, undecomposed residue from the manufacture of glue from non-oily fish. If it contains more than 3 percent salt (NaCl), the amount of salt must constitute a part of the product name, although in no case must the salt content of this product exceed 7 percent.

Fish stock/broth is obtained by cooking fish and/or other marine animal products, including bones, shells, parts and/or muscle, but not including fish solubles. The crude protein content of the stock/broth base material must be no less than 90 percent on a dry matter basis. In order for the stock/broth to be labeled as such, the moisture-to-

crude protein ration must not exceed 135:1 (135 parts water to 1 part crude protein). If the product bears a name descriptive of its kind, composition or origin, it must correspond thereto; and may be called either stock or broth.

Shrimp meal (IFN 5-04-226 Shrimp process residue meal) is the undecomposed, ground dried waste of shrimp and contains parts and/or whole shrimp. If it contains more than 3 percent salt (NaCl), the amount of salt must constitute a part of the product name, although in no case must the salt content of this product exceed 7 percent.

Reported proximate and essential amino acid composition

The average reported proximate and essential amino acid composition of the major fishery products most commonly used in compound aquafeeds is shown in Table 15 and 16, respectively. In general, fishery products are good sources of essential dietary nutrients for most farmed finfish and crustaceans, with the nutrient profile of whole processed meals approximating very closely to the known dietary nutrient requirements, in particular for carnivorous finfish and crustacean species. This is particularly true for the essential amino acids (Table 16) and other essential nutrients,

TABLE 15

Reported proximate composition of selected fish products – values expressed as % as-fed basis; Water-H₂O; Crude Protein-CP; Lipid or Ether Extract-EE; Crude Fibre-CF; Ash; Calcium-Ca; Phosphorus-P

Fish product		H ₂ O	CP	EE	CF	Ash	Ca	P	Ref. ¹
Fishmeals – mechanically extracted, fish silages and hydrolysates									
Anchovy (5-01-985)	min	7.1	65.3	4.1	0.8	14.8	3.75	1.42	1,2,3,
	max	8.3	68.3	10.0	1.3	17.3	4.03	2.49	11,22
	mean	7.9	66.7	6.8	1.0	15.9	3.89	1.95	
Menhaden (5-02-009)	min	3.8	61.1	9.3	0.9	19.0	5.11	2.89	1,3,4,
	max	8.0	67.7	10.7	1.0	21.5	6.89	3.65	22
	mean	6.5	63.4	9.9	0.9	19.9	5.73	3.15	
Herring (5-02-009)	min	7.9	72.0	8.4	0.7	10.1	2.04	1.42	1,3,
	max	8.0	72.7	8.5	0.8	10.5	2.20	1.68	22
	mean	7.9	72.3	8.4	0.7	101.3	2.12	1.55	
Tuna (5-02-023)	min	7.0	59.0	6.9	0.8	17.0	7.86	4.21	1,2,
	max	9.4	65.4	8.0	0.8	21.9	7.86	4.21	15,22
	mean	8.2	62.2	7.4	0.8	19.4	7.86	4.21	
Sardine	min	7.0	59.0	6.7	0.3	14.2	4.44	2.72	3,11
	max	8.5	65.0	9.1	1.0	15.3	-	-	
	mean	7.7	62.0	7.9	0.6	14.7	4.44	2.72	
Horse/Jack mackerel	min	4.6	66.6	9.0	-	13.7	-	-	5,9
	max	7.7	70.0	13.1	-	13.9	-	-	20
	mean	6.1	68.1	11.0	-	13.8	-	-	
White (5-02-025)	min	6.5	62.2	4.2	0.2	18.0	6.84	3.80	1,2,3
	max	10.0	69.0	7.6	0.9	23.7	8.0	4.80	5,6,
	mean	8.3	64.5	5.1	0.6	21.3	7.4	4.12	15
Alaskan pollock (from processing waste)	min	3.4	65.2	5.0	-	10.1	2.67	1.70	7,8
	max	8.0	74.3	11.3	-	23.5	8.51	4.39	
	mean	5.9	69.0	7.6	-	17.3	5.87	3.23	
Cod (from processing waste)	min	8.3	68.6	3.8	-	14.4	3.64	2.35	7,9
	max	10.3	71.8	7.4	-	26.0	-	-	
	mean	9.3	70.2	5.6	-	20.2	3.64	2.35	
Alaskan salmon (from processing waste)	min	2.2	69.0	8.8	-	8.0	-	-	8, 22
	max	10.0	72.0	10.3	-	17.5	-	-	
	mean	6.1	70.5	9.5	-	14.5	-	-	
Farmed salmon (from processing waste)	min	9.0	60.0	9.5	-	13.0	2.5	2.0	22
	max	10.0	66.0	14.0	-	16.0	2.7	2.6	
	mean	9.5	63.5	11.8	-	14.2	2.6	2.3	
Trash fish/processing waste (Viet Nam)	min	DM	30.0	1.0	0.7	15.8	5.0	2.2	10
	max	DM	57.6	12.0	4.2	38.2	8.3	3.2	
	mean	DM	47.8	6.5	2.4	26.6	5.6	2.6	
Dogfish silage		65.4	15.1	17.6	-	1.5	0.17	0.24	22
Salmon hydrolysate (farmed, process waste)		55.0	30.0	5.0	<1	3.5	0.15	0.45	23,24

TABLE 15 – CONTINUED

Fish product		H ₂ O	CP	EE	CF	Ash	Ca	P	Ref. ¹
Fish soluble									
Fish solubles, condensed (5-01-969)	min	49.5	32.0	5.6	0.5	9.6	0.14	0.59	1,3
	max	50.0	32.7	5.7	0.5	9.7	0.22	0.61	
	mean	49.7	32.3	5.65	0.5	9.6	0.18	0.60	
Fish solubles, dehydrated (5-01-971)	min	6.8	48.8	4.9	1.4	11.0	0.26	0.82	1,3,6
	max	8.7	64.1	8.2	5.6	13.7	1.29	1.49	
	mean	7.4	55.9	6.5	3.2	12.6	0.73	1.25	
Menhaden soluble		48.7	31.8	8.9	-	7.8	0.10	0.60	22
Crustacean meals									
Shrimp head meal	min	3.2	32.7	1.3	1.5	18.0	6.97	1.15	2,6
	max	13.3	58.2	10.7	16.3	40.4	10.4	1.60	
	mean	8.8	46.6	6.4	11.1	26.5	8.33	1.33	
Shrimp shell meal	min	4.0	42.0	0.4	12.0	26.2	7.53	1.37	3,6
	max	10.5	47.9	1.3	27.2	37.0	11.1	3.60	
	mean	7.2	44.2	1.4	19.6	31.7	9.91	2.71	
Sergestid shrimp (<i>Acetes</i> sp. whole)	min	8.2	46.9	3.2	3.6	13.1	-	-	2,3, 13, 15
	max	14.0	68.6	6.8	4.4	16.3	-	-	
	mean	10.7	58.6	4.6	4.1	14.9	-	-	
Shrimp meal (process residue) (5-04-226)	min	7.5	37.2	1.3	14.1	26.8	9.73	1.84	1,11
	max	10.0	39.9	3.9	21.4	38.2	15.0	2.20	
	mean	8.7	38.5	2.6	17.7	32.5	12.36	2.02	
Crab meal (process residue) (5-01-663)	min	4.2	31.7	2.0	10.7	38.4	14.56	1.59	1,2
	max	9.1	37.9	4.1	-	46.2	-	-	
	mean	7.1	33.9	2.8	10.7	41.9	14.56	1.59	
Krill meal (5-16-423)	min	5.7	54.3	1.9	0.4	9.3	1.70	1.20	14,18
	max	13.0	69.1	28.0	2.6	29.4	3.20	1.77	
	mean	7.2	61.2	17.8	1.5	12.8	2.58	1.55	
Squat lobster/red crab/langostilla meal	min	4.54	39.3	3.6	7.9	12.8	0.97	1.15	21
	max	7.83	54.7	14.0	12.7	39.1	1.70	1.33	
	mean	5.94	40.4	6.5	10.7	31.3	1.28	1.24	
King crab meal		4.7	39.7	7.4	-	26.6	6.9	-	22
Blue crab meal		4.4	29.4	2.1	-	31.0	18.0	-	22
Molluscan meals									
Squid meal	min	4.7	40.0	4.4	0.17	3.4	0.30	0.92	2,6,9
	max	14.0	80.5	21.0	3.9	15.2	1.28	1.42	
	mean	9.2	67.6	8.2	1.4	8.6	0.79	1.17	
Squid liver meal	min	7.5	49.6	17.2	0.4	7.6	0.75	1.13	6,9
	max	12.2	50.8	21.4	2.6	12.0	1.67	1.28	
	mean	10.3	50.3	18.6	1.5	9.8	1.21	1.15	

¹ The data shown represent mean values from various sources, including: 1 – NRC (1983); 2 – Catacutan (2002); 3 – Tacon (1987); 4 – Anderson *et al.* (1993); 5 – Fenucci (2007); 6 – Bates *et al.* (1995); 7 – Smiley *et al.* (2003); 8 – Forster *et al.* (2005); 9 – Hertrampf and Pascual (2000); 10 Hung and Huy (2007); 11 – Weimin and Mengqing (2007); 12 – Goytortua, E. (2007a); 13 – Ayyappan and Ahmad Ali (2007); 14 – Nur (2007); 15 – Sumagaysay-Chavoso (2007); 16 – Thongrod (2007); 17 – Ayinla (2007); 18 – Goytortua (2007b); 19 – Ezquerro-Brauer *et al.* (2007); 20 – Williams *et al.* (2005); 21 – Goytortua (2007c); 22 – Bimbo (2009); 23 – Wright (2003); 24 – Wright (2004); 25 – Sigve Nordrum, AkerBioMarine, Oslo, Norway (personal communication).

including polyunsaturated fatty acids (eicosapentaenoic acid and docosahexaenoic acid), phospholipids, sterols (cholesterol being an essential nutrient in crustaceans), minerals and trace elements (calcium, phosphorus, potassium, magnesium, iron, copper, iodine, zinc, manganese, selenium, trivalent chromium), fat soluble and water soluble vitamins (choline, vitamin B12, inositol, vitamin A, vitamin D3, niacin, thiamine, riboflavin, pyridoxine, pantothenic acid, biotin, folic acid and vitamin E) and other important potential nutrients (taurine, glycine betaine, biogenic amines, etc. Fenucci, 2007; Fong and Hardy, 2000; Hertrampf and Pascual, 2000; NRC, 1983; Tacon, 1993a).

Quality criteria and reported usage

From a nutritional and economic standpoint, the quality and ultimate feed value of meals derived from fishery products depends on numerous factors, including (1) the origin and source of the fish or crustacean species processed; (2) the freshness and condition of the raw material prior to processing; (3) the cooking and/or drying process used for

TABLE 16

Reported essential amino acid (EAA) composition of selected fish products – all values are expressed as % by weight on as-fed basis unless otherwise stated; Arginine-Arg; Cystine-Cys; Methionine-Met; Threonine-Thr; Isoleucine-Iso; Leucine-Leu; Lysine-Lys; Valine-Val; Tyrosine-Tyr; Tryptophan-Try; Phenylalanine-Phe;

Histidine-His

Fish product		Arg	Cys	Met	Thr	Iso	Leu	Lys	Val	Tyr	Try	Phe	His	Ref. ²
Fishmeals, mechanically extracted														
Anchovy (5-01-985)	min	3.67	0.60	1.94	2.76	2.99	4.98	5.04	3.46	2.17	0.75	2.63	1.52	1-3
	max	3.81	0.65	1.99	2.82	3.10	4.99	5.08	3.52	2.24	0.78	2.78	1.61	
	mean	3.75	0.62	1.96	2.79	3.05	4.98	5.06	3.49	2.21	0.76	2.72	1.57	
	AA%ΣEAA	11.4	1.9	5.9	8.5	9.2	15.1	15.3	10.6	6.7	2.3	8.2	4.8	
	Amino acid score – finfish ¹	98	70	109	80	123	112	91	112	103	135	86	100	
	Amino acid score – shrimp ¹	59	95	140	106	112	106	143	116	82	128	83	112	
Menhaden (5-02-009)	min	3.58	0.56	1.75	2.43	2.81	4.48	4.70	3.22	1.94	0.65	2.40	1.44	1-2
	max	3.75	0.57	1.77	2.50	2.88	4.64	4.72	3.27	1.97	0.68	2.46	1.45	
	mean	3.66	0.56	1.76	2.46	2.84	4.56	4.71	3.24	1.95	0.66	2.43	1.44	
	AA%ΣEAA	12.1	1.8	5.8	8.1	9.4	15.1	15.6	10.7	6.4	2.2	8.0	4.7	
	Amino acid score – finfish	104	67	107	76	125	112	93	113	98	129	84	98	
	Amino acid score – shrimp	63	90	138	101	115	106	146	118	78	122	81	109	
Herring (5-02-009)	min	4.21	0.71	2.08	2.90	3.13	5.19	5.36	3.90	2.20	0.77	2.71	1.65	1-3
	max	4.62	0.74	2.16	3.07	3.23	5.46	5.66	4.37	2.25	0.83	2.82	1.74	
	mean	4.48	0.72	2.13	2.99	3.18	5.32	5.50	4.19	2.22	0.80	2.77	1.70	
	AA%ΣEAA	12.4	2.0	5.9	8.3	8.8	14.8	15.3	11.6	6.2	2.2	7.7	4.7	
	Amino acid score – finfish	107	74	109	78	117	110	91	122	95	129	81	98	
	Amino acid score – shrimp	64	100	140	104	107	104	143	127	76	122	78	109	
Tuna (5-02-023)	min	3.42	0.44	1.46	2.31	2.41	3.79	4.04	2.77	1.69	0.56	2.15	1.75	1-2
	max	3.43	0.47	1.47	2.31	2.45	3.81	4.22	2.80	1.72	0.57	2.16	1.78	
	mean	3.42	0.45	1.46	2.31	2.43	3.80	4.13	2.78	1.70	0.56	2.15	1.76	
	AA%ΣEAA	12.7	1.7	5.4	8.6	9.0	14.1	15.3	10.3	6.3	2.1	8.0	6.5	
	Amino acid score – finfish	109	63	100	81	120	104	91	108	97	123	84	135	
	Amino acid score – shrimp	66	85	129	107	110	99	143	113	77	117	81	151	
White fishmeal (5-02-025)	min	3.86	0.46	1.60	2.29	2.37	4.10	4.37	2.80	1.69	0.58	2.14	1.16	1-4
	max	4.16	0.75	1.72	2.57	2.72	4.38	4.56	3.05	1.86	0.67	2.30	1.45	
	mean	4.04	0.63	1.67	2.48	2.55	4.26	4.49	2.94	1.79	0.62	2.21	1.31	
	AA%ΣEAA	13.9	2.2	5.8	8.6	8.8	14.7	15.5	10.1	6.2	2.1	7.6	4.5	
	Amino acid score – finfish	120	81	107	81	117	109	92	106	95	123	80	94	
	Amino acid score – shrimp	72	110	138	107	107	103	145	111	76	117	77	105	
Horse/Jack mackerel	min	4.46	0.65	1.62	2.68	2.52	4.40	4.71	2.76	-	-	2.30	1.82	3,5,6
	max	6.01	-	1.77	2.70	2.91	4.80	5.41	3.31	-	-	2.34	1.95	
	mean	5.23	0.65	1.69	2.69	2.71	4.60	5.06	3.03	-	-	2.32	1.88	
Salmon meal (farmed) (g/100g protein or g/16gN)	min	4.3	-	3.0	4.7	3.4	6.0	6.5	4.3	3.0	0.45	6.1	2.0	13
	max	7.0	-	5.3	4.8	7.5	11.0	8.0	8.0	5.0	0.46	6.8	2.5	
	mean	5.65	-	4.15	4.75	5.45	8.50	7.25	6.15	4.0	0.45	6.45	2.25	
Salmon hydrolysate (farmed)		1.9	0.2	0.9	1.1	1.2	2.3	2.3	1.5	1.0	0.4	1.1	0.5	14
Fish soluble														
Condensed (5-01-969)	min	1.25	0.19	0.62	0.75	0.79	1.62	1.51	1.10	0.32	0.19	0.74	1.26	1-2
	max	1.63	0.27	0.71	0.87	1.03	1.86	1.86	1.22	0.44	0.34	1.02	1.43	
	mean	1.44	0.23	0.66	0.81	0.91	1.74	1.68	1.16	0.38	0.26	0.88	1.34	
	AA%ΣEAA	12.5	2.0	5.7	7.0	7.9	15.1	14.6	10.1	3.3	2.3	7.7	11.7	
	Amino acid score – finfish	108	74	105	66	105	112	87	106	51	135	81	244	
	Amino acid score – shrimp	65	100	136	87	96	106	136	111	40	128	78	272	
Dehydrated (5-01-971)	min	2.42	0.56	0.91	1.35	1.62	2.80	3.10	1.85	0.85	0.59	1.41	1.50	1-2
	max	3.05	0.62	1.18	2.22	2.05	2.97	3.51	2.10	0.85	1.44	1.53	2.10	
	mean	2.73	0.59	1.04	1.78	1.83	2.88	3.30	1.97	0.85	1.01	1.47	1.80	
	AA%ΣEAA	12.8	2.8	4.9	8.4	8.6	13.5	15.5	9.3	4.0	4.7	6.9	8.5	
	Amino acid score – finfish	110	104	91	79	115	100	92	98	61	276	73	177	
	Amino acid score – shrimp	66	140	117	105	105	95	145	102	49	261	70	198	
Crustacean meals														
Shrimp meal (5-04-226) (process residue)	min	2.50	0.42	0.80	1.42	1.68	2.68	2.17	1.80	1.30	0.36	1.59	0.96	1,6
	max	4.21	0.60	0.95	2.01	1.96	3.07	2.44	2.28	-	-	2.33	0.99	
	mean	3.35	0.51	0.87	1.71	1.82	2.87	2.30	2.04	1.30	0.36	1.96	0.97	
	AA%ΣEAA	16.7	2.5	4.3	8.5	9.1	14.3	11.5	10.2	6.5	1.8	9.8	4.8	
	Amino acid score – finfish	144	93	80	80	121	106	68	107	100	106	103	100	
	Amino acid score – shrimp	86	125	102	106	111	101	107	112	79	100	99	112	

TABLE 16 – CONTINUED

Fish product		Arg	Cys	Met	Thr	Iso	Leu	Lys	Val	Tyr	Try	Phe	His	Ref. ²	
Shrimp head meal (% dry matter basis)	min	1.60	0	0.80	1.21	1.10	1.91	1.66	1.48	1.20	0.41	1.75	0.59	6,7	
	max	2.79	0.66	4.33	2.03	1.86	2.98	2.96	2.09	1.84	0.42	4.36	1.09		
	mean	2.35	0.33	1.71	1.50	1.47	2.41	2.28	1.90	1.54	0.41	2.62	0.83		
	AA%ΣEAA	12.1	1.7	8.8	7.7	7.6	12.4	11.8	9.8	8.0	2.1	13.5	4.3		
	Amino acid score – finfish	104	63	163	73	101	92	70	103	123	123	142	90		
Amino acid score – shrimp	63	85	209	96	93	87	110	108	98	117	136	100			
Krill meal (5-16-423) (g/100g protein or g/16gN)	min	4.60	1.20	2.10	3.90	4.80	6.60	4.60	4.40	2.70	0.90	4.10	1.40	5,8	
	max	7.11	1.30	4.00	4.70	5.40	8.20	8.20	5.70	4.50	1.50	5.30	2.50		11, 15
	mean	6.42	1.31	3.04	4.25	5.02	7.63	7.52	5.06	4.01	1.15	4.63	2.14		
	AA%ΣEAA	12.3	2.5	5.8	8.1	9.6	14.6	14.4	9.7	7.7	2.2	8.9	4.1		
	Amino acid score – finfish	106	93	107	76	128	108	86	102	118	129	94	85		
Amino acid score – shrimp	64	122	137	102	117	103	135	107	94	121	90	95			
Krill/shrimp hydrolysate (% dry matter basis)	min	4.85	0.14	1.21	1.67	0.87	3.37	3.44	1.16	1.71	-	2.26	1.40	12	
	max	6.90	0.34	1.70	2.52	1.80	4.90	8.47	2.25	2.23	-	2.97	2.59		
	mean	6.02	0.23	1.51	2.18	1.32	4.36	6.77	1.76	1.97	-	2.52	2.13		
Squat lobster/Langostilla (g/100g protein or g/16gN)	min	4.00	0.90	1.00	2.80	3.30	4.00	5.30	3.70	3.60	0.70	4.10	1.90	9	
	max	7.60	1.20	3.10	4.90	6.40	9.20	10.3	7.90	9.19	2.00	5.00	9.30		
	mean	5.80	1.05	1.94	4.24	4.30	6.60	6.70	5.66	4.90	1.40	4.42	4.16		
	AA%ΣEAA	11.3	2.0	3.8	8.3	8.4	12.9	13.1	11.1	9.6	2.7	8.6	8.1		
	Amino acid score – finfish	61	74	70	78	112	96	78	117	148	159	91	169		
Amino acid score – shrimp	58	100	90	104	102	91	122	122	117	150	87	188			
Sergestid/mysid shrimp meal (g/100g total amino acids)	min	6.50	0.40	3.00	4.10	0.50	7.30	8.00	4.80	3.60	-	4.10	1.80	2	
	max	8.20	1.20	3.10	5.60	4.50	8.80	8.60	5.30	4.50	-	5.60	2.50		
	mean	7.35	0.80	3.05	4.85	2.50	8.05	8.30	5.05	4.05	-	4.85	2.15		
Molluscan meals															
Squid meal	min	2.67	0.62	0.63	1.64	1.58	2.40	3.09	2.04	1.65	0.90	1.58	1.01	10, Upd	
	max	5.17	0.88	2.26	3.55	3.30	5.23	5.41	3.15	2.11	-	3.02	4.15		
	mean	3.53	0.78	1.27	2.38	2.21	3.90	3.76	2.61	2.31	0.90	2.36	2.08		
	AA%ΣEAA	12.6	2.8	4.5	8.5	7.9	13.9	13.4	9.3	8.2	3.2	8.4	7.4		
	Amino acid score – finfish	109	104	83	80	105	103	80	98	126	188	88	154		
Amino acid score – shrimp	65	140	107	106	96	98	125	102	100	178	85	172			
Squid liver meal (g/100g protein or g/16N)	min	6.50	1.30	2.25	3.80	5.39	7.05	6.44	4.90	3.40	2.40	4.67	5.39	10 Upd	
	max	6.90	-	2.90	4.50	5.50	7.10	6.70	4.92	3.45	-	4.70	5.50		
	mean	6.67	1.30	2.59	4.23	5.44	7.07	6.56	4.91	3.42	2.40	4.68	5.44		
	AA%ΣEAA	12.2	2.4	4.7	7.7	9.9	12.9	12.0	9.0	6.2	4.4	8.5	9.9		
	Amino acid score – finfish	105	89	87	73	132	95	71	95	95	259	89	206		
Amino acid score – shrimp	63	120	112	96	121	91	112	99	76	244	86	230			
Clam/Mussel/Scallop meal (g/100g protein or g/16N)	min	3.95	-	1.19	2.30	2.15	3.37	3.51	2.22	-	-	1.85	0.89	2,5	
	max	8.65	-	1.81	3.00	3.19	5.96	5.81	3.01	-	-	2.72	1.95		
	min	6.14	-	1.49	2.63	2.64	4.57	4.57	2.60	-	-	2.29	1.41		

¹ Individual amino acids are expressed as % of total EAA and compared with the EAA requirement profile of farmed fish (Arg 11.6%, Cys 2.7%, Met 5.4%, Thr 10.6%, Iso 7.5%, Leu 13.5%, Val 9.5%, Tyr 6.5%, Try 1.7%, Phe 9.5% and His 4.8%; Ogino, 1980) and shrimp (Arg 19.3%, Cys 2.0%, Met 4.2%, Thr 8.0%, Iso 8.2%, Leu 14.2%, Val 9.1%, Tyr 8.2%, Try 1.8%, Phe 9.9% and His 4.3%; Tacon *et al.*, 2002), respectively.

² The data shown represent mean values from various sources, including: 1 – NRC (1983); 2 – Tacon (1987); 3 – Fenucci (2007); 4 – Folador *et al.* (2006); 5 – Hertrampf and Pascual (2000); 6 – Williams *et al.* (2005); 7 – Goytortua (2007a); 8 – Goytortua (2007b); 9 – Goytortua (2007c); 10 – Weimin and Mengqing (2007); 11 – Watanabe (2002); 12 – Zhang *et al.* (2002); 13 – Bimbo (2009); 14 – Wright (2004); 15 – Sigve Nordrum, AkerBioMarine, Oslo, Norway (personal communication); upd – unpublished data from the authors.

the manufacture of the meal (time and temperature); (4) the grinding and storage of the processed meal prior to usage (meal particle size, antioxidant stabilization, storage conditions, length of storage, etc.); and (5) the biological availability of the nutrients present within the finished processed meal (for review, see Aksnes and Mundheim, 1997; Aksnes *et al.*, 1997; Caballero *et al.*, 1999; Campos, 1994; Cruz-Suarez *et al.*, 2000; Dong and Hardy, 2000; de Koning, 1999; Galando, Villarreal-Colmenares and Fenucci, 2007; Golez, 2002; Hertrampf and Pascual, 2000; Laohabanjong *et al.*, 2009; Lazo and Davis, 2000; Li, Hardy and Robinson, 2000; Liang and Anders, 2001; Luzanna *et al.*, 1995; Opstvedt *et al.*, 2000, 2003; Ricque-Marie *et al.*, 1998; Tapia-Salazar *et al.*, 2004; Teruel, 2002).

According to Dong and Hardy (2000), the recommended values of chemical tests to measure fishmeal freshness and quality should be as follows:

- Total volatile nitrogen (TVN) < 60 mg N/100g sample (raw material);
- Total volatile nitrogen (TVN) < 150 mg N/100g sample (meal);
- Histamine < 800 ug/g;
- Pepsin digestibility (Torry) > 87.5 percent; and
- *In vivo* “apparent digestibility” coefficient (protein) > 90 percent.

Table 17 shows the major feeding studies that have been published to date (since 1995) concerning the use and performance of different fishery products within compound aquafeeds under controlled experimental conditions for different cultured fish and crustaceans.

TABLE 17

Major feeding studies conducted with fishery products in compound aquafeeds

FISHMEALS AND BY-PRODUCTS

Anchovy fishmeal: Barramundi: Williams *et al.* (2003a, 2003b); Cobia: Zhou *et al.* (2004); Cod: Tibbetts *et al.* (2006); Korean rockfish: Lee (2002); Salmon: Anderson *et al.* (1995); Shrimp: Cruz-Suarez *et al.* (2000); Ricque-Marie *et al.* (1998); Sudaryono *et al.* (1996); Tilapia: Koprucu and Ozdemir (2005); Turbot: Hasimoglu *et al.* (2007);

Alaskan Pollock (white) fishmeal: Pacific threadfin: Forster *et al.* (2003, 2005); Rainbow trout: Satoh *et al.* (2002);

Blue whiting fishmeal: Salmon: Hevroy *et al.* (2004);

Capelin fishmeal: Salmon: Anderson *et al.* (1995); Hevroy *et al.* (2004);

Groundfish fishmeal: Salmon: Anderson *et al.* (1997);

Herring fishmeal: Common carp: Kim *et al.* (1998a, 1998b); Catfish: El-Saidy *et al.* (2000); Cod: Tibbetts *et al.* (2006); Haddock: Tibbetts *et al.* (2004); Salmon: Anderson *et al.* (1995, 1997); Bergheim and Sveier (1995); Hevroy *et al.* (2004); Shrimp: Tapia-Salazar *et al.* (2004); Striped bass: Small *et al.* (1999); Trout: Cheng and Hardy (2002);

Mackerel fishmeal: Salmon: Anderson *et al.* (1997);

Menhaden fishmeal: Channel catfish: Brown *et al.* (1985); El-Saidy *et al.* (2000); Li *et al.* (2006, 2008); Crayfish: Thompson *et al.* (2005, 2006); Minnnow: Kumaran *et al.* (2007); Red drum: Davis *et al.* (1995); McGoogan and Reigh (1996); Whiteman and Gatlin (2005); Salmon: Anderson *et al.* (1995, 1997); Shrimp: Brunson *et al.* (1997); Lim, 1997; Sunshine bass: D’Abramo *et al.* (2000); Lewis and Kohler (2008); Thompson *et al.* (2007); Striped bass: Sullivan and Reigh (1995); Trout: Cheng and Hardy (2002);

Norwegian fishmeal: Salmon: Anderson *et al.* (1997); Wolffish: Moksness *et al.* (1995);

Pacific whiting fishmeal: Red drum: Li *et al.* (2004); Whiteman and Gatlin (2005); Trout: Hardy *et al.* (2005);

Peruvian fishmeal: Tuna: Ji *et al.* (2008);

Red salmon head meal: Red drum: Li *et al.* (2004); Whiteman and Gatlin (2005);

Sandeel fishmeal: Salmon: Hevroy *et al.* (2004); Sea urchin: Hoshikawa *et al.* (1998);

Sardine meal: Rainbow trout: Satoh *et al.* (2002); Shrimp: Sudaryono *et al.* (1995);

Scrap fishmeal: Yellowtail: Aoki *et al.* (1999);

Silver hake fishmeal: Salmon: Anderson *et al.* (1997);

Tilapia (process) meal: Catfish: Akegbejo-Samsons and Fasakin (2008); Tilapia: Boscolo *et al.* (2004, 2005a);

Trout processing waste: Gilthead bream: Kotzamanis *et al.* (2001);

Tuna muscle by-product powder: Flounder: Uyan *et al.* (2006);

Tuna viscera: Shrimp: Hernandez *et al.* (2004b);

White fishmeal: Ayu: Watanabe *et al.* (1996); Common carp/Rainbow trout: Watanabe *et al.* (1996); Yamamoto *et al.* (1998b); Grouper: Lin *et al.* (2004); Red sea bream: Yamamoto *et al.* (1998b); Synechogobius (Gobiidae): Luo *et al.* (2009); Tiger puffer: Furuichi *et al.* (1997a, 1997b); Tilapia: Watanabe *et al.* (1996);

Fishmeal (general): Abalone: Bautista-Teruel *et al.* (2003b); Cho *et al.* (2008); Carp: Jahan *et al.* (2000); Cod: Albrektsen *et al.* (2006); Colossoma: Van der Meer *et al.* (1996); European seabass: Cahu *et al.* 1999; Gilthead seabream: Santigosa *et al.* (2008); Halibut: Aksnes and Mundheim (1997); Japanese seabass: Chang *et al.* (2004); Pacu (Piaractus mesopotamicus): Abimorad *et al.* (2008); Red sea bream: Liang and Anders (2001); Salmon: Espe *et al.* (2006); Lorentzen and Maage (1999); Lorentzen *et al.* (1996); Mundheim *et al.*, (2004); Opstvedt *et al.*, (2000, 2003); Storebakken *et al.* (2000); Sveier *et al.* (1999); Tacon and Metian (2008); Seabream: Aksnes *et al.* (1997); Caballero *et al.* (1999); Shrimp: Cabanillas-Beltran *et al.* (2001); Laohabanjong *et al.* (2009); Liang and Anders (2001); Reyes-Sosa and Castellanos-Molina (1995); Tacon and Metian (2008); Tilapia: Faria *et al.*

TABLE 17 – CONTINUED

(2001); Guimaraes *et al.* (2008); Lim *et al.* (2005); Ogunji and Wirth (2000); Sampaio *et al.* (2001); Trout: Barrias and Oliva-Teles (2000); Rahnema and Borton (2007); Santigosa *et al.* (2008); Sugiura *et al.* (2000); Yellowtail: Shimeno *et al.* (1998);

Fishmeal stickwater: Salmon: Kousoulaki *et al.* (2009);

Fish wastes (general): Salmon: Rathbone *et al.* (2001); Trout: Rathbone *et al.* (2001);

Fish bone meal: Salmon: Nordrum *et al.* (1997); Trout: Vielma *et al.* (1999);

Fish mince (heat coagulated): Salmon: Hemre and Sandnes (2008);

Fish hydrolysate/fish protein hydrolysate: Atlantic cod: Aksnes *et al.* (2006a); Kvale *et al.* (2009); Atlantic halibut: Kvale *et al.* (2009); Common carp: Carvalho *et al.* (1997); Dover sole: Day *et al.* (1997); Japanese sea bass: Liang *et al.* (2006); Octopus: Aguila *et al.* (2007); Salmon: Gildberg *et al.* (1995); Hevroy *et al.* (2005); Murray *et al.* (2003); Shrimp: Cordova-Mureta and Garcia-Carreño (2002); Seabass: Cahu *et al.* 1999; Trout: Aksnes *et al.* (2006b, 2006c); Barrias and Oliva-Teles (2000);

Fish silage (acid/fermented – general): Abalone: Viana *et al.* (1996, 1999); Carp: Ittoop *et al.* (2006); Catfish: Balogun *et al.* (1997); Cisse *et al.* (1995); Fagbenro and Jauncey (1995a); Fagbenro *et al.* (1997); Mondal *et al.* (2008); Colossoma/Pacu: Padilla-Perez *et al.* (2001); Vidotti *et al.* (2002); Freshwater prawn: Ali *et al.* (2000); Tilapia: Borghesi *et al.* (2008); Fagbenro and Jauncey (1995b, 1998); Hoq *et al.* (1995);

Fermented fishery by-products and soybean curd residue mixture: Flounder: Sun *et al.* (2007);

Fermented skipjack tuna viscera: Abalone: Lee *et al.* (2004);

Alkaline preserved herring by-products: Salmon: Sorensen and Denstadli (2008).

CRUSTACEAN MEALS AND BY-PRODUCTS

Arctic amphipod meal/*Themsto libellula*: Halibut: Suontama *et al.* (2007b);

Artemia biomass: General: Zarei and Hafezieh (2007); Freshwater prawn: Anh *et al.* (2009); Nguyen *et al.* (2009); Mud crab: Djunaidah *et al.* (2003); Shrimp: Naegel and Rodriguez-Astudillo (2004);

Crab meal: Abalone: Cho *et al.* (2008); Cod: Tibbetts *et al.* (2006); Grass carp: Lin *et al.* (2001); Haddock: Tibbetts *et al.* (2004); Shrimp: Brunson *et al.* (1997);

Crayfish meal: Crayfish: Jones *et al.* (1996b); Tilapia: Boscolo *et al.* (2004); Koprucu and Ozdemir (2005).

Gammarid meal: Tilapia: Koprucu and Ozdemir (2005);

Krill meal: Abalone: Cho *et al.* (2008); Catfish: Weirich *et al.* (2005); Cod: Moren *et al.* (2007); Tibbetts *et al.* (2006); Cutthroat trout: Smith *et al.* (2004); Halibut: Moren *et al.* (2007); Suontama *et al.* (2007b); Rainbow trout: Moren *et al.* (2007); Palti *et al.* (2006); Yoshitomi *et al.* (2006); Salmon: Anderson *et al.* (1997b); Julshamm *et al.* (2004); Moren *et al.* (2007); Olsen *et al.* (2006); Rungruangsak-Torrissen (2007); Suontama *et al.* (2007); Torstensen *et al.* (2008); Shrimp: Baillet *et al.* (1997); Lopez *et al.* (1998); Naegel and Rodriguez-Astudillo (2004); Perez-Velazquez *et al.* (2002); Sanchez *et al.* (2005); Wouters *et al.* (2002); Tilapia: Gaber (2005); Walleye/Perch/Whitefish: Kolkovski *et al.* (2000); Yellowtail: Verakunpiriya *et al.* (1997); Watanabe *et al.* (2001);

Krill hydrolysate: American lobster: Floreto *et al.* (2001); Red drum: Davis and Arnold (2004); Shrimp: Cordova-Mureta and Garcia-Carreño (2002);

Lobster waste meal: Shrimp: Sudaryono *et al.* (1995);

Mysid meal: Flounder: Park *et al.* (2000);

Pacific white shrimp processing waste meal: Red drum: Whiteman and Gatlin (2005);

Prawn (*Macrobrachium* sp) silage: Catfish: Fagbenro and Bello-Olusoji (1997);

Red crab meal: Shrimp: Civera *et al.* (1999); Goytortua-Bores *et al.* (2006); Villarreal *et al.* (2006);

Shrimp (*Penaeus* sp.) meal: Abalone: Bautista-Teruel *et al.* (2003b); Catfish: Akegbejo-Samsons and Fasakin (2008); Giri *et al.* (2005); Nwadukwe *et al.* (1997); Cod: Tibbetts *et al.* (2006); Haddock: Tibbetts *et al.* (2004); Shrimp: Brunson *et al.* (1997); Fraga *et al.* (1996); Gallardo *et al.* (2002); Villarreal *et al.* (2004);

Shrimp processing waste meal: Red drum: Li *et al.* (2004); Shrimp: Lim (1997); Trout: Hardy *et al.* (2005);

Shrimp by-catch meal: Red drum: Li *et al.* (2004);

Shrimp (*Caridinea* sp.) meal: Tilapia: Liti *et al.* (2006);

Shrimp (*Penaeus* sp.) shell meal: Red porgy: Kalinowski *et al.* (2007); Tilapia: Sheen and Fall (2005);

Shrimp shell waste, fermented: Shrimp: Anwar *et al.* (2006);

Shrimp (*Penaeus* sp.) waste silage: Tilapia: Goncalves and Viegas (2007);

Shrimp (*Penaeus* sp) head meal: General: Nargis *et al.* (2006); Shrimp: Pongmaneerat *et al.* (2001); Sudaryono *et al.* (1995, 1996); Villarreal *et al.* (2006); Barramundi cod: Laining *et al.* (2001);

Shrimp head silage/hydrolysate/fermentation: African catfish: Nwanna (2003), Nwanna *et al.* (2004); Tilapia: Plascencia-Jatomea *et al.* (2002);

Shrimp head waste: General: Coward-Kelly *et al.* (2006);

Squilla meal: Freshwater prawn: Naik *et al.* (2001);

TABLE 17 – CONTINUED

Zooplankton meal: Crayfish: Jones *et al.* (1996b).

MOLLUSC MEALS AND BY-PRODUCTS

Blue mussel extract: Japanese flounder: Kikuchi *et al.* (2002); Tiger puffer: Kikuchi and Furuta (2009);

Clam meal: Freshwater prawn: Naik *et al.* (2001);

Mussel (green-lip) flesh: Spiny lobster: Smith *et al.* (2005);

Scallop meal: Shrimp: Sudaryono *et al.* (1995, 1996);

Squid meal: Abalone: Lee *et al.* (1999); Freshwater prawn: Naik *et al.* (2001); Shrimp: Cordova-Mureta and Garcia-Carreño (2001, 2002); Gallardo *et al.* (2002); Lim (1997); Martinez-Vega *et al.* (2000a; 2000b); Millamena *et al.* (2000); Sanchez *et al.* (2005); Striped jack: Vassallo-Agius *et al.* (2001a, 2001b); Yellowtail: Vassallo-Agius *et al.* (2002);

Squid liver meal/powder: Carp: Bai *et al.* (1998); Rockfish: Sato *et al.* (2006); Shrimp: Brunson *et al.* (1997); Wang *et al.* (2006); Trout: Jang *et al.* (1999); Lee *et al.* (2001);

Squid mantle meal: Wolffish: Moksness *et al.* (1995);

Squid viscera meal: Japanese seabass: Mai *et al.* (2006);

Squid hydrolysate: Atlantic salmon: Espe *et al.* (2006, 2007); Gilthead seabream: Kolkovski and Tandler (2000); Shrimp: Cordova-Mureta and Garcia-Carreño (2002); Summer flounder: Lian *et al.* (2008);

Squid offal silage: Puffer/flounder: Wang and Lied (2001).

4.1.2 Terrestrial livestock products

Official definitions (AAFCO, 2008b)

Animal by-product meal (IFN 5-08-786) is the rendered product from animal tissues, exclusive of any added hair, hoof, horn, hide trimmings, manure, stomach and rumen contents, except in such amounts as may occur unavoidably in good processing practices. It shall not contain added extraneous materials not provided for by this definition. This ingredient definition is intended to cover those individual rendered animal tissue products that cannot meet the criteria as set forth elsewhere in this section. This ingredient is not intended to be used to label a mixture of animal tissue products.

Animal liver meal (IFN 5-00-389) if it bears a name descriptive of its kind, it must correspond thereto. Meal is obtained by drying and grinding liver from slaughtered animals.

Blood meal, flash dried (IFN 5-26-006 Animal blood meal flash dehydrated) is produced from clean, fresh animal blood, exclusive of all extraneous material such as hair, stomach belchings and urine except as might occur unavoidably in good manufacturing processes. A large portion of the moisture (water) is usually removed by a mechanical dewatering process or by condensing by cooling to a semi-solid state. The semi-solid blood mass is then transferred to a rapid drying facility where the more tightly bound water is rapidly removed.

Dried meat solubles (IFN 5-00-393 Animal meat solubles dehydrated) is obtained by drying the defatted water extract of the clean, wholesome parts of slaughtered animals prepared by steaming or hot water extraction. It must be designated according to its crude protein content which shall be no less than 70 percent.

Egg shell meal (IFN 6-26-004 Poultry egg shells meal) is a mixture of egg shells, shell membranes and egg content obtained by drying the residue from an egg breaking plant in a dehydrator to an end product temperature of 180 °F. It must be designated according to its protein and calcium content.

Glandular meal and extracted glandular meal (IFN 5-12-247 Animal glands meal) is obtained by drying liver and other glandular tissues from slaughtered mammals. When

a significant portion of the water-soluble material has been removed, it may be called extracted glandular meal.

Hydrolyzed poultry feathers (IFN 5-03-795 Poultry feathers meal hydrolyzed) is the product resulting from the treatment under pressure of clean, undecomposed feathers from slaughtered poultry, free of additives and/or accelerators. Not less than 75 percent of its crude protein content must be digestible by the pepsin digestibility method.

Meat meal (IFN 5-00-3 85 Animal meat meal rendered) is the rendered product from mammal tissues, exclusive of any added blood, hair, hoof, horn, hide trimmings, manure, stomach and rumen contents, except in such amounts as may occur unavoidably in good processing practices. It shall not contain added extraneous materials not provided for by this definition. The calcium (Ca) level shall not exceed the actual level of phosphorus (P) by more than 2.2 times. It shall not contain more than 12 percent pepsin indigestible residue and not more than 9 percent of the crude protein in the product shall be pepsin indigestible. The label shall include guarantees for minimum crude protein, minimum crude fat, maximum crude fibre, minimum phosphorus (P) and minimum and maximum calcium (Ca). If the product bears a name descriptive of its kind, composition or origin, it must correspond thereto.

Meat and bone meal (IFN 5-00-388 Animal meat with bone rendered) is the rendered product from mammal tissues, including bone, exclusive of any added blood, hair, hoof, horn, hide trimmings, manure, stomach and rumen contents, except in such amounts as may occur unavoidably in good processing practices. It shall not contain added extraneous materials not provided for in this definition. It shall contain a minimum of 4.0 percent phosphorus (P) and the calcium (Ca) level shall not be more than 2.2 times the actual phosphorus (P) level. It shall not contain more than 12 percent pepsin indigestible residue and not more than 9 percent of the crude protein in the product shall be pepsin indigestible. The label shall include guarantees for minimum crude protein, minimum crude fat, maximum crude fibre, minimum phosphorus (P) and minimum and maximum calcium (Ca). If it bears a name description of its kind, composition or origin it must correspond thereto.

Poultry by-product meal (IFN 5-03-798, rendered) consists of the ground, rendered, clean parts of the carcass of slaughtered poultry, such as necks, feet, undeveloped eggs and intestines, exclusive of feathers, except in such amounts as might occur unavoidably in good processing practices. The label shall include guarantees for minimum crude protein, minimum crude fat, maximum crude fibre, minimum phosphorus (P) and minimum and maximum calcium (Ca). The calcium (Ca) level shall not exceed the actual level of phosphorus (P) by more than 2.2 times. If the product bears a name descriptive of its kind, the name must correspond thereto.

Poultry hatchery by-product (IFN 5-03-796 Poultry hatchery by-product meal) is a mixture of eggshells, infertile and unhatched eggs, and culled chicks which have been cooked, dried and ground, with or without removal of part of the fat.

Spray dried animal blood (IFN 5-00-381 Animal blood spray dehydrated) is produced from clean, fresh animal blood, exclusive of all extraneous material such as hair, stomach belching, urine, except in such traces as might occur unavoidably in good processing practice. Moisture is removed from the blood by a low temperature evaporator under vacuum until it contains approximately 30 percent solids. It is then dried by spraying into a draft of warm, dry air which reduces the blood to finely divided particles with a

maximum moisture of 8 percent and a minimum crude protein of 85 percent. It must be designated according to its minimum water solubility.

Reported proximate and essential amino acid composition

The average reported proximate and essential amino acid composition of the major terrestrial livestock products most commonly used in compound aquafeeds is shown in Table 18 and 19, respectively. In general, terrestrial livestock by-products are good sources of dietary protein, lipids and minerals. Of the different by-products, liver meal and poultry by-product meal have the best overall amino acid profile, with other by-product meals usually having specific essential amino acid imbalances, including blood meal (isoleucine and methionine deficiency), hydrolysed feather meal (methionine and lysine deficiency) and to a lesser extent meat and bone meal and meat meal (methionine and tyrosine deficiency; Table 18). In common with fishery by-products, terrestrial livestock products are also rich dietary sources of cholesterol, minerals and trace elements (calcium, phosphorus, potassium, magnesium, iron, copper, zinc, manganese), fat soluble and water soluble vitamins (choline, vitamin B₁₂, inositol, vitamin A, vitamin D₃, niacin, thiamine, riboflavin, pyridoxine, pantothenic acid, biotin, folic acid and vitamin E), and other important nutrients, including arachidonic acid, taurine, nucleotides and hydroxyproline (Bureau, 2006; Cruz-Suarez *et al.*, 2007a; Gaxiola, 2007; Hertrampf and Pascual, 2000; Nates and Bureau, 2007; NRC, 1983; Yu, 2006). Table 20 shows the reported cholesterol content of animal protein ingredients obtained from rendering plants and fishmeal manufacturers.

Quality criteria and reported usage

As with fishery products, the quality and ultimate feed value of meals derived from terrestrial livestock products depends upon numerous factors, including (1) the origin and source of the species processed; (2) the freshness and condition of the raw material used prior to processing (healthy animals and/or fallen stock); (3) the cooking and drying process used for the manufacture of the meal; (4) the grinding and storage of

TABLE 18

Reported proximate composition of selected terrestrial livestock products – values expressed as percent as-fed basis; Water-H₂O; Crude Protein-CP; Lipid or Ether Extract-EE; Crude Fibre-CF; Ash; Calcium-Ca; Phosphorus-P

Terrestrial livestock product		H ₂ O	CP	EE	CF	Ash	Ca	P	Ref. ¹
General									
Blood meal, spray dried (5-00-381)	min	7.0	81.5	1.0	0.7	4.5	0.32	0.24	1,2,3
	max	10.4	88.9	2.0	1.0	6.6	0.48	0.30	4
	mean	9.0	85.5	1.4	0.9	5.3	0.40	0.26	
Feather meal, hydrolysed (5-03-795)	min	7.0	81.0	2.9	0.6	3.4	0.25	0.50	1,2,3
	max	10.0	86.0	7.0	1.4	4.0	0.60	0.75	4,5
	mean	8.4	84.0	4.2	1.0	3.6	0.35	0.73	
Liver meal	min	6.4	66.7	12.2	0.7	5.9	0.28	0.81	2,6
	max	8.0	67.1	16.5	0.8	8.0	0.56	1.26	
	mean	7.2	66.9	14.3	0.7	6.9	0.42	1.03	
Meat and bone meal, rendered (5-00-388)	min	5.6	46.8	9.6	2.0	21.8	9.50	2.49	1,2,3
	max	10.0	54.1	14.3	3.0	34.1	10.3	7.08	4,5,6
	mean	7.5	50.1	10.6	2.4	28.8	10.0	4.95	
Meat meal, rendered (5-09-385)	min	5.9	51.4	4.8	2.0	15.0	6.49	3.55	1,2,3
	max	7.5	56.9	10.0	2.7	27.0	8.22	4.22	7
	mean	6.6	54.1	7.4	2.4	21.2	7.35	3.88	
Poultry by-product, meal rend. (5-03-798)	min	6.0	55.0	8.0	2.0	12.0	2.0	1.60	1,2,3,5,8
	max	10.0	65.0	13.0	4.0	18.0	4.0	3.40	
	mean	7.4	59.0	12.4	2.6	15.3	3.21	1.93	

¹ The data shown represent mean values from various sources, including: 1 – NRC (1983); 2 – Tacon (1987); 3 – Meeker and Hamilton (2006); 4 – Gaxiola (2007); 5 – Bureau (2006); 6 – Forster *et al.* (2005); 7 – Hertrampf and Pascual (2000); 8 – Cruz-Suarez *et al.* (2007).

TABLE 19

Reported essential amino acid (EAA) composition of selected terrestrial livestock products – all values are expressed as % by weight on as-fed basis unless otherwise stated; Arginine-Arg; Cystine-Cys; Methionine-Met; Threonine-Thr; Isoleucine-Iso; Leucine-Leu; Lysine-Lys; Valine-Val; Tyrosine-Tyr; Tryptophan-Try; Phenylalanine-Phe; Histidine-His

Terrestrial livestock product		Arg	Cys	Met	Thr	Iso	Leu	Lys	Val	Tyr	Try	Phe	His	Ref. ²
General														
Blood meal, spray dried	min	3.18	0.50	0.60	3.20	0.89	10.5	6.11	7.01	2.10	1.00	5.70	3.50	1–4
	max	3.60	1.21	1.00	3.88	1.00	11.0	7.48	7.56	2.27	1.30	5.92	5.20	
	mean	3.46	0.81	0.77	3.58	0.93	10.8	6.92	7.29	2.18	1.10	5.79	4.30	
	AA% Σ EAA	7.2	1.7	1.6	7.5	1.9	22.5	14.4	15.2	4.5	2.3	12.1	9.0	
	Amino acid score – finfish ¹	62	63	30	71	25	167	86	160	69	135	127	187	
	Amino acid score – shrimp ¹	37	83	38	94	23	158	135	167	55	127	122	209	
Feather meal, hydrolysed	min	5.60	3.08	0.53	3.76	3.76	6.90	1.72	5.90	2.32	0.52	3.05	0.61	1–3
	max	7.05	4.30	0.60	3.97	4.06	7.32	2.32	6.48	2.50	0.65	3.90	0.99	
	mean	6.18	3.54	0.56	3.84	3.91	7.05	2.11	6.11	2.38	0.59	3.42	0.83	
	AA% Σ EAA	15.2	8.7	1.4	9.5	9.6	17.4	5.2	15.1	5.9	1.5	8.4	2.0	
	Amino acid score – finfish	131	322	26	90	128	129	31	159	91	88	88	42	
	Amino acid score – shrimp	79	424	33	119	117	122	49	166	72	83	85	46	
Meat and bone meal, rend.	min	3.30	0.39	0.64	1.65	1.50	3.06	2.60	2.39	1.13	0.29	1.70	0.96	1–5
	max	3.56	0.70	0.94	1.89	1.77	3.56	2.98	2.56	1.65	0.50	1.92	1.27	
	mean	3.46	0.53	0.73	1.74	1.63	3.28	2.79	2.45	1.19	0.35	1.80	1.08	
	AA% Σ EAA	16.4	2.5	3.5	8.3	7.7	15.6	13.3	11.6	5.7	1.7	8.6	5.1	
	Amino acid score – finfish	141	93	65	78	103	115	79	122	88	100	90	106	
	Amino acid score – shrimp	85	122	82	104	93	110	125	127	69	94	87	119	
Meat meal, rendered	min	3.60	0.65	0.70	1.64	1.75	3.19	3.11	2.52	0.96	0.34	1.81	0.96	1–3
	max	3.65	0.67	0.80	1.72	1.82	3.35	3.23	2.56	-	0.50	1.86	1.03	
	mean	3.62	0.66	0.74	1.68	1.78	3.27	3.18	2.54	0.96	0.40	1.83	0.99	
	AA% Σ EAA	16.7	3.0	3.4	7.7	8.2	15.1	14.7	11.7	4.4	1.8	8.4	4.6	
	Amino acid score – finfish	144	111	63	73	109	112	87	123	68	106	88	96	
	Amino acid score – shrimp	86	146	80	97	100	106	138	129	53	100	85	107	
Poultry by-product meal, rend.	min	3.77	0.65	1.00	1.94	2.01	3.89	2.73	2.51	0.94	0.40	1.82	1.01	1–3
	max	3.94	1.00	1.11	2.20	2.38	4.20	3.32	2.90	1.70	0.50	2.30	1.30	
	mean	3.85	0.88	1.05	2.07	2.23	4.02	3.01	2.75	1.28	0.46	2.05	1.16	
	AA% Σ EAA	15.5	3.5	4.2	8.3	9.0	16.2	12.1	11.1	5.2	1.8	8.3	4.7	
	Amino acid score – finfish	134	130	78	78	120	120	72	117	80	106	87	98	
	Amino acid score – shrimp	80	171	99	104	109	114	114	122	63	99	84	109	
Liver meal (g/100g protein or g/16N)	min	4.04	0.94	1.22	2.49	3.10	5.31	5.21	4.15	1.70	0.69	2.92	1.48	2
	max	-	-	-	-	-	-	-	-	-	-	-	-	
	mean	-	-	-	-	-	-	-	-	-	-	-	-	
	AA% Σ EAA	12.1	2.8	3.7	7.5	9.3	16.0	15.7	12.5	5.1	2.1	8.8	4.4	
	Amino acid score – finfish	104	104	68	71	124	118	93	132	78	123	93	92	
	Amino acid score – shrimp	63	137	87	94	113	113	147	137	62	116	89	102	

¹ Individual amino acids are expressed as % of total EAA and compared with the EAA requirement profile of farmed fish (Arg 11.6%, Cys 2.7%, Met 5.4%, Thr 10.6%, Iso 7.5%, Leu 13.5%, Val 9.5%, Tyr 6.5%, Try 1.7%, Phe 9.5% and His 4.8%; Ogino, 1980) and shrimp (Arg 19.3%, Cys 2.0%, Met 4.2%, Thr 8.0%, Iso 8.2%, Leu 14.2%, Val 9.1%, Tyr 8.2%, Try 1.8%, Phe 9.9% and His 4.3%; Tacon *et al.*, 2002), respectively.

² The data shown represent mean values from various sources, including: 1 – NRC (1983); 2 – Tacon (1987); 3 – Meeker and Hamilton (2006); 4 – Gaxiola (2007); 5 – Catacutan (2002).

the processed meal prior to usage; and (5) the biological availability of the nutrients present within the final finished product (for review, see Bureau, 2006; Cruz-Suarez, 2007a; Dong and Hardy, 2000; Gaxiola, 2007; Hertrampf and Pascual, 2000; Li *et al.*, 2000; Meeker and Hamilton, 2006; Yu, 2006).

Table 21 shows the major feeding studies that have been published to date (since 1995) concerning the use and performance of different terrestrial livestock products within compound aquafeeds under controlled experimental conditions for different cultured fish and crustaceans.

TABLE 20
Reported cholesterol content of animal protein ingredients obtained from rendering plants and fishmeal manufacturers

Ingredient	Cholesterol content (%, as-fed basis)
Fishmeal, menhaden	0.237
Fishmeal, herring	0.302
Blood meal, avian, disc-dried	0.407
Blood meal, mammalian, flash-dried	0.255
Blood meal, bovine, ring-dried	0.241
Feather meal, steam-hydrolysed	0.090
Meat and bone meal, 43% crude protein	0.098
Meat and bone meal, 56% crude protein	0.100
Meat and bone meal, 56% crude protein	0.107
Poultry by-products meal, 65% crude protein	0.168

Source: Nates and Bureau (2007).

TABLE 21
Major feeding studies conducted with terrestrial livestock products in compound aquafeeds

BLOOD BY-PRODUCTS

Blood meal (general): Atlantic silver perch: Allan et al. (2000); Carp: Bai et al. (1998); Hu et al. (2008b); Kim et al. (1997); **Catfish:** Akegbejo-Samsons and Fasakin (2008); Eyo et al. (1995); **Channel catfish:** Brown et al. (1985); **Cuneate drum:** Guo et al. (2007); **Dourado (*Salminus brasiliensis*):** Braga et al. (2008); **Eel:** Engin and Carter (2002); **Grouper:** Millamena (2002); Wang et al. (2008); **Murray cod:** Abery et al. (2002); **Palmetto bass:** Gallagher and LaDouceur (1995); **Red drum:** McGoogan and Reigh (1996); **Rockfish:** Lee et al. (1996); **Rohu:** Paul et al. (1997); Saha and Ray (1998); **Salmon:** Breck et al. (2003); **Seabream:** Martinez-Llorens et al. (2008); **Silver perch:** Rowland et al. (2007); **Striped bass (hybrid):** Gaylord et al. (2004); Sullivan and Reigh (1995); **Sunshine bass:** Rawles et al. (2006); **Tilapia:** Boscolo et al. (2005); Bouda and Chien (2005); El-Sayed (1998); Fasakin et al. (2005); Sampaio et al. (2001); **Trout:** Bureau et al. (1999); El-Haroun and Bureau (2007); El-Haroun et al. (2009); Jang et al. (1999); Johnson and Summerfelt (2000); Lee et al. (2001); Luzier et al. (1995); Selden et al. (2001); Sugiura et al. (1998, 2000); Yanik and Aras (1999);

Haemoglobin meal/powder (general): Eel: Lee and Bai (1997); Seabream: Martinez-Llorens et al. (2008);

Procine plasma (spray dried): Trout: Cheng et al. (2004).

MEAT BY-PRODUCTS

Meat and bone meal (general): African catfish: Goda et al. (2007b); Atlantic silver perch: Allan et al. (2000); Carp: Bai et al. (1998); Hu et al. (2008a, 2008b); Xue et al. (2004); Yang et al. (2004b); Zhang et al. (2006, 2008); **Channel catfish:** Brown et al. (1985); **Cuneate drum:** Guo et al. (2007); Wang et al. (2006); **Flounder:** Kikuchi et al. (1997); Zhu et al. (2006); **Freshwater prawn:** Hossain and Islam (2007); Yang et al. (2004a); **Gilthead seabream:** Robaina et al. (1997); **Grouper:** Li et al. (2009); Wang et al. (2008); **Japanese seabass:** Chang et al. (2004); **Korean rockfish:** Lee (2002); Lee et al. (1996); **Redclaw crayfish:** Pavasovic et al. (2007); **Red drum:** Gaylord and Gatlin (1996); McGoogan and Reigh (1996); **Rohu:** Paul et al. (1997); **Shrimp:** Brunson et al. (1997); Forster et al. (2003); Li and Yu (2003); Menasveta and Yu (2002); Menasveta et al. (2003); Tan and Yu (2003); Tan et al. (2005); Wei and Yu (2003); Yu (2006); Zhu and Yu (2002); Zu et al. (2004); **Striped bass:** Bharadwaj et al. (2002); Sullivan and Reigh (1995); **Tilapia:** El-Sayed (1998); Nguyen, Davis and Saoud (2009); Wu et al. (1999); **Trout:** Bureau et al. (1999, 2000); El-Haroun et al. (2009); Jang et al. (1999); Lee et al. (2001); Satoh et al. (2002); Yanik and Aras (1999); **Yellow croaker:** Ai et al. (2006);

Meat meal (general): Ayu/Common carp: Watanabe et al. (1996); Barramundi: Williams et al. (2003a, 2003b); **Braslian codling:** Bolasina and Fenucci (2005); **Cobia:** Zhou et al. (2004); **Eel:** de la Higuera et al. (1999); Engin and Carter (2005); Garcia-Gallego et al. (1998); **Flounder:** Sato and Kikuchi (1997); **Grouper:** Millamena (2002); **Korean rockfish:** Lee (2002); Lee et al. (1996); **Rainbow trout:** Watanabe et al. (1996); **Rohu:** Jena et al. (1998); **Short-finned eel:** Engin and Carter (2005); **Silver perch:** Allan and Rowland (2005); Hunter et al. (2000); Stone et al. (2000); **Tilapia:** Guimaraes et al. (2008); Watanabe et al. (1996); **Yellowtail:** Shimeno et al. (1996); Watanabe et al. (1998, 2001);

Meat meal (porcine): Shrimp: Hernandez et al. (2004a; 2008);

Meat solubles: Eel: Engin and Carter (2002); Grouper: Millamena and Golez (2001); Shrimp: Millamena et al. (2000);

Leather meal: Carp: Bai et al. (1998); Trout: Lee et al. (2001).

POULTRY BY-PRODUCTS

Poultry by-product meal: Atlantic silver perch: Allan et al. (2000); Carp: Emre et al. (2003); Hu et al. (2008a, 2008b); Yang et al. (2004b; 2006); African catfish: Abdel-Warith et al. (2001); Goda et al. (2007b); Sadiku and Jauncey (1998); **Channel catfish:** Brown et al. (1985); **Cobia:** Zhou et al. (2004); **Cod:** Tibbetts et al. (2006); **Colossoma:** Terrazas et al. (2002); **Crayfish:** Saoud et al. (2008); Pavasovic et al. (2007); **Drum:** Davis and Arnold (2004); Gaylord and Gatlin (1996); Guo et al. (2007); Kureshy et al. (2000); Wang et al. (2006); **Eel:** Engin and Carter (2002); **Flounder:** Zhu et al. (2006); **Freshwater prawn:** Yang et al. (2004); **Grouper:** Li et al. (2009); Shapawi et al. (2007); Wang et al. (2008); **Lambari:** Signor et al. (2008); **Largemouth bass:** Subhadra et al. (2006);

TABLE 21 – CONTINUED

Palmetto/Sunshine Bass: Gallagher and LaDouceur (1995); Rawles *et al.* (2006); Shrimp: Amaya *et al.* (2007); Cheng and Hardy (2004); Cheng *et al.* (2001, 2002a); Cruz-Suarez *et al.* (2004, 2007b); Davis and Arnold (2000); Menesveta and Yu (2002); Roy *et al.* (2009); Samochoa *et al.* (2004); Tan and Yu (2003); Wei and Yu (2003); Yu, 2006; Zhu and Yu (2002); Zu *et al.* (2004); Seabream: Nengas *et al.* (1999); Takagi *et al.* (2000a); Snapper: Quartararo *et al.* (1998); Striped bass: Gaylord and Rawles (2005); Gaylord *et al.* (2004); Rawles *et al.* (2006, 2009); Sunshine bass: Pine *et al.* (2008); Thompson *et al.* (2008); Webster *et al.* (2000); Tilapia: de Faria *et al.* (2002); El-Sayed (1998); Fasakin *et al.* (2005); Guimaraes *et al.* (2008); Sadiku and Jauncey (1995); Trout: Bureau *et al.* (1999); Cheng and Hardy (2002); Cheng *et al.* (2004); El-Haroun and Bureau (2007); El-Haroun *et al.* (2009); Erturk and Sevgili (2003); Jang *et al.* (1999); Lee *et al.* (2001); Pfeffer *et al.* (1995); Yanik and Aras (1999); Turbot: Turker *et al.* (2005); Yigit *et al.* (2006);

Turkey meal: Sunshine bass: Muzinic *et al.* (2006); Thompson *et al.* (2007);

Feather meal: Atlantic silver perch: Allan *et al.* (2000); Atlantic cod: Tibbetts *et al.* (2006); Drum: Guo *et al.* (2007); Wang *et al.* (2006); Grouper: Li *et al.* (2009); Wang *et al.* (2008); Korean rockfish: Lee (2002); Rohu: Hasan *et al.* (1997a); Paul *et al.* (1997); Shahzad *et al.* (2006); Shrimp: Cheng *et al.* (2002b); Mendoza *et al.* (2001); Tilapia: Bishop *et al.* (1995); Fasakin *et al.* (2005); Guimaraes *et al.* (2008); Trout: Bureau *et al.* (1999, 2000); Cheng *et al.* (2004); El-Haroun *et al.* (2009); Jang *et al.* (1999); Lee *et al.* (2001); Rahnama and Borton (2007); Satoh *et al.* (2002); Sugiura *et al.* (1998, 2000);

Spent hen meal: Trout: Cheng *et al.* (2004);

Poultry/chicken offal silage: Tilapia: Belal *et al.* (1995); Middleton *et al.* (2001).

4.1.3 Terrestrial invertebrate products

Reported proximate and essential amino acid composition

The average reported proximate and essential amino acid composition of some terrestrial invertebrate products which have been successfully used in compound aquafeeds is shown in Table 22 and 23, respectively. Insect larvae/pupae have been used as traditional supplementary feed items by small-scale farmers in many Asian

TABLE 22

Reported proximate composition of selected terrestrial invertebrate products – values expressed as percent as-fed basis; Water-H₂O; Crude Protein-CP; Lipid or Ether Extract-EE; Crude Fibre-CF; Ash; Calcium-Ca; Phosphorus-P

Terrestrial invertebrate product		H ₂ O	CP	EE	CF	Ash	Ca	P	Ref. ¹
Insecta/insects									
Silkworm pupae meal, whole (% dry matter basis)	min	4.9	49.4	14.2	3.9	2.2	0.63	1.25	1,7,8
	max	31.5	60.9	30.3	8.8	7.5	-	-	
	mean	11.1	55.1	23.2	5.5	3.8	0.63	1.25	
Silkworm pupae meal, deoiled (% dry matter basis)	min	1.5	44.5	0.7	4.6	4.4	0.63	1.25	1
	max	9.6	77.6	7.0	9.8	9.1	-	-	
	mean	8.1	72.8	2.0	6.2	5.6	0.63	1.25	
Silkworm pupae, dehydrated (5-11-787)		6.0	56.6	12.3	8.6	4.0	-	-	2
Maggot meal (<i>Musca domestica</i>)	min	2.5	37.5	19.8	1.0	9.4	-	-	3,10
	max	3.6	49.0	26.2	-	23.1	-	-	
	mean	3.0	43.2	23.0	1.0	16.2	-	-	
Soldier fly (<i>Hermetia illucens</i>) larvae meal		7.9	42.1	34.8	7.0	14.6	5.0	1.5	5
Locust (<i>Schistocerca gregaria</i>) whole dried		10.5	46.2	9.7	12.0	-	-	-	5
Termite meal		3.7	46.3	30.1	7.3	3.6	0.23	0.38	4
Molluscs/snails									
Snail (flesh) meal (dry matter basis) (% dry matter basis)	min	8.2	54.3	4.2	4.1	1.0	1.13	0.15	1,4,9
	max	9.0	66.8	7.9	4.5	9.6	2.00	0.84	
	mean	8.6	60.5	6.0	4.3	5.3	1.56	0.49	
Snail (shell) meal (dry matter basis)		-	2.8	1.0	-	54.5	36.1	0.14	1
Annelids/worms									
Earthworm (<i>Eisensia foetida</i>) meal		7.4	56.4	7.8	1.6	8.8	0.48	0.87	5
Earthworm (<i>Dendrodrilus sububicundus</i>) meal		9.1	65.1	9.6	-	13.0	0.18	-	5
Earthworm (<i>Hyperiodrilus euryalos</i>) meal		8.6	63.0	5.9	1.9	8.9	0.53	0.94	4
Earthworm (<i>Eudrilus eugeni</i>) meal		0.0	60.4	12.0	-	10.5	1.49	0.89	5
Polychaete (<i>Nereis virens</i>) meal		8.0	55.0	15.0	1.0	12.0	-	0.90	6

¹ The data shown represent mean values from various sources, including: 1 – Hertrampf and Pascual (2000); 2 – NRC (1982); 3 – Eyo (2005); 4 – Sogbesan and Ugwumba (2008); 5 – Tacon (1987); 6 – Robert Serwata, Dragon Feeds Ltd, Swansea, Wales (personal communication); 7 – Barman and Karim (2007); 8 – Ayyappan and Ahamad Ali (2007); 9 – Nur (2007); 10 – Ogunji *et al.* (2008c).

TABLE 23

Reported essential amino acid (EAA) composition of selected terrestrial invertebrate products – all values are expressed as % by weight on as-fed basis unless otherwise stated; Arginine-Arg; Cystine-Cys; Methionine-Met; Threonine-Thr; Isoleucine-Iso; Leucine-Leu; Lysine-Lys; Valine-Val; Tyrosine-Tyr; Tryptophan-Try; Phenylalanine-Phe; Histidine-His

Terrestrial livestock product	Arg	Cys	Met	Thr	Iso	Leu	Lys	Val	Tyr	Try	Phe	His	Ref. ²
Insecta/insects													
Soldier fly larvae (% dry matter)	2.2	0.1	0.9	0.5	2.0	3.5	3.4	3.4	2.5	0.2	2.2	1.9	3
AA%ΣEAA	9.65	0.44	3.95	2.19	8.77	15.3	14.9	14.9	11.0	0.87	9.65	8.33	
Amino acid score – finfish ¹	83	16	73	21	117	113	89	157	169	51	102	173	
Amino acid score – shrimp ¹	50	21	93	27	107	108	140	164	134	48	97	194	
Silkworm pupae meal	3.6	-	1.8	3.6	7.5	2.5	-	-	0.6	1.8	3.2	3.2	1
(g/100g protein or g/16N)	7.8	-	1.9	5.6	8.0	10.1	-	-	1.5	3.2	3.3	3.3	
mean	6.0	-	1.9	4.6	7.8	6.1	4.7	-	1.1	2.5	3.3	3.3	
Magmeal (<i>M. domestica</i> (% DM))	1.7	-	1.66	2.8	0.6	2.1	1.7	0.5	0.9	0.6	3.8	1.9	6
Termite meal (g/16N)	2.87	-	1.68	1.67	1.70	3.11	2.82	2.26	-	-	1.97	1.28	5
Molluscs/snails													
Snail meal	12.0	-	1.33	5.91	6.23	6.79	5.10	5.90	-	-	5.04	1.77	2
(g/100g protein or g/16N)													
Snail meal (% dry matter)	4.9	0.6	1.0	2.8	2.6	4.6	4.3	3.1	2.4	-	2.6	1.4	3
Annelids/worms													
Earthworm meal	1.73	0.23	0.50	1.37	0.99	3.57	1.83	1.15	1.01	0.35	1.19	0.40	3
(% dry meal basis)	3.68	0.39	1.36	2.77	2.24	4.17	3.86	2.46	1.99	0.57	2.65	1.44	
mean	2.97	0.3	1.06	2.32	1.85	3.95	3.18	2.05	1.70	0.45	1.97	1.15	
AA%ΣEAA	16.4	2.5	3.5	8.3	7.7	15.6	13.3	11.6	5.7	1.7	8.6	5.1	
Amino acid score – finfish	141	93	65	78	103	115	79	122	88	100	90	106	
Amino acid score – shrimp	85	122	82	104	93	110	125	127	69	94	87	119	
Marine polychaete meal	3.10	0.40	0.50	1.90	1.70	3.10	2.40	2.00	1.40	0.30	1.50	0.80	4
AA%ΣEAA	16.2	2.1	2.6	10.0	8.9	16.2	12.6	10.5	7.3	1.6	7.8	4.2	
Amino acid score – finfish	140	78	48	94	119	120	75	110	112	94	82	87	
Amino acid score – shrimp	84	102	61	125	108	114	118	115	89	88	79	98	
Earthworm meal (g/16N)	2.83	-	5.30	4.43	2.04	4.11	6.35	4.43	-	-	6.26	1.47	5

¹ Individual amino acids are expressed as % of total EAA and compared with the EAA requirement profile of farmed fish (Arg 11.6%, Cys 2.7%, Met 5.4%, Thr 10.6%, Iso 7.5%, Leu 13.5%, Val 9.5%, Tyr 6.5%, Tryp 1.7%, Phe 9.5% and His 4.8%; Ogino, 1980) and shrimp (Arg 19.3%, Cys 2.0%, Met 4.2%, Thr 8.0%, Iso 8.2%, Leu 14.2%, Val 9.1%, Tyr 8.2%, Tryp 1.8%, Phe 9.9% and His 4.3%; Tacon *et al.* 2002), respectively.

² The data shown represent mean values from various sources, including: ¹ Hertrampf and Pascual (2000); 1 – Tacon (1994); 2 – Sogbesan and Ugwumba (2008); 3 – Tacon (1987); 4 – *Nereis virens* meal: Robert Serwata, Dragon Feeds Ltd (personal communication); 5 – *H. euryalos*: Sogbesan and Ugwumba (2008); 6 – Ogunji *et al.* (2008c).

and sub-Saharan countries and, together with snails and annelids, offer a potential non-conventional feed source for use by small-scale farmers; for review, see Hasan *et al.* (2007) and Sogbesan and Ugwumba (2008).

In general, invertebrate meals are good dietary sources of animal protein, lipids and energy. However, depending on the species, many invertebrates contain chemicals which render them unpalatable to potential predators, and as such may require removal through washing/blanching and/or solvent extraction (Hertrampf and Pascual, 2000; Stafford and Tacon, 1988). By contrast, other species have specific nutrients/chemicals that may exert specific dietary nutritional benefits, including phospholipids, highly unsaturated fatty acids, taurine, arachidonic acid, glycine betaine, theobromine, cholesterol and steroids (Anon, 2001; Meunpol *et al.*, 2007).

Quality criteria and reported usage

As with terrestrial animal products, the quality and ultimate feed value of meals derived from terrestrial invertebrates depends upon (1) the species and origin of the invertebrate processed; (2) the freshness/cleanliness and stage in the life cycle of the invertebrate processed; and (3) the processing and/or lipid extraction/drying method employed prior to usage (for review, see Hertrampf and Pascual, 2000; Sogbesan and Ugwumba, 2008).

Table 24 shows the major feeding studies that have been published to date (since 1995) concerning the use and performance of different terrestrial invertebrate products within compound aquafeeds under controlled experimental conditions for different cultured fish and crustaceans.

TABLE 24

Major feeding studies conducted with terrestrial invertebrate products in compound aquafeeds**INSECTS**

Housefly pupae/maggot meal: Catfish: Akegbejo-Samsons and Fasakin (2008); Akinwande *et al.* (2002); Eyo (2005); Fasakin *et al.* (2003); Tilapia: Ajani *et al.* (2004); Chrappa and Sabo (1999); Ogunji *et al.* (2007, 2008a, 2008b, 2008c); Slawski *et al.* (2008); Trout: St-Hilaire *et al.* (2007);

Rhinoceros beetles: Ornamental fish: Kamarudin *et al.* (2007);

Silkworm pupae/meal: Ayu: Watanabe *et al.* (1996); Carp: Ayyappan and Ahamad Ali (2007); Rahman *et al.* (1996); Watanabe *et al.* (1996); Weimin and Mengqing (2007); Catfish: Ayyappan and Ahamad Ali (2007); Hybrid catfish: Cochasee *et al.* (2003); Rainbow trout: Watanabe *et al.* (1996); Tilapia: Watanabe *et al.* (1996);

Termite meal: Catfish: Sogbesan and Ugwumba (2008);

Mealworm: Catfish: Ng *et al.* (2001); Tilapia: Lim *et al.* (2005);

ANNELIDS/WORMS

Earthworm meal (terrestrial): Carp: Ganesh *et al.* (2003); Catfish: Sogbesan *et al.*; (2007); Sogbesan and Madu (2008); Trout: Pereira and Gomes (1955);

Polychaete worm meal (marine, produced on land): Carp: Parthiban *et al.* (2006);

MOLLUSCS/SNAILS

Garden snail: Catfish: Sogbesan *et al.* (2006); Crayfish: Jones *et al.* (1996b);

Golden apple snail: Shrimp: Bombeotuburan *et al.* (1995).

4.2 PLANT PROTEIN SOURCES**4.2.1 Cereal protein products**

Official definitions (AAFCO, 2008b)

Brewers dried grains (IFN 5-00-516 Barley brewers grains dehydrated) is the dried extracted residue of barley malt alone or in mixture with other cereal grain or grain products resulting from the manufacture of wort or beer and may contain pulverized dried spent hops in an amount not to exceed 3 percent, evenly distributed.

Barley/Cereals/Maize/Rye/Sorghum/Wheat distillers dried solubles (IFN 5-00-520 Barley distillers solubles dehydrated, IFN 5-02-147 Cereals distillers solubles dehydrated, IFN 5-02-844 Maize distillers solubles dehydrated, IFN 5-04-026 Rye distillers solubles dehydrated, IFN 5-04-376 Sorghum distillers solubles dehydrated, IFN 5-05-195 Wheat distillers solubles dehydrated) is obtained after the removal of ethyl alcohol by distillation from the yeast fermentation of a grain or a grain mixture by condensing the thin stillage fraction and drying it by methods employed in the grain distilling industry. The predominating grain must be declared as the first word in the name.

Barley/Maize/Rye/Sorghum/Wheat distillers dried grains (IFN 5-00-518 Barley distillers grains dehydrated, IFN 5-02-144 Cereals distillers grains dehydrated, IFN 5-02-842 Maize distillers grains dehydrated, IFN 5-04-023 Rye distillers grains dehydrated, IFN 5-04-3 74 Sorghum distillers grains dehydrated, IFN 5-05-193 Wheat distillers grains dehydrated) is obtained after the removal of ethyl alcohol by distillation from the yeast fermentation of a grain or a grain mixture by separating the resultant coarse grain fraction of the whole stillage and drying it by methods employed in the grain distilling industry. The predominating grain shall be declared as the first word in the name.

Barley/Maize/Rye/Sorghum/Wheat distillers dried grains with solubles (IFN 5-12-185 Barley distillers grains with solubles dehydrated, IFN 5-07-987 Cereals distillers grains with solubles dehydrated, IFN 5-02-843 Maize distillers grains with solubles dehydrated, IFN 5-04-024 Rye distillers grains with solubles dehydrated, IFN 5-04-375 Sorghum distillers grains with solubles dehydrated, IFN 5-05-194 Wheat distillers grains with solubles dehydrated) is the product obtained after the removal of ethyl alcohol by distillation from the yeast fermentation of a grain or a grain mixture by condensing and drying at least 3/4 of the solids of the resultant whole stillage by methods employed in the grain distilling industry. The predominating grain shall be declared as the first word in the name.

Corn gluten feed (IFN 5-02-903 Maize gluten with bran) is that part of the commercial shelled corn that remains after the extraction of the larger portion of the starch, gluten and germ by the processes employed in the wet milling manufacture of corn starch or syrup. It may or may not contain one or more of the following: fermented corn extractives, corn germ meal.

Corn gluten meal (IFN 5-02-900 Maize gluten meal) is the dried residue from corn after the removal of the larger part of the starch and germ, and the separation of the bran by the process employed in the wet milling manufacture of corn starch or syrup, or by enzymatic treatment of the endosperm. It may contain fermented corn extractives and/or corn germ meal.

Corn protein hydrolysed (IFN 5-02-90 1 Maize gluten hydrolysed) is the product resulting from complete hydrolysis of isolated corn gluten, and after partial removal of the glutamic acid.

Malt sprouts (IFN 5-00-545 Barley malt sprouts dehydrated, IFN 5-04-048 Rye malt sprouts dehydrated, IFN 5-29-796 Wheat malt sprouts dehydrated) is obtained from malted barley by the removal of the rootlets and sprouts which may include some of the malt hulls, other parts of malt and foreign material unavoidably present. It must contain not less than 24 percent crude protein. The term malt sprouts when applied to a corresponding portion of other malted cereals must be used in qualified form, i.e. "Rye Malt Sprouts", "Wheat Malt Sprouts", etc.

Sorghum gluten feed (IFN 5-04-3 89 Sorghum gluten with bran meal) is that part of the grain of grain sorghums that remains after the extraction of the larger part of the starch and germ, by the processes employed in the wet milling manufacture of starch or syrup.

Sorghum gluten meal (IFN 5-04-388 Sorghum gluten meal) is that part of the grain of grain sorghums that remains after the extraction of the larger part of the starch and germ, and the separation of the bran by the processes employed in the wet milling manufacture of starch or syrup.

Sorghum germ cake or grain sorghum germ meal (IFN 5-04-377 Sorghum germs meal mechanical extracted, IFN 5-12-178 Sorghum germs mechanical extracted caked) consists of the germ of grain sorghum grains from which part of the oil has been pressed and is the product obtained in the wet milling process of manufacture of starch, syrup and other grain sorghum products.

Wheat germ meal (IFN 5-05-218 Wheat germs ground) consists chiefly of wheat germ together with some bran and middlings or shorts. It must contain not less than 25 percent crude protein and 7 percent crude fat.

Wheat germ meal defatted (IFN 5-05-217 Wheat germ meal mechanical extracted) is obtained after the removal of part of the oil or fat from wheat germ. The meal must not contain less than 30 percent crude protein.

Reported proximate and essential amino acid composition

The average reported proximate and essential amino acid composition of the major protein-rich cereal products used in compound aquafeeds is shown in Table 25 and 26, respectively. In general, the major carbohydrate usually present within cereal by-products is in the form of starch granules, with linoleic and oleic acid normally being the principal unsaturated fatty acids present within the oil fraction. The crude fibre content of cereal grains is highest in those species which contain a fibrous husk or hull (i.e. 'coarse' cereal grains – oats, barley and rice), with dried brewers grains usually having the highest crude fibre content (Table 25). Cereal grains are usually rich sources of phosphorus (mainly in the form of phytates) and good sources of vitamin E and B vitamins (Tacon, 1987). However, as with most plant feedstuffs, cereal products may also contain a variety of endogenous anti-nutritional factors (see section 2.1.9). In general, cereal proteins are limiting in lysine, but are usually good sources of cystine (Table 26).

TABLE 25

Reported proximate composition of selected plant protein cereal products – values expressed as percent as-fed basis; Water-H₂O; Crude Protein-CP; Lipid or Ether Extract-EE; Crude Fibre-CF; Ash; Calcium-Ca; Phosphorus-P

Plant proteins – cereal products		H ₂ O	CP	EE	CF	Ash	Ca	P	Ref. ¹
Brewing/distillery cereal products									
Brewers grains, dehydrated (5-02-141)	min	7.7	20.8	5.7	13.2	3.6	0.29	0.24	1-3
	max	9.4	27.1	7.0	15.3	5.1	0.48	0.54	
	mean	8.4	25.9	6.4	14.3	4.3	0.36	0.44	
Distillers dried grains (DDG) (barley/corn/maize/rye/sorghum/wheat)	min	6.0	20.9	3.5	8.0	1.8	0.09	0.39	1-4
	max	10.5	31.8	11.6	12.7	6.0	0.14	0.70	
	mean	8.2	27.1	8.0	11.2	3.8	0.13	0.57	
Distillers dried solubles (DDS) (barley/corn/maize/rye)	min	5.1	26.5	0.2	3.4	7.2	0.32	0.61	1-4
	max	9.4	35.1	11.3	5.4	9.0	0.37	1.27	
	mean	6.8	28.7	6.0	4.3	7.9	0.34	1.10	
Distillers dried grains with solubles (DDGS) (barley/corn/maize/rye/sorghum)	min	5.0	26.7	4.1	8.1	4.2	0.14	0.65	1-4
	max	10.2	33.2	10.0	10.9	6.4	0.24	0.92	
	mean	8.2	28.4	8.5	9.4	4.9	0.17	0.75	
Malt sprouts (culms), dehydrated		8.4	25.4	1.7	14.3	4.3	0.36	0.44	1
Corn/maize protein meals									
Corn gluten feed	min	9.9	23.7	2.4	7.1	5.8	0.20	0.64	1-2
	max	10.3	24.7	3.5	9.4	7.0	0.30	0.80	
	mean	10.1	24.2	2.9	8.2	6.4	0.25	0.72	
Corn gluten meal	min	7.3	42.7	2.0	1.5	1.2	0.10	0.40	1-6
	max	9.9	62.6	7.7	4.4	3.2	0.20	0.48	
	mean	8.6	56.1	4.0	2.9	2.1	0.15	0.44	
Corn germ meal		4.5	47.4	8.5	6.4	0.8	-	-	5
Wheat protein meals									
Wheat germ meal	min	6.0	25.0	4.3	3.0	4.5	0.05	0.98	1,2, 5-7
	max	11.3	28.5	8.8	3.5	4.9	0.06	1.05	
	mean	9.7	26.6	7.3	3.3	4.7	0.05	1.01	
Wheat gluten meal	min	8.6	80.0	0.8	0.1	0.7	0.22	0.10	1,2, 5-6
	max	8.9	80.7	1.5	0.5	1.1	-	-	
	mean	8.7	80.3	1.2	0.3	0.9	0.22	0.10	
Rice protein meals									
Rice protein meal	min	7.0	50.0	5.0	1.0	2.2	-	-	8
	max	8.0	54.0	6.0	2.0	3.0	-	-	
	mean	7.5	52.0	5.5	1.5	2.6	-	-	

¹ The data shown represent mean values from various sources, including: 1 – Tacon (1987); 2 – Hertrampf and Pascual (2000); 3 – NRC (1983); 4 – NRC (1982); 5 – Sumagaysay-Chavoso (2007); 6 – Catacutan (2002); 7 – Weimin and Mengqing (2007); 8 – Falcon Trading International (www.falconti.com/RiceProtein.htm).

TABLE 26
Reported essential amino acid (EAA) composition of selected plant protein cereal products – all values are expressed as % by weight on as-fed basis unless otherwise stated; Arginine-Arg; Cystine-Cys; Methionine-Met; Threonine-Thr; Isoleucine-Iso; Leucine-Leu; Lysine-Lys; Valine-Val; Tyrosine-Tyr; Tryptophan-Try; Phenylalanine-Phe; Histidine-His

Cereal product	Arg	Cys	Met	Thr	Iso	Leu	Lys	Val	Tyr	Try	Phe	His	Ref. ²	
Brewery/distillery cereal products														
Brewers grains, dehydrated	min	1.27	0.35	0.46	0.93	1.54	2.49	0.88	1.61	1.15	0.36	1.44	0.52	1-3
	max	1.27	0.35	0.46	0.99	1.62	2.73	0.95	1.62	1.38	0.37	1.55	0.54	
	mean	1.27	0.35	0.46	0.95	1.57	2.59	0.90	1.61	1.24	0.36	1.48	0.53	
	AA%ΣEAA	9.5	2.6	3.4	7.1	11.8	19.4	6.8	12.1	9.3	2.8	11.1	4.0	
	Amino acid score – finfish ¹	82	96	63	67	157	144	40	127	143	165	117	83	
Amino acid score – shrimp ¹	49	127	80	89	143	137	64	133	113	155	112	93		
Malt sprouts (culms), dehydrated		1.12	0.24	0.33	0.95	1.04	1.56	1.18	1.38	0.59	0.40	0.87	0.50	1
	AA%ΣEAA	11.0	2.4	3.2	9.4	10.2	15.3	11.6	13.6	5.8	3.9	8.6	4.9	
	Amino acid score – finfish	95	89	59	89	136	113	69	143	89	229	90	102	
	Amino acid score – shrimp	57	117	75	118	124	108	109	149	70	215	87	114	
Corn/maize protein products														
Corn gluten feed		0.94	0.51	0.49	0.85	0.75	2.21	0.63	1.15	0.80	0.18	0.86	0.68	1
	AA%ΣEAA	9.4	5.1	4.9	8.5	7.5	22.0	6.3	11.4	8.0	1.79	8.60	6.80	
	Amino acid score – finfish	81	189	91	80	100	163	37	120	123	105	91	142	
	Amino acid score – shrimp	49	249	116	107	91	155	59	125	97	99	87	158	
Corn gluten meal (41% prot.)		1.36	0.67	1.0	1.42	2.09	6.7	0.77	2.10	1.01	0.21	2.78	0.90	1,2
	min	1.39	0.72	1.04	1.45	2.25	7.22	0.80	2.19	1.33	0.23	2.84	0.97	
	max	1.37	0.69	1.02	1.43	2.15	7.0	0.78	2.14	1.17	0.22	2.81	0.94	
	mean	6.3	3.2	4.7	6.6	9.9	32.2	3.6	9.8	5.4	1.01	12.9	4.3	
	AA%ΣEAA	54	118	87	62	132	238	21	103	83	59	136	90	
Amino acid score – finfish	33	156	111	83	120	227	34	108	66	56	130	100		
Amino acid score – shrimp														
Corn gluten meal (60% prot.)	min	1.93	1.04	1.43	2.07	2.42	9.81	1.0	2.79	3.19	0.30	3.84	1.28	1-3
	max	2.02	1.20	1.84	2.11	2.54	10.2	1.11	3.09	3.32	0.43	3.96	1.31	
	mean	1.98	1.11	1.63	2.09	2.48	10.1	1.04	2.92	3.25	0.35	3.90	1.30	
	AA%ΣEAA	6.2	3.4	5.1	6.5	7.7	31.4	3.2	9.1	10.1	1.1	12.1	4.0	
	Amino acid score – finfish	53	126	94	61	103	232	19	96	155	65	127	83	
Amino acid score – shrimp	32	166	120	82	93	221	30	100	123	61	122	93		
Corn DDS	min	0.97	0.45	0.56	1.01	1.28	2.23	0.90	1.55	0.87	0.22	1.49	0.64	1-3
	max	1.05	0.52	0.57	1.02	1.33	2.36	1.07	1.58	0.87	0.24	1.50	0.68	
	mean	1.00	0.47	0.56	1.02	1.29	2.28	0.96	1.56	0.87	0.23	1.49	0.65	
	AA%ΣEAA	8.1	3.8	4.5	8.2	10.4	18.4	7.7	12.6	7.0	1.8	12.0	5.4	
	Amino acid score – finfish	70	141	83	77	139	136	46	133	108	106	126	112	
Amino acid score – shrimp	42	185	106	103	126	130	72	138	85	99	121	126		
Corn DDGS	min	0.96	0.29	0.50	0.93	1.09	2.23	0.65	1.50	0.70	0.10	1.39	0.64	1-3
	max	1.12	0.46	0.52	1.00	1.44	2.89	0.70	1.55	0.99	0.19	1.55	0.68	
	mean	1.04	0.38	0.51	0.97	1.31	2.51	0.68	1.52	0.80	0.15	1.48	0.65	
	AA%ΣEAA	8.7	3.2	4.2	8.1	10.9	20.9	5.7	12.7	6.7	1.2	12.3	5.4	
	Amino acid score – finfish	75	118	78	76	145	124	34	134	103	71	129	112	
Amino acid score – shrimp	45	156	99	102	132	196	53	140	81	66	124	126		
Corn DDG		0.99	0.28	0.43	0.40	0.96	2.81	0.84	1.19	0.84	0.21	0.74	0.61	1
	AA%ΣEAA	9.6	2.7	4.2	3.9	9.3	27.3	8.1	11.5	8.1	2.0	7.2	5.9	
	Amino acid score – finfish	83	100	78	37	124	202	48	121	125	118	76	123	
	Amino acid score – shrimp	50	132	99	49	113	192	76	126	98	110	73	137	
Corn germ meal		1.20	0.50	0.58	1.05	0.68	1.52	0.83	1.16	0.54	0.21	0.79	0.68	1
	AA%ΣEAA	12.3	5.1	5.9	10.8	7.0	15.6	8.5	11.9	5.5	2.2	8.1	7.0	
	Amino acid score – finfish	106	189	109	102	93	115	51	125	85	129	85	146	
	Amino acid score – shrimp	64	249	139	135	85	110	80	131	67	121	82	163	
Sorghum protein products														
Sorghum gluten feed		0.80	0.45	0.40	0.80	1.00	2.50	0.90	1.30	-	0.20	1.00	0.80	1
	AA%ΣEAA	7.9	4.4	3.9	7.9	9.8	24.6	8.9	12.8	-	2.0	9.8	7.9	
	Amino acid score – finfish	68	163	72	74	131	182	53	135	-	118	103	164	
	Amino acid score – shrimp	41	215	92	99	119	173	83	141	-	110	99	184	
Sorghum gluten meal		1.40	0.80	0.75	1.40	2.30	7.40	0.80	2.50	-	0.40	2.60	1.40	1
	AA%ΣEAA	6.4	3.7	3.4	6.4	10.6	34.0	3.7	11.5	-	1.8	11.9	6.4	
	Amino acid score – finfish	55	137	63	60	141	252	22	121	-	106	125	133	
	Amino acid score – shrimp	33	180	80	80	129	239	35	126	-	99	120	149	

TABLE 26 – CONTINUED

Cereal product	Arg	Cys	Met	Thr	Iso	Leu	Lys	Val	Tyr	Try	Phe	His	Ref. ²	
Wheat protein products														
Wheat germ meal	1.84	0.43	0.41	0.96	0.85	1.37	1.51	1.18	0.73	0.29	0.95	0.61	1	
AA% Σ EAA	16.5	3.9	3.7	8.6	7.6	12.3	13.6	10.6	6.6	2.6	8.5	5.5		
Amino acid score – finfish	142	144	68	81	101	91	81	112	101	153	89	115		
Amino acid score – shrimp	85	190	87	108	92	87	128	116	80	144	86	128		
Wheat gluten meal	2.59	1.61	1.17	1.89	2.65	5.20	1.24	2.88	2.57	0.68	3.88	1.54	4	
AA% Σ EAA	9.3	5.8	4.2	6.8	9.5	18.6	4.4	10.3	9.2	2.4	13.9	5.5		
Amino acid score – finfish	80	215	78	64	127	138	26	108	141	141	146	115		
Amino acid score – shrimp	48	283	99	85	115	131	41	113	112	133	140	128		
Rice protein products														
Rice protein concentrate	min	3.96	1.08	1.29	1.96	2.01	4.15	1.54	2.82	2.66	0.68	2.68	1.13	5
	max	4.13	1.13	1.31	2.06	2.09	4.39	1.71	2.95	2.95	0.73	2.82	1.18	
	mean	4.04	1.10	1.30	2.01	2.05	4.27	1.62	2.88	2.80	0.70	2.75	1.15	
	AA% Σ EAA	15.1	4.1	4.9	7.5	7.7	16.0	6.1	10.8	10.5	2.6	10.3	4.3	
	Amino acid score – finfish	130	152	91	71	103	118	36	114	161	153	108	90	
	Amino acid score – shrimp	78	200	116	94	94	113	57	119	128	144	104	100	

¹ Individual amino acids are expressed as % of total EAA and compared with the EAA requirement profile of farmed fish (Arg 11.6%, Cys 2.7%, Met 5.4%, Thr 10.6%, Iso 7.5%, Leu 13.5%, Val 9.5%, Tyr 6.5%, Try 1.7%, Phe 9.5% and His 4.8%; Ogino, 1980) and shrimp (Arg 19.3%, Cys 2.0%, Met 4.2%, Thr 8.0%, Iso 8.2%, Leu 14.2%, Val 9.1%, Tyr 8.2%, Try 1.8%, Phe 9.9% and His 4.3%; Tacon *et al.* 2002), respectively.

² The data shown represent mean values from various sources, including: ¹Hertrampf and Pascual (2000); 1 – Tacon (1994); 2 – NRC (1982); 3 – NRC (1983); 4 – Degussa AG, Amino Acid Database 1.1 (1997); 5 – Falcon Trading International (www.falconti.com/RiceProtein.htm).

Quality criteria and reported usage

The quality and ultimate feed value of meals derived from cereal products depends on a variety of different factors, including: (1) the basic nutrient profile of the cereal processed; (2) the brewing/fermentation process and/or heat treatment/lipid extraction processed used, including drying method; (3) the grinding and storage of the processed meal prior to usage; (4) the presence of anti-nutritional factors within the processed meal; and (5) the biological availability of the nutrients present within the meal (the latter can also be improved through the addition of specific enzymes such as phytase and limiting nutrients such as the amino acid taurine (for review, see Cheng and Hardy, 2002b; Davis and Arnold, 1995; Francis *et al.*, 2001; Galano *et al.*, 2007; Gatlin *et al.*, 2007; Gaylord *et al.*, 2007; Hertrampf and Pascual, 2000; Li *et al.*, 2000; Mahajan and Dua, 1998; Medale and Kaushik (2009); Papatryphon, 2001; Ramseyer *et al.*, 1999; Tacon, 1997).

Table 27 shows the major feeding studies that have been published to date (since 1995) concerning the use and performance of different protein-rich cereal products within compound aquafeeds under controlled experimental conditions for different cultured fish and crustaceans.

TABLE 27

Major feeding studies conducted with protein-rich cereal products in compound aquafeeds

BREWERY/DISTILLERY CEREAL PRODUCTS

Barley fermented grains: Shrimp: Molina-Poveda and Morales (2004);

Brewers grains: Crayfish: Muzinic *et al.* (2004); Tilapia: Zerai *et al.* (2008);

Corn fermentation solubles: Shrimp: Amaya *et al.* (2007a);

Corn distillers grains with solubles: Channel catfish: Robinson and Li (2008); Rainbow trout: Stone *et al.* (2005); Tilapia: Wu *et al.* (1996);

Distillers dried grains: Grass carp: Lin *et al.* (2001); Rainbow trout: Cheng *et al.* (2003); Tilapia: Tudor *et al.* (1996);

Dried distillers grains with solubles: General: Chevanan *et al.* (2009); Channel catfish: Lim *et al.* (2009); Shrimp: Roy *et al.* (2009);

TABLE 27 – CONTINUED

Malt protein flour: Carp: Yamamoto *et al.* (1996a, 1998b); Japanese flounder: Yamamoto *et al.* (1998a); Red sea bream: Yamamoto *et al.* (1996b, 1998b); Trout: Akiyama *et al.* (1995); Yamamoto *et al.* (1995, 1997, 1998b); Yellowtail: Shimeno *et al.* (1996);

Thin distillers soluble: Trout: Thiessen *et al.* (2003).

CORN/MAIZE PROTEIN PRODUCTS

Corn gluten meal: Abalone: Sales and Britz (2003); Atlantic cod: Aksnes *et al.* (2006a), Alrektsen *et al.* (2006); Hansen *et al.* (2006, 2007); Atlantic salmon: Anderson *et al.* (1992); Hatlan *et al.* (1992); Mente *et al.* (2003); Mundheim *et al.* (2004); Opstvedt *et al.* (2003b); Atlantic silver perch: Allan *et al.* (2000); Australian short-finned eel: Engin and Carter (2005); Ayu: Watanabe *et al.* (1996); Channel catfish: Brown *et al.* (1985); Robinson *et al.* (2001); Cobia: Zhou *et al.* (2004); Common carp: Watanabe *et al.* (1996); Yamamoto *et al.* (1998b); Cutthroat trout: Smith *et al.* (2004); Dourado (*Salminus brasiliensis*): Braga *et al.* (2008); European seabass: Dias *et al.* (2005); El-Ebiary *et al.* (2001); Gilthead seabream: Amerio *et al.* (1998); Kissil and Lupatsch (2003, 2004); Pereira and Oliva-Teles (2003); Robaina *et al.* (1997); Santigosa *et al.* (2008); Sitja-Bobadilla *et al.* (2005); Grass carp: Lin *et al.* (2001); Haddock: Tibbetts *et al.* (2004); Indian carps: Kaur and Saxena (2005); Japanese flounder: Kikuchi (1999); Yamamoto *et al.* (1998a); Korean rockfish: Bai *et al.* (2001); Lee (2002); Mirror carp: Davies and Gouveia (2006); Pacu (*Piaractus mesopotamicus*): Abimorad *et al.* (2008); Rainbow trout: Aksnes *et al.* (2006b, 2006c, 2006d); Arzel *et al.* (1999); Cheng and Hardy (2003); Gomes *et al.* (1995); El-Haroun and Bureau (2007); Nang Thu *et al.* (2007); Palti *et al.* (2006); Ramseyer *et al.* (1999); Santigosa *et al.* (2008); Satoh *et al.* (2002); Stone *et al.* (2005); Sugiura *et al.* (1998); Watanabe *et al.* (1996); Yamamoto *et al.* (1995, 1997, 1998b); Red sea bream: Takagi *et al.* (2000b, 2003); Yamamoto *et al.* (1998b); Short-finned eel: Engin and Carter (2005); Shrimp: Amaya *et al.* (2007a, 2007b); Striped bass: Papatryphon (2001); Small *et al.* (1999); Sunshine bass: Lewis and Kohler (2008); Tilapia: Borgeson *et al.* (2006); Goda *et al.* (2007); Guimaraes *et al.* (2008); Koprucu and Ozdemir (2005); Tudor *et al.* (1996); Watanabe *et al.* (1996); Wu *et al.* (1995a, 1995b, 1996, 2000a, 2000b); Turbot: Fournier *et al.* (2004); Regost *et al.* (1999); Yellowtail: Masumoto *et al.* (1996); Ruchimat *et al.* (1997); Watanabe *et al.* (1998, 2001);

Corn gluten feed: Tilapia: Tudor *et al.* (1996); Wu *et al.* (1996);

Corn germ meal: Grass carp: Lin *et al.* (2001).

RICE PROTEIN PRODUCTS

Rice protein concentrate: Blackspot seabream: Palmegiano *et al.* (2007); Trout: Palmegiano *et al.* (2006);

WHEAT PROTEIN PRODUCTS

Wheat gluten meal: Atlantic cod: Hansen *et al.* (2006, 2007a, 2007b); Atlantic halibut: Helland and Grisdale-Helland (2006); Atlantic salmon: Espe *et al.* (2007); Storebakken *et al.* (2000b); Atlantic silver perch: Allan *et al.* (2000); Cutthroat trout: Smith *et al.* (2004); European seabass: Robaina *et al.* (1999); Lanari *et al.* (1998); Gilthead seabream: Amerio *et al.* (1998); De Francesco *et al.* (2007); Kissil and Lupatsch (2003, 2004); Santigosa *et al.* (2008); Sitja-Bobadilla *et al.* (2005); Rainbow trout: Davies *et al.* (1997a); Nang Thu *et al.* (2007); Palti *et al.* (2006); Pfeffer *et al.* (1995); Santigosa *et al.* (2008); Sugiura *et al.* (1998); Shrimp: Brunson *et al.* (1997); Molina-Poveda and Morales (2004); Tilapia: Schneider *et al.* (2004); Turbot: Fournier *et al.* (2004).

4.2.2 Oilseed protein products

Official definitions (AAFCO, 2008b)

Canola meal (IFN 5-05-145 Canola meal prepress solvent extracted, low erucic acid, low glucosinolate; IFN 5-05-146 canola meal solvent extracted, low erucic acid, low glucosinolate) consists of the meal obtained after the removal of most of the oil, by a direct solvent or prepress solvent extraction process, from the whole seeds of the species *Brassica napus*, *Brassica campestris* or *Brassica juncea*. The oil component of which seed contains less than two percent erucic acid and the solid component of which seed contains less than 5 micromoles of alkyl glucosinolate and less than 30 micromoles of any mixture of 3-butenyl glucosinolate, 4-pentenyl glucosinolate, 2-hydroxy-3-butenyl glucosinolate and 2-hydroxy-4-pentenyl glucosinolate, and alkyl glucosinolate per gram of air dry, oil free solid. It must contain a maximum of 12 percent crude fibre and a maximum of 30 micromoles of glucosinolates per gram. Note: a method of analysis for glucosinolates is contained in the publication by J.K. Daun and D.L. McGregor, 15 December 1981, Glucosinolate Analysis of Rapeseed (Canola). Method of the Canadian Grain Commission, Grain Research Laboratory.

Coconut meal (IFN 5-01-572 Coconut kernels with coats meal mechanical extracted) is the ground residue which remains after removal of most of the oil from dried meat of coconuts by a mechanical extraction process. May also be called “Copra Meal.”

Coconut meal (IFN 5-01-573 Coconut kernels with coats meal solvent extracted) is the ground residue which remains after removal of most of the oil from dried meat of coconuts by a solvent extraction process. May also be called “Copra Meal”.

Cottonseed cake (IFN 5-01-623 Cotton seeds mechanical extracted cake 36 percent protein) is the unground product composed of the kernel and such portions of the lint, hull and oil which remain after removal of most of the oil from cottonseed by a mechanical process. It must contain not less than 36 percent crude protein. The words “mechanical extracted” are not required when listing as an ingredient in a manufactured feed.

Cottonseed flakes (IFN 5-08-820 Cotton seeds mechanical extracted flake 36 percent protein) is the unground product, composed of the kernel and such portions of the lint, hull and oil which remain after removal of the oil from cottonseed by a mechanical extraction process. It must contain not less than 36 percent crude protein. The words “mechanical extracted” are not required when listing as an ingredient in a manufactured feed.

Cottonseed flakes (IFN 5-01-629 Cotton seeds solvent extracted flake 36 percent protein), is the unground product, composed of the kernel and such portions of the lint hull, and oil which remain after removal of the oil from cottonseed by a solvent extraction process. It must contain not less than 36 percent crude protein. The words “solvent extracted” are not required when listing as an ingredient in a manufactured feed.

Cottonseed meal (5-01-625 Cotton seeds meal mechanical extracted 36 percent protein) is the product obtained by finely grinding the cake, which remains after removal of most of the oil from cottonseed by a mechanical extraction process. It must contain not less than 36 percent crude protein. It may contain an inert, non-toxic conditioning agent either nutritive or non-nutritive or any combination thereof, to reduce caking and improve flowability in an amount not to exceed that necessary to accomplish its intended effect and in no case exceed 0.5 percent. The name of the conditioning agent must be shown as an added ingredient. The words “mechanical extracted” are not required when listing as an ingredient in a manufactured feed.

Cottonseed meal (IFN 5-01-632 Cotton seeds meal solvent extracted 36 percent protein) is the product obtained by finely grinding the flakes which remain after removal of most of the oil from cottonseed by a solvent extraction process. It must contain not less than 36 percent crude protein. It may contain an inert, non-toxic conditioning agent either nutritive or non-nutritive or any combination thereof to reduce caking and improve flowability in an amount not to exceed that necessary to accomplish its intended effect and in no case exceeding 0.5 percent. The name of the conditioning agent must be shown as an added ingredient. The words “solvent extracted” are not required when listing as an ingredient in a manufactured feed.

Crambe meal (IFN 5-16-280 *Crambe abyssinica* seeds meal solvent extracted toasted) is the seed meal of *Crambe abyssinica* after the removal of oil from the seed and hull by pre-press solvent extraction or by solvent extraction alone. The resulting seed meal is heat toasted. It should conform to the restriction of glucosinolate, goitrin and nitrogen soluble as set forth in 21 CFR573, Section 310. It should have a crude protein, crude fat and a crude fibre guarantee. Myrosinase enzyme activity should be absent. It is used or intended for use in the feed of feedlot cattle as a source of protein in an amount not to exceed 4.2 percent of the total ration.

Flaxseed screenings meal (IFN 5-12-228 Flax seed screenings meal solvent extracted) is the ground product obtained after solvent extraction of part of the oil from the smaller imperfect flaxseeds, weed seeds, other oilseeds and other foreign material having feeding value, separated in cleaning flaxseed.

Ground extruded whole soybeans (IFN 5-14-005 Soybean seeds extruded ground, IFN 5-26-010 Soybean protein product chemically modified) is the meal product resulting from extrusion, by friction heat and/or steam, of whole soybeans without removing any of the component parts. It must be sold according to its crude protein, fat and fibre content.

Ground soybeans (IFN 5-04-596 Soybean seeds ground) is obtained by grinding whole soybeans without cooking or removing any of the oil.

Heat processed soybeans (IFN 5-04-597 Soybean seeds heat processed) is the product resulting from heating whole soybeans without removing any of the component parts. It may be ground, pelleted, flaked or powdered. The maximum pH rise using standard urease testing procedure should not exceed 0.10 pH units. It must be sold according to its crude protein, crude fat and crude fibre content.

Hydrolysed soy protein is made from soybean flours, concentrates or isolates, treated with an acid or a base or an enzyme and then dried.

Kibbled soybean meal (IFN 5-09-343 Soybean seeds kibbled solvent extracted) is the product obtained by cooking ground solvent extracted soybean meal under pressure and extruding from an expeller or other mechanical pressure device. It must be designated and sold according to its protein content and should contain not more than 7 percent crude fibre.

Linseed meal (IFN 5-30-287 Flax seeds meal mechanical extracted) is the product obtained by grinding the cake or chips which remain after removal of most of the oil from flaxseed by a mechanical extraction process. It must contain not more than 10% fibre.

Linseed meal (IFN 5-30-288 Flax seeds meal solvent extracted) is the product obtained by grinding the flakes which remain after removal of most of the oil from flaxseed by a solvent extraction process. It must contain not more than 10 percent fibre.

Low gossypol cottonseed meal (IFN 5-09-002 Cotton seeds low gossypol meal mechanical extracted) is a meal in which the gossypol is not more than 0.04 percent free gossypol. The words “mechanical extracted” are not required when listing as an ingredient in a manufactured feed.

Low gossypol cottonseed meal (IFN 5-09-002 Cotton seeds low gossypol meal mechanical extracted) is a meal in which the gossypol is not more than 0.04 percent free gossypol. The words “mechanical extracted” are not required when listing as an ingredient in a manufactured feed.

Mustard meal (IFN 5-12-149 Mustard seeds meal solvent extracted) is the product obtained by grinding the cake which remains after removal of some of the oil by mechanical extraction and removing most of the remaining oil by solvent extraction. Obtained from the seed of cultivated mustard plants (*Brassica* sp.).

Peanut meal (IFN 5-03-649 Peanut seeds without coats meal mechanical extracted, IFN 5-03-650 Peanut seeds without coats meal solvent extracted) is a ground product of shelled peanuts, composed principally of the kernels, with such portion of the hull, or fibre, and oil as may be left in the ordinary course of manufacture. It must contain no more than 7 percent crude fiber.

Peanut meal and hulls (IFN 5-03-655 Peanut pods with seeds meal mechanical extracted, IFN 5-03-656 Peanut pods with seeds meal solvent extracted) is a product of shelled peanuts, composed principally of the kernels and hulls, with such portion of the oil as may be left in the ordinary course of manufacture.

Rapeseed meal (IFN 5-03-870 Rapeseeds meal mechanical extracted) obtained by grinding the cake which remains after removal of most of the oil by mechanical extraction of the seed from the rapeseed plant (Brassica). It must contain a minimum of 32 percent protein and a maximum of 12 percent crude fibre.

Safflower meal (IFN 5-04-109 Safflower seeds meal mechanical extracted) is the ground residue obtained after extracting the oil from whole safflower seed by a mechanical extraction process.

Safflower meal (IFN 5-04-110 Safflower seeds meal solvent extracted) is the ground residue obtained after extracting the oil from whole safflower seed by a solvent extraction process.

Soybean feed (IFN 5-04-613 Soybean seeds low protein low carbohydrates meal solvent extracted) is the product remaining after the partial removal of protein and nitrogen free extract from dehulled solvent extracted soybean flakes. The words “Solvent Extracted” are not required when listing as an ingredient in a manufactured feed.

Soy flour (IFN 5-12-177 Soybean flour mechanical extracted, IFN 5-04-593 Soybean flour solvent extracted) is the finely powdered material resulting from the screened and graded product after removal of most of the oil from selected, sound, cleaned and dehulled soybeans by a mechanical or solvent extraction process. It must contain not more than 4.0 percent crude fibre.

Soy grits (IFN 5-12-176 Soybean grits mechanical extracted, IFN 5-04-592 Soybean grits solvent extracted) is the granular material resulting from the screened and graded product after removal of most of the oil from selected, sound, clean and dehulled soybeans by a mechanical or solvent extraction process. It must contain not more than 4.0 percent crude fibre.

Soybean meal (IFN 5-04-600 Soybean seeds meal mechanical extracted) is the product obtained by grinding the cake or chips which remain after removal of most of the oil from soybeans by a mechanical extraction process. It must contain not more than 7.0 percent crude fibre. It may contain calcium carbonate or an anti-caking agent not to exceed 0.5 percent as defined in section 87 (Special Purpose Products) to reduce caking and improve flowability. The name of the conditioning agent must be shown as an added ingredient. The words “Mechanical Extracted” are not required when listing as an ingredient in a manufactured feed.

Soybean meal (IFN 5-04-604 Soybean seeds meal solvent extracted) is the product obtained by grinding the flakes which remain after removal of most of the oil from soybeans by a solvent extraction process. It must contain not more than 7.0 percent

crude fibre. It may contain calcium carbonate or an anti-caking agent not to exceed 0.5 percent as defined in section 87 (Special Purpose Products) to reduce caking and improve flowability. The name of the conditioning agent must be shown as an added ingredient. The words “Solvent Extracted” are not required when listing as an ingredient in a manufactured feed.

Soybean meal (IFN 5-04-612 Soybean seeds without hulls meal solvent extracted) is obtained by grinding the flakes remaining after removal of most of the oil from dehulled soybeans by a solvent extraction process. It must contain not more than 3.5 percent crude fibre. It may contain calcium carbonate or an anti-caking agent not to exceed 0.5 percent as defined in section 87 (Special Purpose Products) to reduce caking and improve flowability. The name of the conditioning agent must be shown as an added ingredient. When listed as an ingredient in a manufactured feed it may be identified as “Dehulled Soybean Meal”. The words “Solvent Extracted” are not required when listing as an ingredient in a manufactured feed.

Soybean meal (Dehulled, mechanical extracted) is the product obtained by grinding of flakes that remain after removal of most of the oil from dehulled soybean seeds by mechanical extraction process. It must contain not less than 46.5 percent crude protein. It may contain calcium carbonate or an anti-caking agent not to exceed 0.5 percent as defined in section 87 (Special Purpose Products) to reduce caking and improve flowability. The name of the conditioning agent must be shown as an added ingredient. When listed as an ingredient in a manufactured feed it may be identified as “Dehulled Soybean Meal”. The words “Mechanical Extracted” are not required when listing as an ingredient in a manufactured feed.

Soy protein concentrate (IFN 5-32-183 Soybean protein concentrate) is prepared from high-quality sound, clean, dehulled soybean seeds by removing most of the oil and water soluble non-protein constituents and must contain not less than 65 percent protein on a moisture-free basis.

Soy protein isolate (IFN 5-24-811 Soybean protein isolate) is the major proteinaceous fraction of soybeans prepared from dehulled soybeans by removing the majority of non-protein components and must contain not less than 90 percent protein on a moisture-free basis.

Soybean soluble (IFN 5-09-344 Soybean solubles condensed) is the product resulting from the washing of soy flour or soybean flakes with water and acid; water, alkali and acid; or water and alcohol. The wash water is then concentrated to a solids content of not less than 50 percent.

Soybean soluble (IFN 5-16-733 Soybean solubles dehydrated) is the product resulting from the washing of soy flour or soybean flakes with water and acid; water, alkali and acid; or water and alcohol. The wash water is then dried.

Sunflower meal (IFN 5-30-033 Sunflower seeds without hulls meal mechanical extracted) is obtained by grinding the residue remaining after the extraction process.

Sunflower meal (IFN 5-30-034 Sunflower seeds without hulls meal solvent extracted) is obtained by grinding the residue remaining after extraction of most of the oil from dehulled sunflower seed by a solvent extraction process.

Sunflower meal (IFN 5-27-477 Sunflower seeds meal mechanical extracted) is obtained by grinding the residue remaining after extraction of the oil from whole sunflower seed by a mechanical extraction process.

Sunflower meal (IFN 5-30-032 Sunflower seeds meal solvent extracted) is obtained by grinding the residue remaining after extraction of most of the oil from whole sunflower seed by a solvent extraction process. The words “Mechanical Extracted” or “Solvent Extracted” are not required when listing as an ingredient in a manufactured feed.

Whole-pressed cottonseed (IFN 5-0 1-609 Cotton seeds meal mechanical extracted) is composed of sound, mature, clean, delinted and unhulled cottonseed, from which most of the oil has been removed by mechanical pressure. It must be designated and sold by its cottonseed crude protein content. If ground, it must be so designated. The words “Mechanical Extracted” are not required when listing as an ingredient in a manufactured feed.

Reported proximate and essential amino acid composition

The average reported proximate and essential amino acid composition of the major oilseed protein products commonly used in compound aquafeeds is shown in Table 28 and 29, respectively. Oilseeds differ from cereals in that lipid replaces carbohydrate as the major food reserve within the plant seed. Although some oilseeds can be used in their whole or ‘full-fat’ form within animal feeds, the majority are used in the form of defatted oilseed cakes and meals; the extracted oil being used for human consumption, animal feeding or within industrial/pharmaceutical preparations. Oilseeds are commonly defatted by using either mechanical pressure to force out the oil (hydraulic or expeller process) or through dissolution by solvent extraction with hexane or alcohol. Some oilseeds such as groundnut, cotton and sunflower are enclosed in a close fitting fibrous hull which usually requires removal by cracking and riddling (a process also known as decortication) prior to oil extraction. Oilseeds which are defatted by mechanical pressing methods are called press cakes, and on grinding are usually termed oilmeals (Tacon, 1987).

Compared with the cereal grains, the oilseeds and their oil extraction products are rich sources of protein (20 to 50 percent by weight: Medale and Kaushik, 2009) and relatively poor sources of digestible carbohydrate. Although the biological value of oilseed proteins is generally higher than that of cereal proteins, the essential amino acid pattern of oilseed proteins is usually imbalanced, with lysine, methionine and threonine usually being limiting and tryptophan and arginine being in excess of dietary requirements (Table 29). The lipid content of oilseed cakes and meals varies according to the oil extraction method employed, ranging from below 1 percent within solvent extracted oilseed meals to 8 percent within hydraulically pressed oilseed cakes. Similarly, the crude fibre content of oilseed meals varies widely depending on the removal or not of the seed coat or hulls during the production process (Table 28). Oilseeds are generally good sources of phosphorus (mainly in the form of phytates) and B vitamins (Hertrampf and Pascual, 2000), but are poor sources of calcium (with the exception of sesame), vitamin E and provitamin A (i.e. carotenes). However, the main factor affecting the nutritional value of oilseeds is the presence of endogenous anti-nutritional factors which, unless destroyed or deactivated, can seriously reduce their nutritional value to fish or shrimp (see section 2.1.9).

TABLE 28

Reported proximate composition of selected plant protein oilseed products – values expressed as percent as-fed basis; Water-H₂O; Crude Protein-CP; Lipid or Ether Extract-EE; Crude Fibre-CF; Ash; Calcium-Ca; Phosphorus-P

Plant proteins – cereal products		H ₂ O	CP	EE	CF	Ash	Ca	P	Ref. ¹
Canola/Mustard/Rapeseed products (<i>Brassica campestris</i> / <i>B. napus</i>, <i>B. juncea</i>)									
Canola meal (solvent extracted)		10.0	35.0	3.5	12.0	6.1	0.63	1.08	1
Canola protein concentrate	min	2.6	58.6	0.2	0.43	7.4	0.06	1.16	2–3
	max	7.9	67.9	0.4	7.03	10.1	1.16	1.80	
	mean	4.9	61.7	0.32	4.2	8.8	0.70	1.53	
Mustard seed (kernel)		8.3	21.5	42.8	7.9	4.7	0.03	0.55	4
Mustard oilcake (expeller, mech. extr.)	min	9.5	28.2	8.9	8.1	8.2	1.24	1.14	4–5
	max	10.8	36.3	8.9	8.2	10.2	1.24	1.14	
	mean	10.15	32.2	8.9	8.1	9.2	1.24	1.14	
Mustard seed meal (solvent extracted)		10.1	42.4	1.8	9.1	6.3	-	-	5
Rape seed (kernel)		8.2	19.2	42.0	1.4	3.7	0.3	0.6	4
Rapeseed meal (expeller mech. extr.) (5-03-870)	min	8.0	34.1	7.2	12.0	6.5	0.57	0.90	4–6
	max	8.8	35.6	7.9	12.8	6.9	0.75	1.07	
	mean	8.30	34.7	7.5	12.3	6.7	0.66	1.00	
Rapeseed meal (solvent extracted) (5-03-871)	min	7.0	37.0	1.7	11.1	6.8	0.61	0.95	4–5
	max	9.0	38.0	3.8	12.0	7.2	0.64	1.07	
	mean	8.5	37.4	2.3	11.5	7.0	0.62	1.00	
Rapeseed protein concentrate		3.6	63.0	8.0	4.7	5.9	0.76	1.92	7
Coconut products (<i>Cocos nucifera</i>)									
Coconut kernel (endosperm, meat, copra)		4.0	7.2	64.6	3.8	1.9	0.03	0.19	4
Coconut oilcake (expeller, mech. extr.)	min	8.5	20.6	6.3	12.0	5.7	0.17	0.58	4–5
	max	9.0	20.8	8.9	12.4	7.0	0.19	0.60	
	mean	8.7	20.7	7.6	12.2	6.3	0.18	0.59	
Coconut oilmeal (copra meal, solv. extr.) (5-01-573)	min	7.9	21.0	1.6	14.0	6.0	0.17	0.59	4–5
	max	9.8	22.0	6.7	17.3	9.7	0.18	0.60	
	mean	8.7	21.5	3.5	14.8	7.1	0.18	0.60	
Cotton products (<i>Gossypium</i> spp.)									
Cotton seeds (kernel), whole		7.9	20.4	20	21.1	4.3	0.14	0.64	4
Cottonseed oilcake (expeller, mech. extr.) (corticated – with hulls)	min	10.3	21.9	4.9	21.9	5.4	-	-	4–5
	max	10.7	22.9	5.6	23.4	5.7	-	-	
	mean	10.5	22.4	5.2	22.6	5.5	-	-	
Cottonseed oilcake (expeller, mech. extr.) (decorticated – without hulls) (5-01-617)	min	7.0	41.0	4.6	11.1	6.0	0.19	1.06	4–6, 8
	max	7.9	41.2	6.2	11.9	6.4	0.20	1.16	
	mean	7.6	41.1	5.6	11.4	6.2	0.19	1.10	
Cottonseed meal (solvent extracted) (corticated – with hulls)		10.0	32.9	1.7	21.8	6.0	-	-	5
Cottonseed meal (solvent extracted) (decorticated – 41% protein) (5-01-621)	min	9.2	41.2	1.2	9.7	6.5	0.16	1.09	4–6,8
	max	9.8	44.2	1.5	12.1	6.9	0.21	1.41	
	mean	9.3	42.4	1.4	11.0	6.7	0.18	1.20	
Cottonseed meal (solvent extracted) (decorticated – 50% protein) (5-07-874)	min	7.0	50.0	1.3	8.2	6.5	0.17	1.08	4,8
	max	7.5	50.3	1.6	8.2	6.6	0.18	1.16	
	mean	7.25	50.1	1.4	8.2	6.5	0.17	1.12	
Groundnut/peanut products (<i>Arachis hypogaea</i>)									
Groundnut seed (kernel) (corticated – with hulls)		7.1	20.2	36.3	14.3	2.5	-	-	4
Groundnut seed (kernel) (decorticated – without hulls)		6.5	28.4	44.7	15.9	2.3	0.07	0.39	4
Groundnut oilcake (expeller, mech. extr.) (corticated – with hulls)	min	8.9	30.2	9.1	18.1	5.4	-	-	4–5
	max	10.0	34.1	10.3	23.0	5.7	-	-	
	mean	9.45	32.1	9.7	20.5	5.5	-	-	
Groundnut oilcake (expeller, mech. extr.) (decorticated) (5-03-649)	min	7.0	46.2	5.8	6.1	5.1	0.14	0.57	4–5
	max	9.6	48.1	7.0	7.5	6.0	0.19	0.71	
	mean	8.5	46.9	6.5	6.8	5.4	0.16	0.63	
Groundnut meal (solvent extracted) (corticated – with hulls)	min	7.8	31.7	1.9	25.0	4.3	-	-	4–5
	max	8.9	32.0	2.6	29.1	5.1	-	-	
	mean	8.3	31.8	2.2	27.0	4.7	-	-	
Groundnut meal (solvent extracted) (decorticated) (5-03-650)	min	8.0	46.5	1.0	7.7	5.4	0.25	0.59	4–5, 6,8
	max	9.8	48.7	1.3	9.9	6.0	0.29	0.96	
	mean	8.8	47.8	1.1	8.6	5.7	0.27	0.72	

TABLE 28 – CONTINUED

Plant proteins – cereal products		H ₂ O	CP	EE	CF	Ash	Ca	P	Ref. ¹
Linseed/flax products (<i>Linum usitatissimum</i>)									
Linseed (kernel)		6.7	25.6	34.7	5.4	4.7	0.2	0.54	4
Linseed oilcake (expeller, mech. extr.) (5-02-045)	min	9.0	33.4	5.4	8.8	5.7	0.38	0.80	4–6
	max	9.9	34.3	5.7	9.5	6.4	0.41	0.87	
	mean	9.6	33.8	5.5	9.2	6.0	0.40	0.83	
Linseed meal (solvent extracted) (5-02-048)	min	10.0	34.1	1.3	9.1	5.8	0.37	0.80	4–6
	max	10.7	35.0	2.0	9.2	6.2	0.39	0.85	
	mean	10.2	34.6	1.6	9.1	6.0	0.38	0.82	
African oil palm products (<i>Elaeis guineensis</i>)									
Seed (kernel/nut)		7.2	9.4	47.8	5.1	1.9	0.08	0.28	4
Palm-kernel oilcake (expeller, mech. extr.)	min	10.1	16.7	7.6	14.7	3.9	0.20	0.49	4-5
	max	10.5	17.7	9.7	17.5	4.0	0.26	0.63	
	mean	10.3	17.1	8.6	16.1	3.9	0.23	0.56	
Palm-kernel meal (solvent extracted)	min	9.7	16.3	1.4	17.8	3.9	0.28	0.73	4-5
	max	10.2	18.8	1.5	21.5	4.0	0.32	0.77	
	mean	9.9	17.5	1.4	19.6	3.9	0.30	0.75	
Safflower products (<i>Carthamus tinctorius</i>)									
Safflower seed (kernel)		7.0	17.1	31.1	27.6	2.9	0.24	0.62	4
Safflower oilcake (expeller, mech. extr.) (corticated – with hulls) (5-04-109)	min	8.1	20.2	5.6	30.7	3.8	0.22	0.64	4-6
	max	9.0	21.7	6.1	32.4	4.8	0.25	0.71	
	mean	8.7	21.0	5.9	31.4	4.3	0.24	0.68	
Safflower meal (solvent extracted) (corticated – with hulls) (5-04-110)	min	8.0	22.5	1.0	30.0	4.7	0.32	0.75	4-6
	max	8.7	23.4	1.4	32.8	5.4	0.34	0.92	
	mean	8.5	23.0	1.3	31.4	5.0	0.33	0.82	
Safflower oilcake (expeller, mech. extr.) (decorticated – without hulls)	min	8.6	41.1	6.4	10.4	7.3	0.45	1.0	4-5
	max	9.3	45.2	6.9	13.6	7.3	-	-	
	mean	8.9	43.1	6.6	12.0	7.3	0.45	1.0	
Safflower meal (solvent extracted) (decorticated – without hulls)	min	8.8	42.3	1.2	11.5	7.1	0.38	0.64	4-5
	max	9.1	43.1	1.6	14.6	7.2	0.40	1.28	
	mean	8.9	42.7	1.4	13.0	7.1	0.39	0.96	
Safflower meal, decorticated, debittered		8.9	63.0	0.8	4.4	7.4	-	-	5
Sesame products (<i>Sesamum orientale/S. radiatum</i>)									
Sesame seed (kernel)		7.0	21.1	46.5	7.6	5.6	0.9	0.75	4
Sesame oilcake (expeller, mech. extr.)	min	8.0	37.0	10.6	6.4	10.4	2.1	1.2	4-5
	max	9.4	40.4	13.3	7.8	11.1	-	-	
	mean	8.7	38.7	11.9	7.1	10.7	2.1	1.2	
Sesame meal		7.6	45.0	4.8	6.7	13.0	2.33	1.29	5
Soybean products (<i>Glycine max</i>)									
Soybean seed (kernels) with hulls		8.8	24.1	10.0	17.3	6.6	-	-	4
Soybean seed (kernel) without hulls		9.1	37.8	17.8	4.9	4.8	0.25	0.59	4
Soybean seeds, full-fat (heat processed) (5-04-597)	min	5.6	35.8	17.8	3.1	4.4	0.25	0.59	4-6, 8-10
	max	10.8	38.0	20.6	5.4	5.6	0.28	0.66	
	mean	8.9	37.3	19.0	4.7	5.0	0.26	0.61	
Soybean oilcake (expeller – mech. extr.) (corticated – with hulls) (5-04-600)	min	10.0	41.6	4.8	5.4	6.0	0.20	0.61	4-6,8
	max	11.4	43.5	5.6	5.9	6.2	0.26	0.63	
	mean	10.8	42.7	5.2	5.7	6.1	0.24	0.62	
Soybean meal (solvent extracted) (corticated – with hulls) (5-20-604/637)	min	8.4	43.6	1.0	5.5	6.1	0.28	0.63	4-6, 8-9
	max	11.6	45.9	1.5	6.3	7.7	0.30	0.68	
	mean	10.3	44.7	1.3	6.0	6.7	0.29	0.65	
Soybean meal (solvent extracted) (decorticated – without hulls) (5-04-612)	min	10.0	49.0	0.8	3.0	5.6	0.25	0.63	4-6, 8
	max	10.5	49.8	0.9	3.4	5.9	0.28	0.66	
	mean	10.3	49.5	0.8	3.2	5.8	0.26	0.64	
Soybean protein concentrate (5-08-038)		8.0	84.3	0.5	0.1	3.5	0.11	0.68	4-6,8
Sunflower products (<i>Helianthus annuus</i>)									
Sunflower seed (kernel) with hulls	min	6.1	14.2	32.6	18.7	3.0	0.18	0.54	4-5
	max	7.0	18.9	36.2	27.6	3.6	0.19	0.66	
	mean	6.5	16.5	34.4	23.1	3.3	0.18	0.60	
Sunflower seed (kernel) without hulls (decorticated)		5.0	25.7	44.2	5.0	3.8	0.16	0.88	4
Sunflower oilcake (expeller – mech. extr.) (corticated – with hulls)	min	7.3	31.6	8.2	17.3	6.4	-	-	4-5
	max	7.3	35.1	8.9	24.0	6.5	-	-	
	mean	7.3	33.3	8.5	20.6	6.4	-	-	

TABLE 28 – CONTINUED

Plant proteins – cereal products		H ₂ O	CP	EE	CF	Ash	Ca	P	Ref. ¹
Sunflower oilcake (expeller – mech. extr.) (decorticated – without hulls) (5-04-738)	min	7.0	37.1	8.0	12.2	6.3	0.36	1.06	4–6
	max	7.8	41.4	9.3	12.3	6.6	0.39	1.08	
	mean	7.5	38.5	8.9	12.2	6.4	0.37	1.07	
Sunflower meal (solvent extracted) (5-09-340)		10.0	23.3	1.1	31.6	5.6	0.21	0.93	6
Sunflower meal (solvent extracted) (corticated – with hulls)		9.7	30.8	1.5	24.8	6.3	0.26	1.16	4–5
Sunflower meal (solvent extracted) (decorticated – without hulls) (5-04-739)	min	7.0	43.4	2.5	11.1	6.6	0.39	0.91	4–6,8
	max	7.7	46.3	3.2	12.5	7.6	0.43	1.30	
	mean	7.4	44.4	2.9	11.7	7.1	0.41	1.06	

¹ The data shown represent mean values from various sources, including: 1 – Hickling (2001); 2 – MCN CanPro (MCN Bioproducts, Canada: www.mcnbioproducts.com); 3 – Samah Garinger, Bio Extraction Technologies, Canada – www.bioex.com (personal communication); 4 – Tacon (1987); 5 – Hertrampf and Pascual (2000); 6 – NRC (1982); 7 – Higgs *et al.* (1994); 8 – NRC (1983); 9 – Millamena *et al.* (2002); 10 – Carrillo (2007).

TABLE 29

Reported essential amino acid (EAA) composition of selected plant protein oilseed products – all values are expressed as % by weight on as-fed basis unless otherwise stated; Arginine-Arg; Cystine-Cys; Methionine-Met; Threonine-Thr; Isoleucine-Iso; Leucine-Leu; Lysine-Lys; Valine-Val; Tyrosine-Tyr; Tryptophan-Trp; Phenylalanine-Phe; Histidine-His

Plant oilseed product	Arg	Cys	Met	Thr	Iso	Leu	Lys	Val	Tyr	Try	Phe	His	Ref. ²	
Canola/Mustard/Rapeseed products (<i>Brassica campestris/ B. napus, B. juncea</i>)														
Canola meal, solv. extr. (5-06-145)	min	2.12	0.47	0.70	1.50	1.41	2.39	2.02	1.71	0.93	0.44	1.52	1.07	1,2
	max	2.32	0.94	0.77	1.71	1.51	2.65	2.27	1.94	1.05	0.46	1.54	1.13	
	mean	2.22	0.70	0.73	1.60	1.46	2.52	2.14	1.82	0.99	0.45	1.53	1.10	
	AA%ΣEAA	12.8	4.0	4.2	9.2	8.4	14.6	12.4	10.5	5.7	2.6	8.8	6.4	
	Amino acid score – finfish ¹	110	148	78	87	112	108	74	111	88	153	93	133	
Amino acid score – shrimp ¹	66	195	99	115	102	103	116	115	69	144	89	149		
Canola protein concentrate	min	4.02	1.25	1.28	2.58	2.02	3.61	3.38	2.22	1.68	0.68	1.93	1.13	3,4
	max	4.60	1.64	1.44	2.90	3.08	5.54	4.30	3.67	11.8	1.06	3.15	2.17	
	mean	4.20	1.39	1.34	2.70	2.53	4.84	3.69	3.16	1.76	0.84	2.57	1.64	
	AA%ΣEAA	13.7	4.5	4.4	8.8	8.2	15.8	12.0	10.3	5.7	2.7	8.4	5.3	
	Amino acid score – finfish	118	167	81	83	109	117	71	108	88	159	88	110	
Amino acid score – shrimp	71	219	104	110	100	111	113	113	69	149	85	123		
Rapeseed meal, mech. extr. (5-03-870)	min	1.93	0.30	0.68	1.51	1.38	2.40	1.67	1.76	0.85	0.42	1.39	0.90	5,6
	max	1.99	0.35	0.68	1.53	1.41	2.41	1.68	1.81	0.85	0.48	1.42	0.90	
	mean	1.96	0.32	0.68	1.52	1.39	2.40	1.67	1.78	0.85	0.45	1.40	0.90	
	AA%ΣEAA	12.8	2.1	4.4	9.9	9.0	15.6	10.9	11.6	5.5	2.9	9.1	5.9	
	Amino acid score – finfish	110	78	81	93	120	115	65	122	85	170	96	123	
Amino acid score – shrimp	66	102	104	124	109	110	102	127	67	160	92	137		
Rapeseed meal, solv. extr. (5-03-871)	min	2.06	0.30	0.70	1.56	1.35	2.50	1.98	1.79	0.79	0.43	1.41	0.99	5–7
	max	2.11	0.43	0.71	1.61	1.41	2.55	2.12	1.83	0.80	0.44	1.43	1.00	
	mean	2.09	0.37	0.70	1.59	1.38	2.52	2.05	1.81	0.79	0.43	1.42	0.99	
	AA%ΣEAA	12.9	2.3	4.3	9.8	8.5	15.6	12.7	11.2	4.9	2.7	8.8	6.1	
	Amino acid score – finfish	111	85	80	92	113	115	76	118	75	159	93	127	
Amino acid score – shrimp	67	112	101	123	103	110	119	123	60	149	89	142		
Mustard oilcake, mech. extracted		2.12	0.92	0.82	1.67	1.62	2.46	3.64	1.90	-	0.48	1.43	0.93	6
	AA%ΣEAA	11.8	5.1	4.5	9.3	9.0	13.7	20.2	10.6	-	2.7	7.9	5.2	
	Amino acid score – finfish	102	189	83	88	120	101	120	112	-	159	83	108	
	Amino acid score – shrimp	61	249	106	117	109	96	189	116	-	149	80	121	
Coconut products (<i>Cocos nucifera</i>)														
Coconut kernel (endosperm) dry		1.03	0.09	0.15	0.26	0.31	0.52	0.27	0.42	0.21	0.08	0.35	0.16	6
	AA%ΣEAA	26.7	2.3	3.9	6.7	8.0	13.5	7.0	10.9	5.4	2.1	9.1	4.2	
	Amino acid score – finfish	230	85	72	63	107	100	42	115	83	123	96	87	
	Amino acid score – shrimp	138	112	92	84	97	95	66	120	66	116	92	98	
Copra meal, mech. extr.		2.31	0.26	0.32	0.65	0.80	1.33	0.58	1.00	0.50	0.19	0.82	0.35	6
	AA%ΣEAA	25.4	2.8	3.5	7.1	8.8	14.6	6.4	11.0	5.5	2.1	9.0	3.8	
	Amino acid score – finfish	219	104	65	67	117	108	38	116	85	123	95	79	
	Amino acid score – shrimp	131	136	82	89	107	103	60	121	67	116	91	88	
Copra meal, solvent extracted (5-01-573)		2.41	0.25	0.32	0.66	0.83	1.44	0.60	1.04	0.57	0.20	0.86	0.38	6,7
	AA%ΣEAA	25.2	2.6	3.3	6.9	8.7	15.1	6.3	10.9	6.0	2.1	9.0	4.0	
	Amino acid score – finfish	217	96	61	65	116	112	37	115	92	123	95	83	
	Amino acid score – shrimp	130	127	78	87	106	106	59	120	73	116	91	93	

TABLE 29 – CONTINUED

Plant oilseed product	Arg	Cys	Met	Thr	Iso	Leu	Lys	Val	Tyr	Try	Phe	His	Ref. ²
Cotton products (<i>Gossypium</i> spp.)													
Cottonseed (kernel), whole	2.67	0.37	0.31	0.78	0.78	1.41	1.05	1.10	0.69	0.30	1.24	0.65	6
AA%ΣEAA	23.5	3.2	2.7	6.9	6.9	12.4	9.2	9.7	6.1	2.6	10.9	5.7	
Amino acid score – finfish	202	118	50	65	92	92	55	102	94	153	115	119	
Amino acid score – shrimp	122	156	64	87	84	87	86	106	74	144	110	132	
Cottonseed meal, mech. extr. (5-01-617)	4.15	0.72	0.58	1.33	1.45	2.32	1.58	1.90	0.94	0.53	2.15	1.00	5-7
max	4.18	0.73	0.59	1.34	1.45	2.42	1.60	2.11	1.17	0.55	2.18	1.07	
mean	4.16	0.72	0.58	1.33	1.45	2.37	1.59	2.00	1.05	0.54	2.16	1.03	
AA%ΣEAA	21.9	3.8	3.0	7.0	7.6	12.5	8.4	10.5	5.5	2.8	11.3	5.4	
Amino acid score – finfish	189	141	55	66	101	92	50	110	85	165	119	112	
Amino acid score – shrimp	113	185	71	88	92	88	79	115	67	155	114	126	
Cottonseed meal, solv. extr. (5-01-621)	3.97	0.45	0.50	1.02	1.15	1.80	1.69	1.68	0.80	0.42	2.10	0.83	1,5-7
max	4.57	0.77	0.59	1.42	1.52	2.35	1.89	1.93	1.03	0.56	2.33	1.13	
mean	4.25	0.66	0.56	1.27	1.36	2.16	1.76	1.83	0.92	0.51	2.22	1.02	
AA%ΣEAA	22.9	3.6	3.0	6.8	7.3	11.6	9.5	9.9	5.0	2.7	12.0	5.5	
Amino acid score – finfish	197	133	55	64	97	86	56	104	77	159	126	114	
Amino acid score – shrimp	118	176	71	85	89	82	89	109	61	149	121	128	
Cottonseed meal (dehulled) solv. extr. (5-07-874)	4.83	1.05	0.76	1.66	1.48	2.28	1.70	2.16	0.81	0.62	2.62	1.21	7
AA%ΣEAA	22.8	4.9	3.6	7.8	7.0	10.8	8.0	10.2	3.8	2.9	12.4	5.7	
Amino acid score – finfish	196	181	67	74	93	80	48	107	58	171	130	119	
Amino acid score – shrimp	118	239	85	98	88	76	75	112	46	160	125	132	
Linseed/flax products (<i>Linum usitatissimum</i>)													
Linseed/flax (kernel)	2.03	0.41	0.42	0.81	0.92	1.30	0.81	1.15	0.58	0.33	1.02	0.44	6
AA%ΣEAA	19.9	4.0	4.1	7.9	9.0	12.7	7.9	11.2	5.7	3.2	10.0	4.3	
Amino acid score – finfish	171	148	76	74	120	94	47	118	88	188	105	90	
Amino acid score – shrimp	103	195	97	99	109	89	74	123	69	177	101	100	
Linseed meal, mech. extr. (5-02-045)	2.81	0.49	0.54	1.14	1.65	1.92	1.17	1.61	0.85	0.50	1.38	0.62	5,6
max	2.86	0.61	0.58	1.18	1.69	1.95	1.18	1.67	0.96	0.52	1.44	0.65	
mean	2.83	0.55	0.56	1.16	1.67	1.93	1.17	1.64	0.90	0.51	1.41	0.63	
AA%ΣEAA	18.9	3.7	3.7	7.7	11.1	12.9	7.8	10.9	6.0	3.4	9.4	4.2	
Amino acid score – finfish	163	137	68	73	148	95	46	115	92	200	99	87	
Amino acid score – shrimp	98	180	87	97	135	91	73	120	73	188	95	98	
Linseed meal, solv. extr. (5-02-048)	2.82	0.59	0.51	1.21	1.68	2.01	1.13	1.67	1.09	0.50	1.46	0.69	5,6
max	2.94	0.61	0.54	1.22	1.74	2.02	1.16	1.74	1.09	0.51	1.48	0.69	
mean	2.88	0.60	0.52	1.21	1.71	2.01	1.14	1.70	1.09	0.50	1.47	0.69	
AA%ΣEAA	18.5	3.8	3.3	7.8	11.0	12.9	7.3	10.9	7.00	3.2	9.4	4.4	
Amino acid score – finfish	159	141	61	74	147	95	43	115	108	188	99	92	
Amino acid score – shrimp	96	185	78	98	134	91	68	120	85	177	95	102	
Oil palm products (<i>Elaeis guineensis</i>)													
Oil palm seed (kernel)	1.16	0.15	0.20	0.27	0.30	0.52	0.30	0.47	0.23	0.08	0.32	0.18	6
AA%ΣEAA	27.7	3.6	4.8	6.5	7.2	12.4	7.2	11.2	5.5	1.9	7.6	4.3	
Amino acid score – finfish	239	133	89	61	53	92	43	118	85	112	80	90	
Amino acid score – shrimp	143	176	113	81	87	87	67	123	67	105	77	100	
Oil palm (kernel), solv. extr.	2.36	0.28	0.33	0.61	0.64	1.19	0.54	0.82	0.47	0.20	0.79	0.32	6
AA%ΣEAA	27.6	3.3	3.9	7.1	7.5	13.9	6.3	9.6	5.5	2.3	9.2	3.7	
Amino acid score – finfish	238	122	72	67	100	103	37	101	85	135	97	77	
Amino acid score – shrimp	143	161	92	89	91	98	59	105	67	127	93	86	
Groundnut/peanut products (<i>Arachis hypogaea</i>)													
Peanut meal, mech. extr. (5-03-649)	5.06	0.75	0.49	1.24	1.69	3.02	1.50	2.08	1.66	0.47	2.34	1.08	5,7
AA%ΣEAA	23.7	3.5	2.3	5.8	7.9	14.1	7.0	9.7	7.8	2.2	10.9	5.0	
Amino acid score – finfish	204	130	43	55	105	104	42	102	120	129	115	104	
Amino acid score – shrimp	123	171	54	73	96	99	66	106	95	121	110	116	
Peanut meal, solv. extr. (5-03-650)	4.55	0.59	0.42	1.16	1.76	2.70	1.71	1.88	1.51	0.48	2.04	0.95	1,5-7
max	5.89	0.73	0.49	1.67	1.84	3.33	1.77	2.19	2.23	0.49	2.49	1.33	
mean	5.04	0.68	0.44	1.37	1.79	3.02	1.73	1.98	1.75	0.48	2.26	1.10	
AA%ΣEAA	23.3	3.1	2.0	6.3	8.3	13.9	8.0	9.1	8.1	2.2	10.4	5.1	
Amino acid score – finfish	201	115	37	59	111	103	48	96	125	129	109	106	
Amino acid score – shrimp	121	151	47	79	101	98	75	100	98	121	105	119	
Safflower products (<i>Carthamus tinctorius</i>)													
Safflower seed (kernel)	1.28	0.21	0.14	0.45	0.61	0.92	0.46	0.72	0.35	0.14	0.53	0.35	6
AA%ΣEAA	20.8	3.4	2.3	7.3	9.9	14.9	7.5	11.7	5.7	2.3	8.6	5.7	
Amino acid score – finfish	179	126	43	69	132	110	45	123	88	135	90	119	
Amino acid score – shrimp	108	166	54	92	120	105	70	129	69	127	87	132	

TABLE 29 – CONTINUED

Plant oilseed product	Arg	Cys	Met	Thr	Iso	Leu	Lys	Val	Tyr	Try	Phe	His	Ref. ²
Safflower, undecorticated min	1.29	0.65	0.39	0.52	0.42	1.16	0.68	1.05	-	0.29	1.08	0.44	5,6
mech. extr. max	1.38	0.81	0.40	0.56	0.56	1.21	0.69	1.09	-	0.30	1.16	0.46	
(5-04-109) mean	1.34	0.73	0.39	0.54	0.49	1.19	0.68	1.07	-	0.29	1.12	0.45	
AA%ΣEAA	16.1	8.8	4.7	6.5	5.9	14.3	8.2	12.9	-	3.5	13.5	5.4	
Amino acid score – finfish	139	326	87	61	79	106	49	136	-	206	142	112	
Amino acid score – shrimp	83	429	111	81	72	101	77	142	-	193	136	126	
Safflower oilmeal, undec. solv. extr. AA%ΣEAA	1.93	0.36	0.34	0.51	0.28	1.20	0.71	1.0	-	0.27	1.0	0.50	6
Amino acid score – finfish	23.8	4.4	4.2	6.3	3.4	14.8	8.8	12.3	-	3.3	12.3	6.2	
Amino acid score – shrimp	205	163	78	59	45	110	52	129	-	194	129	129	
	123	215	99	79	41	104	82	135	-	182	124	144	
Safflower oilcake, decorticated mech. extr. AA%ΣEAA	2.75	0.7	0.79	1.36	1.60	2.44	1.04	2.15	0.95	0.68	1.75	0.91	6
Amino acid score – finfish	16.1	4.1	4.6	7.9	9.3	14.2	6.1	12.5	5.5	4.0	10.2	5.3	
Amino acid score – shrimp	139	152	85	74	124	105	36	131	85	235	107	110	
	83	200	108	99	113	100	57	137	67	221	103	123	
Safflower oilmeal, decorticated solv. extr. AA%ΣEAA	3.68	0.70	0.69	1.33	1.63	2.48	1.29	2.33	1.07	0.60	1.80	1.04	6
Amino acid score – finfish	19.7	3.8	3.7	7.1	8.7	13.3	6.9	12.5	5.7	3.2	9.7	5.6	
Amino acid score – shrimp	170	141	68	67	116	98	41	132	88	188	102	117	
	102	185	87	89	106	94	65	137	69	177	98	130	
Sesame (<i>Sesamum orientale/S. radiatum</i>)													
Sesame seed (kernel) AA%ΣEAA	2.59	0.39	0.60	0.76	0.77	1.43	0.58	0.98	0.67	0.29	0.95	0.52	6
Amino acid score – finfish	24.6	3.7	5.7	7.2	7.3	13.6	5.5	9.3	6.4	2.7	9.0	4.9	
Amino acid score – shrimp	212	137	105	68	97	101	33	98	98	159	95	102	
	127	180	134	90	89	96	52	102	78	149	91	114	
Sesame oilcake, mech. extr. min	4.75	0.71	1.15	1.44	1.47	2.74	1.01	1.85	1.52	0.54	1.77	0.98	6,8
max	4.86	0.82	1.33	1.63	1.98	3.15	1.22	2.26	1.71	0.61	2.12	1.08	
mean	4.81	0.77	1.24	1.54	1.73	2.95	1.12	2.06	1.62	0.58	1.95	1.03	
AA%ΣEAA	22.5	3.6	5.8	7.2	8.1	13.8	5.2	9.6	7.6	2.7	9.1	4.8	
Amino acid score – finfish	194	133	107	68	108	102	31	101	117	159	96	100	
Amino acid score – shrimp	116	176	137	90	98	97	49	105	92	149	92	112	
Soybean products (<i>Glycine max</i>)													
Soybean seeds (5-04-597) heat processed min	2.53	0.34	0.46	1.41	1.60	2.57	2.24	2.02	1.12	0.52	1.72	0.85	1,5-7
max	2.82	0.55	0.54	1.69	2.18	2.79	2.41	2.03	1.25	0.53	2.10	1.01	
mean	2.72	0.48	0.51	1.59	1.98	2.66	2.35	2.02	1.20	0.52	1.97	0.95	
AA%ΣEAA	14.3	2.5	2.7	8.4	10.4	14.0	12.4	10.6	6.3	2.7	10.4	5.0	
Amino acid score – finfish	123	93	50	79	139	104	74	112	97	159	109	104	
Amino acid score – shrimp	74	122	64	105	126	99	116	116	76	149	105	116	
Soybean meal, mech.extr. (5-04-600) undecorticated min	3.07	0.56	0.63	1.71	2.63	3.62	2.75	2.24	1.55	0.61	2.15	1.12	5-7
max	3.14	0.59	0.65	1.72	2.72	3.71	2.79	2.28	1.55	0.63	2.20	1.14	
mean	3.11	0.58	0.64	1.71	2.68	3.67	2.77	2.26	1.55	0.62	2.18	1.13	
AA%ΣEAA	13.6	2.5	2.8	7.5	11.7	16.0	12.1	9.9	6.8	2.7	9.5	4.9	
Amino acid score – finfish	117	93	52	71	156	118	72	104	105	159	100	102	
Amino acid score – shrimp	70	122	66	94	142	113	113	109	83	149	96	114	
Soybean meal, solv.extr. (5-04-604) undecorticated min	3.03	0.70	0.52	1.62	2.03	3.12	2.68	2.02	1.33	0.61	2.00	1.07	1,6-7
max	3.48	0.75	0.59	1.78	2.14	3.49	2.85	2.27	1.57	0.64	2.22	1.19	
mean	3.30	0.72	0.56	1.69	2.07	3.29	2.76	2.10	1.41	0.63	2.11	1.13	
AA%ΣEAA	15.2	3.3	2.6	7.8	9.5	15.1	12.7	9.6	6.5	2.9	9.7	5.2	
Amino acid score – finfish	131	122	48	74	127	112	76	101	100	171	102	108	
Amino acid score – shrimp	79	161	61	98	115	106	119	105	79	160	98	121	
Soybean meal, solv.extr. (5-04-612) dehulled min	3.67	0.73	0.68	1.89	2.14	3.63	3.08	2.45	1.68	0.60	2.44	1.22	1,5-7
max	3.74	0.75	0.71	1.94	2.46	3.73	3.17	2.55	1.77	0.69	2.54	1.23	
mean	3.69	0.74	0.70	1.92	2.32	3.69	3.12	2.52	1.74	0.66	2.47	1.22	
AA%ΣEAA	14.9	3.0	2.8	7.7	9.3	14.9	12.6	10.2	7.0	2.7	10.0	4.9	
Amino acid score – finfish	128	111	52	73	124	110	75	107	108	159	105	102	
Amino acid score – shrimp	77	146	66	97	113	105	118	112	85	149	101	114	
Soybean protein concentrate (5-08-038) min	5.00	0.92	0.88	2.74	3.14	5.10	4.28	3.35	2.31	0.77	3.39	1.79	5-7
max	7.34	1.04	1.55	3.34	4.60	6.33	5.61	4.38	3.10	0.94	4.33	2.41	
mean	5.66	1.00	1.08	2.95	3.59	5.51	4.66	3.70	2.57	0.88	3.67	1.96	
AA%ΣEAA	15.2	2.7	2.9	7.9	9.6	14.8	12.5	9.9	6.9	2.4	9.9	5.3	
Amino acid score – finfish	131	100	54	74	128	110	74	104	106	141	104	110	
Amino acid score – shrimp	79	132	68	99	117	104	117	109	84	133	100	123	9-10
Sunflower products (<i>Helianthus annus</i>)													
Sunflower seed (kernel), whole with hulls AA%ΣEAA	1.19	0.22	0.28	0.55	0.64	0.95	0.54	0.75	0.28	0.20	0.66	0.35	6
Amino acid score – finfish	18.0	3.3	4.2	8.3	9.7	14.4	8.2	11.3	4.2	3.0	10.0	5.3	
Amino acid score – shrimp	155	122	78	78	129	107	49	119	65	176	105	110	
	93	161	99	104	118	101	77	124	51	166	101	123	

TABLE 29 – CONTINUED

Plant oilseed product	Arg	Cys	Met	Thr	Iso	Leu	Lys	Val	Tyr	Try	Phe	His	Ref. ²	
Sunflower seed meal, undec (5-09-340) solvent extr.	min	2.30	0.50	0.50	1.05	1.00	1.60	1.00	1.51	-	0.33	1.15	0.55	5–6
	max	2.57	0.53	0.55	1.14	1.13	1.79	1.17	1.60	-	0.45	1.25	0.99	
	mean	2.44	0.51	0.52	1.09	1.06	1.69	1.08	1.56	-	0.39	1.20	0.77	
	AA%ΣEAA	19.8	4.1	4.2	8.8	8.6	13.7	8.8	12.6	-	3.2	9.7	6.2	
	Amino acid score – finfish	171	152	78	83	115	101	52	133	-	188	102	129	
Amino acid score – shrimp	102	200	99	110	104	96	82	138	-	177	98	144		
Sunflower seed meal, decor. (5-04-738) mech. extr.	min	3.45	0.69	0.94	1.37	1.76	2.47	1.61	2.01	1.00	0.50	1.80	0.90	5–6
	max	4.00	0.78	1.24	1.57	2.06	2.67	1.79	2.29	1.12	0.56	2.17	1.08	
	mean	3.73	0.74	1.09	1.47	1.91	2.57	1.70	2.15	1.06	0.53	1.99	0.99	
	AA%ΣEAA	18.7	3.7	5.5	7.4	9.6	12.9	8.5	10.8	5.3	2.7	10.0	5.0	
	Amino acid score – finfish	161	137	102	70	128	95	51	114	81	159	105	104	
Amino acid score – shrimp	97	180	130	93	120	91	80	119	64	149	101	116		
Sunflower seed meal, decor. (5-04-739) solvent extr.	min	3.60	0.72	0.83	1.61	1.96	2.73	1.66	2.45	0.75	0.56	2.09	0.95	1,5–7
	max	4.42	0.74	1.33	1.93	2.25	3.83	1.92	2.60	1.39	0.61	2.36	1.23	
	mean	3.99	0.73	1.11	1.75	2.13	3.26	1.80	2.55	1.18	0.59	2.24	1.10	
	AA%ΣEAA	17.8	3.2	4.9	7.8	9.5	14.5	8.0	11.4	5.3	2.6	10.0	4.9	
	Amino acid score – finfish	153	118	91	74	127	107	48	120	81	153	105	102	
Amino acid score – shrimp	92	156	115	98	115	102	75	125	64	144	101	114		

¹ Individual amino acids are expressed as % of total EAA and compared with the EAA requirement profile of farmed fish (Arg 11.6%, Cys 2.7%, Met 5.4%, Thr 10.6%, Iso 7.5%, Leu 13.5%, Val 9.5%, Tyr 6.5%, Try 1.7%, Phe 9.5% and His 4.8%; Ogino, 1980) and shrimp (Arg 19.3%, Cys 2.0%, Met 4.2%, Thr 8.0%, Iso 8.2%, Leu 14.2%, Val 9.1%, Tyr 8.2%, Try 1.8%, Phe 9.9% and His 4.3%; Tacon *et al.*, 2002), respectively.

² The data shown represent mean values from various sources, including: 1 – NRC (1993); 2 – Hickling (2001); 3 – MCN CanPro (MCN Bioproducts, Canada: www.mcnbioproducts.com); 4 – Samah Garinger, Bio Extraction Technologies, Canada – www.bioexx.com (personal communication); 5 – NRC (1982); 6 – Tacon (1987); 7 – NRC (1983); 8 – Degussa AG, Amino Acid Database 1.1 (1997); 9 – Forster *et al.* (2002); 10 – Profine VF/F (www.solae.com).

Quality criteria and reported usage

As with cereals, the quality and ultimate feed value of oilseed meals depends upon a variety of interlinked factors, including: (1) the nutritional profile of the oilseed processed; (2) the lipid extraction process and/or heat treatment/cooking process used; (3) the grinding, dehulling, drying and storage of the processed meal prior to usage; (4) the presence or not of anti-nutritional factors within the final processed meal (depending upon processing method); and (5) the biological availability of the nutrients present within the meal (for review, see Allan and Booth (2004); Arndt *et al.* (1999); Barrows *et al.* (2007); Francis *et al.*, 2001; Gatlin *et al.*, 2007; Glencross *et al.*, 2004a, 2004b; Hertrampf and Pascual, 2000; Li *et al.*, 2000; Swick, 2002; Tacon, 1997). For example, Table 30 gives the recommended quality control parameters for soybean meal.

Table 31 shows the major feeding studies that have been published to date (since 1995) concerning the use and performance of different major oilseed products and meals within compound aquafeeds under controlled experimental conditions for different cultured fish and crustaceans.

TABLE 30
Recommended quality control parameters for soybean meal

Parameter	Value
Ash	< 7.5%
Acid-insoluble ash	< 1.0%
Lysine	> 2.9%
Protein solubility in 0.2% KOH	73 – 85%
Protein dispersibility index	15 – 40%
Urease activity	0.02 – 0.3 increase in pH
Trypsin inhibitor activity	< 4 mg/g meal
Density	67 – 74g/100ml
Texture	Homogeneous, free-flowing
Contaminants	Free of urea, ammonia, mycotoxins and fungi

Source: Carrillo (2007).

TABLE 31

Major feeding studies conducted with plant oilseed products in compound aquafeeds

CANOLA/MUSTARD/RAPE SEED PRODUCTS

Canola meal: Abalone: Sales and Britz (2002, 2003); Atlantic cod: Tibbetts *et al.* (2006); Channel catfish: Lim *et al.* (1998); Webster *et al.* (1997); Indian major carps: Abbas *et al.* (2008); Pacu: Viegas *et al.* (2008); Redclaw crayfish: Pavasovic *et al.* (2007); Red seabream: Glencross *et al.* (2004a, 2004b); Salmon: Sajjadi and Carter (2004); Shrimp: Buchanan *et al.* (1997); Cruz-Suarez *et al.* (2001); Lim *et al.* (1997); Silver perch: Allan and Booth (2004); Rowland *et al.* (2007); Striped bass (hybrid): Gaylord *et al.* (2004); Sunshine bass: Webster *et al.* (2000); Tilapia: Abdul-Aziz *et al.* (1999); Furuya *et al.* (1997, 2001); Soares *et al.* (2001); Trout: Brown *et al.* (2003); Burel *et al.* (2001); Cheng and Hardy (2002b); Drew *et al.* (2005); Mwachireya *et al.* (1999); Shafaeipour *et al.* (2008); Thiessen *et al.* (2003);

Canola protein concentrate: Atlantic cod: Tibbetts *et al.* (2006); Gilthead seabream: Kissil *et al.* (1997, 2000); Red seabream: Glencross *et al.* (2004a); Tilapia: Borgeson *et al.* (2006); Trout: Drew (2004); Drew *et al.* (2007); Forster *et al.* (1999); Stickney *et al.* (1996); Thiessen *et al.* (2004); Winter flounder: Ramsay *et al.* (2000);

Mustard seed oilcake: Common carp: Hasan *et al.* (1997b); Mullet: Sawant *et al.* (2005); Silver barb: Mohanta *et al.* (2007, 2008);

Rapeseed meal: Catla: Gangadhara *et al.* (2002); European seabass: Lanari and D'Agaro (2005) Lanari *et al.* (1998); Gilthead sea bream: Amerio *et al.* (1998); Santigosa *et al.* (2008); Takii *et al.* (1999); Grass carp: Lin *et al.* (2001); Japanese seabass: Chang *et al.* (2004); Sturgeon: Mazurkiewicz and Rozek (2006); Synechogobius (Gobiidae): Luo *et al.* (2009); Trout: Burel *et al.* (2000, 2001); Santigosa *et al.* (2008); Turbot: Burel *et al.* (2000);

Rapeseed protein concentrate: Gilthead seabream: Kissil *et al.* (1997, 2000); Trout: Teskeredzic *et al.* (1995);

COCONUT/COPRA PRODUCTS

Copra meal: Common carp: Hasan *et al.* (1997b); Rohu: Mukhopadhyay (2000), Mukhopadhyay and Ray (1999c); Tilapia: Olude *et al.* (2008);

COTTON SEED PRODUCTS

Cottonseed cake/meal: Abalone: Sales and Britz (2003); African catfish: Imorou Toko *et al.* (2008); Middendorp (1995a, 1995b); Toko *et al.* (2008b); Channel catfish: Barros *et al.* (2000, 2002); Lee *et al.* (2008b); Robinson and Tiersch (1995); Robinson and Li (2008); Yildirim-Aksoy *et al.* (2004); Grass carp: Lin *et al.* (2001); Japanese seabass: Chang *et al.* (2004); Olive flounder: Lim and Lee (2008); Pham *et al.* (2007); Parrot fish: Lim and Lee (2009); Red drum: McGoogan and Reigh (1996); Rohu: Usmani *et al.* (1997); Shrimp: Divakaran and Velasco (2002); Lim (1996); Striped bass: Sullivan and Reigh (1995); Tilapia: El-Saidy and Gaber (2003, 2004); Guimaraes *et al.* (2008); Mbahinzireki *et al.* (2001); Ofojekwu *et al.* (2003); Rincharde *et al.* (2002); Salaro *et al.* (1999a, 1999b); Sintayehu *et al.* (1996); Yue and Zhou (2008); Trout: Blom *et al.* (2001); Cheng and Hardy (2002c); Lee (2002); Lee *et al.* (2002, 2005, 2006); Luo *et al.* (2006); Morales *et al.* (1999); Rincharde *et al.* (2003a, 2003b); Vundu catfish: Toko *et al.* (2008);

GROUNDNUT/PEANUT PRODUCTS

Peanut meal: Abalone: Sales and Britz (2002); Common carp: Hasan *et al.* (1997b); Grouper: Lin *et al.* (2004); Japanese seabass: Chang *et al.* (2004); Mullet: Sawant *et al.* (2005); Shrimp: Lim (1997); Silver barb: Mohanta *et al.* (2007, 2008); Silver perch: Rowland *et al.* (2007); Striped bass (hybrid): Gaylord *et al.* (2004); Synechogobius (Gobiidae): Luo *et al.* (2009); Trout: Adelizi *et al.* (1998);

Peanut leaf meal: Tilapia: Garduno-Lugo and Olvera-Novoa (2008);

AFRICAN OIL PALM PRODUCTS

Palm kernel meal (including fermented products): General: Ezieshi and Olomu (2007); Hem *et al.* (2008); Asian seabass: Mohammed-Suhaimi *et al.* (2006); Hybrid Asian-African catfish: Ng and Chen (2002a); Labeo (cyprinid): Omoregie (2001); Tilapia: de Oliveira *et al.* (1997, 1998); Lim *et al.* (2001, 2005); Ng and Chong (2002b); Ng *et al.* (2002); Ofojekwu *et al.* (2003);

LINSEED PRODUCTS

Linseed meal: Gilthead seabream: Robaina *et al.* (1995); Rohu: Mukhopadhyay and Ray (2001); Tilapia: El-Saidy and Gaber (2003);

Dehulled flax: Tilapia: Borgeson *et al.* (2006);

Flax seed: Atlantic cod: Tibbetts *et al.* (2006);

MACADAMIA PRODUCTS

Macadamia presscake: Tilapia: Balogun and Fagbenro (1995);

MUCUNA PRODUCTS (*Mucuna pruriens var. utilis*)

Seed meal: Common carp: Siddhuraju and Becker (2001);

TABLE 31 – CONTINUED

SALSEED PRODUCTS (*Shorea robusta*)

Seed meal: Rohu: Mukhopadhyay and Ray (1996, 1997);

SESAME PRODUCTS

Sesame seed meal: Common carp: Hasan *et al.* (1997b); Grass carp: Lin *et al.* (2001); Rohu: Mukhopadhyay and Ray (1999a, 1999b); Shrimp: Fraga *et al.* (1996); Silver barb: Mohanta *et al.* (2007); Trout: Nang Thu *et al.* (2007);

SOYBEAN SEED PRODUCTS

Soybean meal: Abalone: Britz (1996); Bautista-Teruel *et al.* (2003b); Cho *et al.* (2008); Lee *et al.* (2004); Sales and Britz (2003); Shipton and Britz (2000, 2001); African catfish: Balogun *et al.* (1997); Davies and Gouveia (2008); Fafioye *et al.* (2005); Fagbenro, 1999; Fagbenro and Davies (2001); Fagbenro *et al.* (1997); Goda *et al.* (2007b); Hoffman *et al.* (1997); Imorou Toko *et al.* (2008); Toko *et al.* (2008b); van Weerd *ET AL.* (1999); Asian seabass: Boonyaratpalin *et al.* (1998); Tantikitti *et al.* (2005); Atlantic cod: Aksnes *et al.* (2006a); Forde-Skjaervik *et al.* (2006); Hansen *et al.* (2007b); Lilleeng *et al.* (2007b); Refstie *et al.* (2001, 2006b); Ringo *et al.* (2006); Tibbetts *et al.* (2006); Atlantic halibut: Grisdale-Helland *et al.* (2002a); Black sea turbot: Ergun *et al.* (2008); Catla: Patnaik *et al.* (2005); Channel catfish: Barros *et al.* (2002); Belal and Assem (1995); Cai and Burtle (1996); Evans *et al.* (2005); Lim *et al.* (1998); Peres *et al.* (2003); Rab *et al.* (2008); Robinson and Li (2008); Twibell and Wilson (2004); Webster *et al.* (1995); Chinese longsnout catfish: Xie *et al.* (1998); Chinese mitten crab: Chen *et al.* (1994); Cobia: Chou *et al.* (2004); Romarheim *et al.* (2008b); Wang *et al.* (2005); Zhou *et al.* (2005); Colossoma: Van der Meer *et al.* (1996, 1997); Common carp: Appleford and Anderson (1997a); Jahan *et al.* (2003); Jiang and Zhou (2005a); Uran *et al.* (2008b); Crayfish: Colmenares (2003); Garcia-Ulloa *et al.* (2003); Jones *et al.* (1996a, 1996b); Muzinic *et al.* (2004); Cuneate drum: Wang *et al.* (2006); Egyptian sole: Bonaldo *et al.* (2006); European sea bass: Bonaldo *et al.* (2008); Lanari and D'Agaro (2005); Lanari *et al.* (1998); Tibaldi *et al.* (2006); Freshwater prawn: Du and Niu (2003); Garcia-Ulloa *et al.* (2008); Gomez *et al.* (2008); General: Li *et al.* (2007); Sorensen *et al.* (2009); Giant gourami: Suprayudi *et al.* (2000); Gibel carp: Zhou *et al.* (2002); Gilthead sea bream: Amerio *et al.* (1998); Bonaldo *et al.* (2008); Dias *et al.* (2009); Martinez-Llorens *et al.* (2007, 2009); Nengas *et al.* (1996); Robaina *et al.* (1995, 1998); Venou *et al.* (2006); Grass carp: Lin *et al.* (2001); Greenback flounder: Brandsen and Carter (1999); Grouper: Lin *et al.* (2004); Luo *et al.* (2004); Haddock: Kim *et al.* (2007); Hybrid catfish: Cochasee *et al.* (2003); Indian major carp: Garg *et al.* (2002); Jose *et al.* (2006a, 2006b); Japanese flounder: Kikuchi (1999b); Masumoto *et al.* (2001); Ng and Chen (2002); Pham *et al.* (2007); Japanese seabass: Chang *et al.* (2004); Japanese seaperch: Hu *et al.* (1995); Pan *et al.* (2000); Jian carp: Jiang and Zhou (2005a); Korean rockfish: Lee and Jeon (1996); Lee *et al.* (1996); Lim *et al.* (2004); Yoo *et al.* (2005); Lobster: Floreto *et al.* (2000); Milkfish: Chien *et al.* (2007); Mud crab: Truong *et al.* (2009); Mullet: Kalla *et al.* (2003); Sawant *et al.* (2005); Murray cod: Abery *et al.* (2002); Olive flounder: Bai *et al.* (2005); Choi *et al.* (2004); Kim *et al.* (2008); Lim and Lee (2008); Sun *et al.* (2007); Pacu (*Piaractus mesopotamicus*): Abimorad *et al.* (2008); Ostaszewska *et al.* (2005); Red drum: Burr *et al.* (2008); Davis and Arnold (2004); Davis *et al.* (1995); McGoogan and Reigh (1996); McGoogan and Gatlin (1997); Red snapper: Davis *et al.* (2005); Catacutan and Pagador (2004); Rohu: Devi *et al.* (1998, 1999); Khan *et al.* (2003); Salmon: Arndt *et al.* (1999); Bakke-McKellep *et al.* (2000, 2006); Bergheim and Sveier (1995); Bjerkgeng *et al.* (1997); Bureau *et al.* (1998); Buttle *et al.* (2001); Froystad *et al.* (2008); Haard *et al.* (1996); Hemre *et al.* (2005); Kraugeerud *et al.* (2007); Krogdahl *et al.* (2000, 2003); Lilleeng *et al.* (2007a); Nordrum *et al.* (2000); Olli and Krogdahl (1995); Olli *et al.* (1995); Refstie *et al.* (1998, 2005, 2006a); Sissener *et al.* (2009); Storebakken *et al.* (1998); Uran *et al.* (2008a, 2008c); Red sea bream: Biswas *et al.* (2007); Sharpnose seabream: Hernandez *et al.* (2007); Rondan *et al.* (2004); Short-finned eel: Engin and Carter (2005); Shrimp: Abe *et al.* (2008); Alvarez *et al.* (2007); Cabanillas-Beltran *et al.* (2001); Cruz-Suarez *et al.* (2009); Divakaran *et al.* (2000); Divakaran and Velasco (2002); Fraga *et al.* (1996); Gallardo *et al.* (2002); Samocha *et al.* (2004); Sudaryono *et al.* (1995, 1999); Valdenebro-Ruiz *et al.* (2003); Villarreal *et al.* (2006); Silver barb: Mohanta *et al.* (2007, 2008); Silver perch: Allan and Booth (2004); Allan and Rowland (2005); Yang *et al.* (2005); Southern catfish: Ai and Xie (2002a, 2002b, 2005a, 2005b, 2006); Striped bass: Brown *et al.* (1997b); Papatryphon (2001); Sullivan and Reigh (1995); Sturgeon: Sener *et al.* (2006); Sunshine bass: Keembiyehetty and Gatlin (1997); Thompson *et al.* (2008); Synechogobius (Gobiidae): Luo *et al.* (2009); Tiger puffer: Kikuchi and Furuta (2009); Tilapia: Abdelghany *et al.* (1997); Adebayo *et al.* (2004); Azaza *et al.* (2009a); Borgeson *et al.* (2006); Chien *et al.* (2005); Chien and Chiu (2003); DelCarratore *et al.* (1996); El-Saidy and Gaber (2002b, 2003); Fasakin *et al.* (2005); Fontainhas-Fernandes *et al.* (1999); Gaber (2005); Goda (2007); Guimaraes *et al.* (2008); Lin *et al.* (2004); Nguyen, Davis and Saoud (2009); Nyirenda *et al.* (2000); Olvera-Novoa *et al.* (2002b); Riche *et al.* (2001); Silva *et al.* (2005); Sintayehu *et al.* (1996); Yue and Zhou (2008); Trout: Adelizi *et al.* (1998); Aksnes *et al.* (2006d); Allameh *et al.* (2007); Barrows *et al.* (2007, 2008); Bilgin *et al.* (2007); Bureau *et al.* (1998); Burrells *et al.* (1999); Buttle *et al.* (2001); Cain and Garling (1995); Chainark *et al.* (2006); Cheng *et al.* (2003, 2004b); Davies and Morris (1997); Davies *et al.* (1997a); D'Souza *et al.* (2006); Heikkinen *et al.* (2006); Hemre *et al.* (2007a); Iwashita *et al.* (2005); Kaushik *et al.* (1995); Morales *et al.* (1999); Nordrum *et al.* (2000); Ogunkoya *et al.* (2006); Ostaszewska *et al.* (2005); Pfeffer *et al.* (1995); Ramseyer *et al.* (1999); Refstie *et al.* (1997, 2000); Romarheim *et al.* (2006, 2008a); Satoh *et al.* (2002); Selden *et al.* (2001); Sugiura *et al.* (2001); Vielma *et al.* (2004); Yamamoto *et al.* (1995, 2007, 2008); Turbot: Ergun *et al.* (2008a, 2008b); Hasimoglu *et al.* (2007); Vundu catfish: Toko *et al.* (2008); Winter flounder: Ramsay *et al.* (2000); Yellow perch: Kasper *et al.* (2007); Yellowtail: Shimeno *et al.* (1995, 1996, 1997b); Takagi *et al.* (2006); Tomas *et al.* (2005);

Soybean protein concentrate: African catfish: Fagbenro and Davies (2004); Atlantic cod: Aksnes *et al.* (2006a); Hansen *et al.* (2006, 2007a, 2007b); Tibbetts *et al.* (2006); Atlantic halibut: Berge *et al.* (1999); Common carp: Cahu *et al.* (1998); Escaffre and Kaushik (1995); Escaffre *et al.* (1997); Jahan *et al.* (2003); Kim *et al.* (1998a, 1998b); Dentex: Chatzifotis *et al.* (2008); European seabass: Alexis (1997); Cahu *et al.* (1998); Dias *et al.* (2005); Gomes *et al.* (1997); Lanari *et al.* (1998); Viviani *et al.* (1998); Gilthead seabream: Alexis (1997); Amerio *et al.* (1998); Kissil and Lupatsch (2003, 2004); Kissil *et al.* (2000); Sanchez-Muroa *et al.* (2003); Viviani *et al.* (1998); Japanese flounder: Deng *et al.* (2006); Matsuoka *et al.* (2006); Mitten crab: Li *et al.* (2005, 2006); Pacu: Ostaszewska *et al.* (2005); Red drum: Davis *et al.* (1995); Red seabream: Aoki *et al.* (1996); Takagi *et al.* (2001);

TABLE 31 – CONTINUED

Salmon: Brown *et al.* (1997); Denstadi *et al.* (2007); Glencross *et al.* (2004c); Krogdahl *et al.* (2000); Refstie *et al.* (2001); Storebakken *et al.* (1998b; 2000); Sveier *et al.* (2001); **Shrimp:** Cruz-Suarez *et al.* (2009); Forster *et al.* (2002); Liu *et al.* (2002); Paripatananont *et al.* (2001); **Senegalese sole:** Aragao *et al.* (2003); **Sturgeon:** Mazurkiewicz and Rozek (2006); **Trout:** Adelizi *et al.* (1998); Aksnes *et al.* (2006d); Bureau *et al.* (1998); Escaffre *et al.* (2007); Glencross *et al.* (2004c, 2005); Kaushik *et al.* (1995); Medale *et al.* (1998); Ostaszewska *et al.* (2005); Satoh *et al.* (2002); Stickney *et al.* (1996); Vielma *et al.* (2000, 2002); **Turbot:** Day and Gonzalez (2000); **Yellowtail:** Aoki *et al.* (2001); Masumoto *et al.* (1996); Ruchimat *et al.* (1997);

Soybean protein isolate: **Atlantic cod:** Tibbetts *et al.* (2006); **Jian carp:** Jiang and Zhou (2005a, 2005b); **Shrimp:** Alam *et al.* (2005); Cruz-Suarez *et al.* (2009); **Striped bass:** Papatryphon (2001); **Sturgeon:** Ustaoglu *et al.* (2002, 2006); **Trout:** Glencross *et al.* (2005);

Soybean meal (fermented): **Parrot fish:** Kim *et al.* (2009);

SUNFLOWER SEED PRODUCTS

Sunflower meal: **Abalone:** Sales and Britz (2002, 2003); Shipton and Britz (2000, 2001); **Eel:** de la Higuera *et al.* (1999); Garcia-Gallego *et al.* (1998); **Gilthead sea bream:** Amerio *et al.* (1998); Lozano *et al.* (2007); Sanchez Lozano *et al.* (2007); **Indian major carps:** Abbas *et al.* (2005); **Salmon:** Gill *et al.* (2006); **Shrimp:** Fraga *et al.* (1996); **Silver barb:** Mohanta *et al.* (2007); **Striped bass (hybrid):** Gaylord *et al.* (2004); **Sturgeon:** Sener *et al.* (2006); **Tilapia:** El-Saidy and Gaber (2002a, 2003); Maina *et al.* (2003); Olvera-Novoa *et al.* (2002); Sintayehu *et al.* (1996); **Trout:** Morales *et al.* (1999);

Sunflower protein concentrate: **Trout:** Stickney *et al.* (1996).

4.2.3 Pulse and grain legume seed products

Official definitions (AAFCO, 2008b)

Bean seeds (IFN 5-00-594 Bean seeds, IFN 5-00-600 Bean kidney seeds, IFN 5-00-623 Bean navy seeds, IFN 5-00-624 Bean pinto seeds). Dried beans are the residue of the normal packaging and processing of dried beans for human consumption. This residue shall consist of the broken, small, shriveled and cull beans. They shall be identified by variety such as navy, northern, pinto, kidney, etc. Where further processing, such as grinding, roasting, etc., has occurred, ground, roasted or other acceptable description may be part of the name, i.e. ground roasted dried beans.

Dried beans (IFN 5-00-594 Bean seeds, IFN 5-00-600 Bean kidney seeds, IFN 5-00-623 Bean navy seeds, IFN 5-00-624 Bean pinto seeds) are the residue of the normal packaging and processing of dried beans for human consumption. This residue shall consist of the broken, small, shriveled and cull beans. They shall be identified by variety such as navy, northern, pinto, kidney, etc. Where further processing, such as grinding, roasting, etc., has occurred, ground, roasted or other acceptable description may be part of the name, i.e. ground roasted dried beans.

Guar meal (IFN 5-05-687 Guar seeds without endosperm ground) is obtained from whole guar beans after removal of most of the endosperm. If the product is heat treated, it may be designated as “heat treated” or “toasted”.

Lablab (*Lablab purpureus* or *Dolichos lablab*), also known as hyacinth bean, is an annual legume that produces forage as either hay or pasture for ruminants. Leaves and/or stems can be used as a feed ingredient if they are free of mature seed.

Sweet lupin meal is the product resulting from the grinding of the entire seed of the species *Lupinus albus* (white), *L. angustifolius* (blue) or *L. luteus* (yellow) which contain less than 0.03 percent alkaloids.

Sweet lupin meal (dehulled) is the product resulting from the grinding of seeds after mechanical removal of the hulls from the species of *Lupinus albus* (white), *L. angustifolius* (blue) or *L. luteus* (yellow) which contain less than 0.03 percent alkaloids.

Sweet lupin meal (solvent extracted) is the product obtained by grinding of the flakes after the removal of most of the oil by a solvent extraction process from the seeds of the species *Lupinus albus* (white), *L. angustifolius* (blue) or *L. luteus* (yellow) which contain less than 0.03 percent alkaloids. It must contain not more than 7 percent crude fibre.

Reported proximate and essential amino acid composition

Grain legumes, or pulses, are plant species belonging to the family Leguminosae which are cultivated for their mature seed or immature green pods and include the bambara groundnut, broad bean, chickpea, cluster bean, cowpea, grass pea, haricot bean, horse gram, hyacinth bean, jack bean, kersting's groundnut, lentil, lima bean, lupin, mung bean, pea, pigeon pea, rice bean, runner bean, sword bean, urd, velvet bean and winged bean. The two oleaginous legume crops, groundnut (*A. hypogaea*) and soybean (*G. max*), which are grown primarily for processing into edible oils and protein concentrates, have been discussed previously in section 4.2.2 under plant oilseeds products.

Grain legumes are good sources of protein (average protein content of the dry seed being 20–26 percent; Table 32), energy (either in the form of lipid or starch carbohydrates) and several B vitamins (including thiamine, riboflavin and nicotinic acid). The grain legumes are often considered as natural supplements to the cereal grains, since, although they are usually deficient in the sulphur amino acids methionine and cystine, they contain adequate amounts of lysine (cereal grains being deficient in lysine but usually containing adequate methionine and cystine; Table 33).

Quality criteria and reported usage

As with cereals and oilseeds, the nutritional quality and ultimate feed value of oilseed meals depend on numerous factors, including: (1) the nutritional profile of the pulse or grain legume processed; (2) the lipid extraction process and/or heat treatment/cooking process used; (3) the grinding, dehulling, drying and storage of the processed meal prior to usage; (4) the presence or not of anti-nutritional factors within the final processed meal; and (5) the biological availability of the nutrients present within the meal (for review, see Allan and Booth (2004); Booth *et al.* (2001); Davies and Gouveia (2008); Francis *et al.* 2001; Gatlin *et al.* 2007; Glencross *et al.* 2007a, 2007b; Hertrampf and Pascual, 2000; Li *et al.* 2000; Molina-Poveda and Lucas, 2007; Tacon, 1997).

Table 34 shows the major feeding studies that have been published to date (since 1995) concerning the use and performance of different pulse and seed grain products and meals within compound aquafeeds under controlled experimental conditions for different cultured fish and crustaceans.

TABLE 32

Reported average proximate composition of selected grain legume seed products – all values are expressed as percent by weight on as-fed basis: Water-H₂O; Crude Protein-CP; Lipid or Ether Extract-EE; Crude Fibre-CF; Nitrogen-Free Extractives-NFE; Ash; Calcium-Ca; Phosphorus-P

Grain legume/by-product	Average composition (% by weight)								Ref. ¹
	H ₂ O	CP	EE	CF	NFE	Ash	Ca	P	
<i>Pigeon pea/red gram/dahl (Cajanus cajan)</i>									
Seed (pea), mature, dry	10.0	20.1	2.1	7.5	56.1	4.2	0.17	0.30	1
<i>Jack/sword bean (Canavalia ensiformis)</i>									
Seed (bean), mature, dry	11.1	31.2	2.1	9.4	43.5	2.7	0.13	0.29	1
<i>Carob/locust bean (Ceratonia siliqua)</i>									
Seed (bean), mature, dry	13.5	7.7	0.9	7.7	67.6	2.6	0.34	0.08	1
Germ meal	10.6	40.3	4.6	3.2	36.0	5.3	0.10	0.87	1

TABLE 32 – CONTINUED

Grain legume/by-product	Average composition (% by weight)								Ref. ¹	
	H ₂ O	CP	EE	CF	NFE	Ash	Ca	P		
Chickpea/garbanzo bean/Egyptian pea/gram pea/Bengal gram (<i>Cicer arietinum</i>)										
Seed (pea), mature, dry	min	9.2	19.9	4.3	5.7	56.7	3.0	0.05	0.12	1,2
	max	10.4	20.6	4.4	7.7	64.0	3.3	0.17	0.29	
	mean	9.8	20.2	4.3	6.7	60.3	3.1	0.11	0.20	
Cluster bean (<i>Cyamopsis tetragonoloba</i>)										
Seed (bean), mature, dry		8.7	28.2	3.0	8.8	47.9	3.4	-	0.39	1
Egyptian bean/Lablab/hyacinth bean/bonavist bean (<i>Lablab purpureus/Dolichos lablab</i>)										
Seed (bean), mature, dry		9.8	23.8	0.9	5.6	56.2	3.7	0.20	0.39	1
Grass pea (<i>Lathyrus sativus</i>)										
Seed (pea), mature, dry		10.3	22.8	1.2	9.3	53.1	3.3	0.38	0.27	1
Lentil/red dahl (<i>Lens esculenta</i>)										
Seed with hulls, mature, dry		10.9	24.4	0.9	3.3	58.0	2.5	0.06	0.31	1
Seed dehulled, mature, dry		10.4	23.9	1.1	0.4	53.5	10.7	-	-	1
Lead tree/ipil-ipil (<i>Leucaena leucocephala</i>)										
Seed, mature, dry		9.0	32.6	6.8	10.4	37.2	4.0	-	-	1
Lupin (<i>Lupinus albus</i>, <i>L. angustifolius</i>, <i>L. luteus</i>, <i>L. mutabilis</i>)										
Seed, mature, dry (5-02-707)	min	9.0	29.8	3.0	12.1	16.1	2.8	0.19	0.30	1,2
	max	11.5	40.0	12.8	15.5	43.3	4.1	0.26	0.57	
	mean	10.0	34.8	6.3	14.1	31.3	3.5	0.20	0.41	
Lupin seed meal		8.5	36.5	6.6	-	-	3.1	-	0.30	6
Lupin kernel meal		9.0	49.2	9.6	-	-	3.1	-	0.40	6
Lupin protein concentrate		6.0	54.0	12.0	-	-	4.0	-	-	7
Velvet bean (<i>Mucana pruriens/M. utilis</i>)										
Seed (bean), mature, dry		8.7	24.1	3.2	7.8	52.9	3.3	0.21	0.65	1
African locust bean (<i>Parkia filicoidea</i>)										
Seed (bean), mature, dry		7.2	30.8	12.8	8.2	36.9	4.1	-	-	1
Lima bean (<i>Phaseolus lunatus</i>)										
Seed (bean), mature, dry		9.1	21.5	1.1	4.7	59.0	4.6	0.32	0.35	1
Kidney bean/navy bean/haricot bean/string or dwarf bean (<i>Phaseolus vulgaris</i>)										
Seed (bean), mature, dry (5-00-623)	min	10.5	22.6	1.3	4.2	57.0	4.1	0.16	0.48	1,3
	max	11.0	22.6	1.6	4.5	55.6	4.7	0.16	0.52	
	mean	10.7	22.6	1.4	4.3	56.3	4.4	0.16	0.50	
Pea/field pea (<i>Pisum sativum</i>)										
Seed (pea), mature, dry (5-03-600)	min	11.0	22.5	1.2	5.7	55.1	3.0	0.11	0.28	1-3
	max	11.7	23.7	1.7	6.8	64.3	3.5	0.25	0.54	
	mean	11.3	23.1	1.5	6.2	59.7	3.2	0.17	0.40	
Pea protein concentrate		10.0	55.0	2.0	-	-	6.0	0.09	0.84	8
Velvet mesquite (<i>Prosopis velutina</i>)										
Seed, mature, dry		10.0	49.7	8.0	4.0	24.3	4.0	-	-	1
Saman/rain tree/monkey pod/cow tamarind (<i>Samanea saman</i>)										
Seed, mature, dry		13.5	27.3	5.2	12.1	38.2	3.7	0.14	0.29	1
<i>Sesbania</i> (<i>Sesbania</i> spp.)										
Seed (bean), mature, dry	min	9.4	30.1	2.6	10.3	39.6	1.4	-	-	1,2
	max	12.3	32.5	6.2	10.9	51.7	5.3	-	-	
	mean	10.8	31.3	4.4	10.6	45.6	3.3	-	-	
Urd/black gram (<i>Vigna mungo</i>)										
Seed (bean), mature, dry	min	11.0	23.9	1.4	6.1	62.0	3.4	0.20	0.40	1,2
	max	-	25.8	1.7	-	-	4.4	-	-	
	mean	11.0	24.8	1.5	6.1	62.0	3.9	0.20	0.40	
Mung/green gram/golden gram (<i>Vigna radiata/Phaseolus aureus</i>)										
Seed (bean), mature, dry	min	9.0	22.1	1.0	4.8	57.4	3.9	0.10	0.35	1,2
	max	10.8	24.2	2.0	5.0	64.7	4.1	-	-	
	mean	9.9	23.1	1.5	4.9	61.0	4.0	0.10	0.35	

TABLE 32 – CONTINUED

Grain legume/by-product	Average composition (% by weight)								Ref. ¹	
	H ₂ O	CP	EE	CF	NFE	Ash	Ca	P		
Horse gram (<i>Vigna unguiculata</i>/Macrotyloma uniflorum)										
Seed, mature, dry	8.4	24.7	4.8	6.1	53.2	2.8	0.34	0.27	1	
Broad bean/horse bean (<i>Vicia faba</i>)										
Seed (bean), mature, dry	12.7	25.6	1.4	6.7	49.9	3.7	0.14	0.54	1	
Seed, mature, dehulled, dry	11.7	29.2	1.9	0.8	53.8	2.6	-	-	1	
Red bean/rice bean (<i>Vigna umbellata</i>)										
Seed (bean), mature, dry	10.0	22.6	1.4	5.8	55.9	4.3	0.34	0.36	1	
Winged bean (<i>Psophocarpus tetragonolobus</i>)										
Seed (bean), mature, dry	9.7	37.3	18.1	5.4	25.2	4.3	-	-	1	
Cowpea (<i>Vigna unguiculata</i>/V. sinensis)										
Seed (pea), mature, dry	min	7.4	22.3	0.9	1.4	58.1	3.2	0.15	0.41	1,2
	max	10.9	25.4	4.9	7.2	58.7	4.1	0.27	0.42	4
	mean	8.7	23.9	2.4	4.7	58.4	3.8	0.21	0.41	
Bambarra groundnut (<i>Voandzeia subterranea</i>)										
Seed, mature, dry	9.8	18.4	6.6	5.6	56.4	3.2	0.01	0.28	1	
Ground bean/Kerstings groundnut (<i>Kerstingiella geocarpa</i>)										
Seed (bean), mature, dry	10.9	19.7	1.6	5.1	59.7	3.0	0.16	0.40	1	

¹ 1 – Tacon (1987); 2 – Hertrampf and Pascual (2000); 3 – NRC (1982); 4 – Catacutan (2002); 5 – Molina-Poveda and Lucas (2007); 6 – Glencross *et al.* (2007a); 7 – Lupin protein concentrate (NaProLup P56-H125; www.naprofood.de); 8 – Pea protein concentrate 55 (AgriMarinNutrition; www.agrimarin.com).

TABLE 33

Reported essential amino acid (EAA) composition of selected pulse and grain legume seed products – all values are expressed as % by weight on as-fed basis unless otherwise stated; Arginine-Arg; Cystine-Cys; Methionine-Met; Threonine-Thr; Isoleucine-Iso; Leucine-Leu; Lysine-Lys; Valine-Val; Tyrosine-Tyr; Tryptophan-Trp; Phenylalanine-Phe; Histidine-His)

Pulse/grain	Average EAA composition (%)												Ref. ²	
	Arg	Cys	Met	Thr	Iso	Leu	Lys	Val	Tyr	Try	Phe	His		
Pigeon pea (<i>C. cajan</i>)	1.01	0.20	0.11	0.61	0.65	1.32	1.61	0.75	0.42	0.12	1.73	0.78	1	
	AA% Σ EAA	10.8	2.1	1.2	6.5	7.0	14.2	17.3	8.0	4.5	1.3	18.6		8.4
	Amino acid score – finfish ¹	93	78	22	61	93	105	103	84	69	76	196		175
	Amino acid score – shrimp ¹	56	102	28	81	85	100	162	88	55	72	188		195
Jack bean (<i>C. ensiformis</i>)	1.15	0.29	0.33	1.08	0.98	1.78	1.35	1.13	0.86	0.29	1.26	0.66	1	
	AA% Σ EAA	10.3	2.6	2.9	9.7	8.8	15.9	12.1	10.1	7.7	2.6	11.3		5.9
	Amino acid score – finfish	89	96	54	91	117	118	72	106	118	153	119		123
	Amino acid score – shrimp	53	127	68	122	107	112	113	111	93	144	114		137
Chickpea (<i>C. arietinum</i>)	1.89	0.24	0.21	0.76	0.89	1.51	1.38	0.91	0.59	0.17	1.15	0.53	1	
	AA% Σ EAA	18.5	2.3	2.0	7.4	8.7	14.8	13.5	8.9	5.8	1.7	11.2		5.2
	Amino acid score – finfish	159	85	37	70	116	110	80	94	89	100	118		108
	Amino acid score – shrimp	96	112	47	93	106	104	127	98	70	94	113		121
Egyptian bean (<i>L. purpureus</i>)	1.43	0.21	0.13	0.75	0.93	1.80	1.59	1.07	0.72	0.16	1.09	0.68	1	
	AA% Σ EAA	13.5	2.0	1.2	7.1	8.8	17.0	15.1	10.1	6.8	1.5	10.3		6.4
	Amino acid score – finfish	116	74	22	67	117	126	90	106	105	88	108		133
	Amino acid score – shrimp	70	97	28	89	107	120	142	111	83	83	104		149
Lentil (<i>L. esculenta</i>)	2.10	0.22	0.19	0.96	1.04	1.85	1.74	1.21	0.79	0.23	1.27	0.66	1	
	AA% Σ EAA	17.1	1.8	1.5	7.8	8.5	15.1	14.2	9.9	6.4	1.9	10.3		5.4
	Amino acid score – finfish	147	67	28	74	113	112	84	104	98	112	108		112
	Amino acid score – shrimp	88	88	35	98	103	106	133	109	78	105	104		126
Lupin (<i>Lupinus</i> spp.)	2.96	0.43	0.24	1.14	1.37	2.24	1.65	1.26	1.10	0.31	1.15	0.81	1–2	
	AA% Σ EAA	20.2	2.9	1.6	7.8	9.3	15.3	11.2	8.6	7.5	2.1	7.8		5.5
	Amino acid score – finfish	174	107	30	74	124	113	67	90	115	123	82		115
	Amino acid score – shrimp	104	141	38	98	113	108	105	94	91	116	98		128
Lupin kernel meal (g/16g N) (<i>L. angustifolius</i>)	min	10.7	1.6	1.0	3.9	3.8	6.8	5.7	3.3	3.4	-	3.6	2.3	3
	max	10.8	1.8	1.1	4.0	3.9	6.8	6.0	3.4	3.8	-	3.8	2.4	
	mean	10.7	1.7	1.0	3.9	3.8	6.8	5.8	3.3	3.6	-	3.7	2.3	
	AA% Σ EAA	23.0	3.6	2.1	8.4	8.1	14.6	12.4	7.1	7.7	-	7.9	4.9	
	Amino acid score – finfish	198	133	39	79	108	30	74	75	118	-	83	102	
	Amino acid score – shrimp	119	176	49	105	98	38	116	78	93	-	80	114	

TABLE 33 – CONTINUED

Pulse/grain	Average EAA composition (%)												Ref. ²
	Arg	Cyt	Met	Thr	Iso	Leu	Lys	Val	Tyr	Try	Phen	His	
Velvet bean (<i>M. utilis</i>)	2.59	0.29	0.39	1.31	1.57	2.49	2.04	1.81	1.67	-	1.57	0.69	1
AA% Σ EAA	15.8	1.8	2.4	8.0	9.6	15.2	12.4	11.0	10.2	-	9.6	4.2	
Amino acid score – finfish	136	67	44	75	128	113	74	116	157	-	101	87	
Amino acid score – shrimp	82	88	57	100	117	107	116	121	124	-	97	98	
African locust bean (<i>P. filicoidea</i>)	2.03	0.38	0.31	1.01	1.29	2.22	2.09	1.54	1.17	0.29	1.53	0.87	1
AA% Σ EAA	13.8	2.6	2.1	6.9	8.7	15.1	14.2	10.4	7.9	2.0	10.4	5.9	
Amino acid score – finfish	119	96	39	65	116	112	84	109	121	118	109	123	
Amino acid score – shrimp	71	127	49	87	106	106	133	114	96	110	105	137	
Lima bean (<i>P. lunatus</i>)	1.17	0.20	0.25	0.82	0.98	1.60	1.47	1.01	0.64	0.20	1.19	0.62	1
AA% Σ EAA	11.5	2.0	2.5	8.1	9.6	15.8	14.5	9.9	6.3	2.0	11.7	6.1	
Amino acid score – finfish	99	74	46	76	128	117	86	104	97	118	123	127	
Amino acid score – shrimp	59	97	59	102	117	111	136	109	76	110	118	142	
Kidney bean (<i>P. vulgaris</i>)	1.23	0.21	0.24	0.88	0.93	1.68	1.59	1.02	0.56	0.23	1.15	0.63	1
AA% Σ EAA	11.9	2.0	2.3	8.5	9.0	16.2	15.4	9.8	5.4	2.2	11.1	6.1	
Amino acid score – finfish	103	74	43	80	120	120	92	103	83	129	117	127	
Amino acid score – shrimp	62	97	54	107	109	114	144	108	66	121	112	142	
Peafield pea (<i>P. sativum</i>)	1.39	0.19	0.23	0.93	1.05	1.72	1.48	1.15	-0.80	0.21	1.15	0.60	1-2
max	1.92	0.24	0.28	0.97	1.14	1.78	1.54	1.25	0.80	0.22	1.25	0.65	
mean	1.65	0.21	0.25	0.95	1.09	1.75	1.51	1.20	6.9	0.21	1.20	0.62	
AA% Σ EAA	14.3	1.8	2.2	8.2	9.5	15.2	13.1	10.4	106	1.8	10.4	5.4	
Amino acid score – finfish	123	67	41	77	127	113	78	109	84	106	109	112	
Amino acid score – shrimp	74	88	52	103	115	107	123	114	84	99	105	126	
Pea protein concentrate	4.83	0.62	0.41	1.85	2.15	3.75	3.75	2.35	1.58	0.49	2.56	1.30	4
AA% Σ EAA	18.8	2.4	1.6	7.2	8.4	14.6	14.6	9.2	6.2	1.9	10.0	5.1	
Amino acid score – finfish	162	89	30	68	112	30	87	97	95	112	105	106	
Amino acid score – shrimp	97	117	38	90	102	38	137	101	75	105	101	119	
Sesbania (<i>S. grandiflora</i>)	2.23	0.22	0.18	0.77	0.82	1.38	1.22	0.96	0.69	-	0.86	0.64	1
AA% Σ EAA	22.4	2.2	1.8	7.7	8.2	13.8	12.2	9.6	6.9	-	8.6	6.4	
Amino acid score – finfish	193	81	33	73	109	102	73	101	106	-	90	133	
Amino acid score – shrimp	116	107	42	97	100	97	114	105	84	-	87	149	
Urd (<i>V. mungo</i>)	1.32	0.17	0.13	0.80	1.89	1.69	1.93	0.99	0.60	0.19	1.17	0.70	1
AA% Σ EAA	11.4	1.5	1.1	6.9	16.3	14.6	16.7	8.5	5.2	1.6	10.1	6.0	
Amino acid score – finfish	98	55	20	65	217	108	99	89	80	94	106	125	
Amino acid score – shrimp	59	73	26	87	198	103	157	93	63	88	102	139	
Broad bean (<i>V. faba</i>)	2.08	0.16	0.21	0.89	0.96	1.63	1.51	1.13	0.82	0.22	1.00	0.58	1
AA% Σ EAA	18.6	1.4	1.9	7.9	8.6	14.6	13.5	10.1	7.3	2.0	8.9	5.2	
Amino acid score – finfish	160	52	35	74	115	108	80	106	112	118	94	108	
Amino acid score – shrimp	96	68	45	99	104	103	127	111	89	110	90	121	
Cowpea (<i>V. unguiculata</i>)	1.50	0.25	0.27	0.84	0.89	1.65	1.60	1.06	0.61	0.25	1.21	0.76	1
AA% Σ EAA	13.8	2.3	2.5	7.7	8.2	15.1	14.7	9.7	5.6	2.3	11.1	7.0	
Amino acid score – finfish	119	85	46	73	109	112	87	102	86	135	117	146	
Amino acid score – shrimp	71	112	59	97	100	106	138	107	68	127	112	163	
Bambarra groundnut (<i>V. subterranea</i>)	1.12	0.18	0.31	0.62	0.77	1.38	1.14	0.94	0.62	0.19	0.99	0.53	1
AA% Σ EAA	12.7	2.0	3.5	7.0	8.8	15.7	13.0	10.7	7.0	2.2	11.3	6.0	
Amino acid score – finfish	109	74	65	66	117	116	77	113	108	129	119	125	
Amino acid score – shrimp	66	97	82	88	107	111	122	117	85	121	114	139	
Ground bean (<i>K. geocarpa</i>)	1.25	0.19	0.27	0.74	0.87	1.48	1.28	1.21	0.68	0.15	1.12	0.54	1
AA% Σ EAA	12.8	1.9	2.8	7.6	8.9	15.1	13.1	12.4	6.9	1.5	11.4	5.5	
Amino acid score – finfish	110	70	52	72	119	112	78	130	106	88	120	115	
Amino acid score – shrimp	66	93	66	95	108	106	123	136	84	83	115	128	

¹ Individual amino acids are expressed as % of total EAA and compared with the EAA requirement profile of farmed fish (Arg 11.6%, Cys 2.7%, Met 5.4%, Thr 10.6%, Iso 7.5%, Leu 13.5%, Val 9.5%, Tyr 6.5%, Try 1.7%, Phe 9.5% and His 4.8%; Ogino, 1980) and shrimp (Arg 19.3%, Cys 2.0%, Met 4.2%, Thr 8.0%, Iso 8.2%, Leu 14.2%, Val 9.1%, Tyr 8.2%, Try 1.8%, Phe 9.9% and His 4.3%; Tacon *et al.*, 2002), respectively.

² The data shown represent mean values from various sources, including: 1 – Tacon (1987); 2 – NRC (1982); 3 – Smith *et al.* (2007a); 4 – Pea protein concentrate (AgriMarinNutrition; www.agrimarin.com).

TABLE 34
Major feeding studies conducted with pulse and grain seed products in compound aquafeeds

BEACH-BEAN SEED MEAL PRODUCTS (*Canavalia maritima*)

Tilapia: Martinez-Palacios *et al.* (2003);

BLACK GRAM (*Phaseolus mungo*)

Rohu: Ramachandran and Ray (2007); Ray (2007);

BROAD BEAN SEED MEAL PRODUCTS

Tilapia: Gaber (2006);

CASTOR BEAN SEED MEAL PRODUCTS (*Ricinus communis*)

Grass carp: Cai *et al.* (2005);

CHICKPEA SEED MEAL PRODUCTS

European seabass: Adamidou *et al.* (2009); Silver perch: Booth *et al.* (2001);

CLUSTER BEAN SEED MEAL PRODUCTS (*Cyamopsis tetragonoloba*)

Common carp: El-Saidy *et al.* (2005);

COWPEA SEED SEED MEAL PRODUCTS

Indian major carps: Garg *et al.* (2002); Shrimp: Eusebio and Coloso (1998); Tilapia: El-Saidy and Saad (2008); Olvera-Novoa *et al.* (1997);

FABA/FIELD BEAN SEED MEAL PRODUCTS

European seabass: Adamidou *et al.* (2009); Silver perch: Booth *et al.* (2001); Tilapia: Azaza *et al.* (2009a); Fontainhas-Fernandes *et al.* (1999); Trout: Pfeffer *et al.* (1995);

GRASS PEA (*Lathyrus sativus*)

Rohu: Ramachandran *et al.* (2005);

GUAR SEED MEAL PRODUCTS (*Cyamopsis tetragonoloba*)

Indian major carp: Garg *et al.* (2002); Tilapia: Al-Hafedh and Siddiqui (1998);

JACKBEAN SEED MEAL PRODUCTS (*Canavalia ensiformis*)

African catfish hybrid: Osuigwe *et al.* (2005, 2006);

LUPIN SEED MEAL PRODUCTS

Abalone: Sales and Britz (2003); Asian seabass/barramundi: Katersky and Carter (2009); Crayfish: Fotedar (2004); Pavasovic *et al.* (2007); Gilthead seabream: Amerio *et al.* (1998); Pereira and Oliva-Teles (2004); Robaina *et al.* (1995); Haddock: Tibbetts *et al.* (2004); Red seabream: Glencross *et al.* (2003e); Glencross and Hawkins (2004); Salmon: Carter (2000); Carter and Hauler (2000); Glencross *et al.* (2004c); Refstie *et al.* (2006c); Short-finned eel: Engin and Carter (2005); Shrimp: Smith *et al.* (2007a, 2007b); Sudaryono *et al.* (1995, 1999a, 1999b, 1999c); Silver perch: Allan and Booth (2004); Rowland *et al.* (2007); Tilapia: Chien and Chiu (2003); Fontainhas-Fernandes *et al.* (1999); Trout: Burel *et al.* (1998, 2000); Farhangi and Carter (2001); Glencross *et al.* (2003a, 2003b, 2004c, 2004d, 2005, 2006, 2007a, 2007b; 2008a, 2008b); Morales *et al.* (1999); Turbot: Burel *et al.* (2000);

MUNG BEAN SEED MEAL PRODUCTS (*Vigna radiata*)

Indian major carps: Garg *et al.* (2002); Shrimp: Eusebio and Coloso (1998);

PEA/FIELD SEED MEAL PRODUCTS

African catfish: Davies and Gouveia (2008); European seabass: Gouveia and Davies (1998, 2000); Gilthead seabream: Amerio *et al.* (1998); Dias *et al.* (2009); Pereira and Oliva-Teles (2002); Santigosa *et al.* (2008); Haddock: Tibbetts *et al.* (2004); Milkfish: Borlongan *et al.* (2003); Salmon: Carter (2000); Carter and Hauler (2000); Overland *et al.* (2009); Shrimp: Bautista-Teruel *et al.* (2003a); Cruz-Suarez *et al.* (2001); Davis *et al.* (2002); Roy *et al.* (2009); Silver perch: Allan and Booth (2004); Booth *et al.* (2001); Tilapia: Fontainhas-Fernandes *et al.* (1999); Schultz *et al.* (2007); Trout: Burel *et al.* (2000); Drew *et al.* (2005); Pfeffer *et al.* (1995); Santigosa *et al.* (2008); Thiessen (2004); Thiessen *et al.* (2003a, 2003b); Turbot: Burel *et al.* (2000);

SESBANIA SEED MEAL PRODUCTS (*S. aculeate*)

Common carp: Hossain *et al.* (2001);

WINGED BEAN SEED MEAL PRODUCTS (*Psophocarpus tetragonolobus*)

African catfish: Fagbenro (1999a, 1999b, 1999c); Tilapia: Lim *et al.* (2005);

4.2.4 Miscellaneous plant protein products

Official definitions (AAFCO, 2008b)

Alfalfa meal, sun-cured (IFN 1-00-104 Alfalfa hay sun-cured chopped, IFN 1-00-090 Alfalfa hay sun-cured 13 percent protein, IFN 1-00-095 Alfalfa hay sun-cured 15 percent protein, IFN 1-00-096 Alfalfa hay sun-cured 17 percent protein, IFN 1-30-293 Alfalfa hay sun-cured 18 percent protein, IFN 1-00-088 Alfalfa hay sun-cured 20 percent protein, IFN 1-30-295 Alfalfa hay sun-cured 22 percent protein, IFN 1-00-111 Alfalfa hay sun-cured ground, IFN 1-00-112 Alfalfa hay sun-cured ground 13 percent protein, IFN 1-00-113 Alfalfa hay sun-cured ground 15 percent protein, IFN 1-00-114 Alfalfa hay sun-cured ground 17 percent protein, IFN 1-30-296 Alfalfa hay sun-cured ground 18 percent protein, IFN 1-00-116 Alfalfa hay sun-cured ground 20 percent protein, IFN 1-00-117 Alfalfa hay sun-cured ground 22 percent protein, or Pellets of Ground Alfalfa Hay) is the portion of the alfalfa plant, reasonably free of other crop plants, weeds and mold, which has been dried by solar means, stored as bales or stacks and finely or coarsely ground. If it is chopped instead of ground, it must be designated as “Sun-cured Chopped Alfalfa” or “Chopped Alfalfa Hay.”

Alfalfa meal, dehydrated (IFN 1-00-025 Alfalfa Meal dehydrated, IFN 1-00-021 Alfalfa Meal dehydrated 13 percent protein, IFN 1-00-022 Alfalfa Meal dehydrated 15 percent protein, IFN 1-00-023 Alfalfa Meal dehydrated 17 percent protein, IFN 1-30-297 Alfalfa Meal dehydrated 18 percent protein, IFN 1-00-024 Alfalfa Meal dehydrated 20 percent protein, IFN 1-07-851 Alfalfa Meal dehydrated 22 percent protein, or pellets) is the aerial portion of the alfalfa plant reasonably free of other crop plants, weeds and mold, which has been finely ground and dried by thermal means under controlled conditions.

Note: The following guarantees are recommended for the various grades of alfalfa meal and ground alfalfa hay: for 15 percent Crude protein, Crude Fibre not more than 30 percent; for 17 percent Crude Protein, Crude Fibre not more than 27 percent; for 18 percent Crude Protein, Crude Fibre not more than 25 percent; for 20 percent Crude Protein, Crude Fibre not more than 22 percent; for 22 percent Crude Protein, Crude Fibre not more than 20 percent.

Food processing waste is composed of any and all animal and vegetable products from basic food processing. This may include manufacturing or processing waste, cannery residue, production over-run and otherwise unsaleable material. The guaranteed analysis shall include the maximum moisture, unless the product is dried by artificial means to less than 12 percent moisture and designated as “Dehydrated Food Processing Waste”. If part of the grease and fat is removed, it must be designated as “Degreased”.

Potato protein is derived from destarched potato juice from which the proteinaceous fraction has been precipitated by thermal coagulation followed by dehydration.

Restaurant food waste is composed of edible food waste collected from restaurants, cafeterias and other institutes of food preparation. Processing and/or handling must remove any and all undesirable constituents including crockery, glass, metal, string and similar materials. The guaranteed analysis shall include maximum moisture, unless the product is dried by artificial means to less than 12 percent moisture and designated as “Dehydrated Restaurant Food Waste”. If part of the grease and fat is removed, it must be designated as “Degreased”.

TABLE 36 – CONTINUED

Product	Average EAA composition (%)												Ref. ²
	Arg	Cys	Met	Thr	Iso	Leu	Lys	Val	Tyr	Try	Phe	His	
Sweet potato leaf meal (g/100g protein) (<i>I. batatas</i>)	3.7	0.3	1.8	4.4	3.7	7.9	4.4	5.8	6.5	-	6.5	2.8	2
AA% Σ EAA	7.7	0.6	3.8	9.2	7.7	16.5	9.2	12.1	13.6	-	13.6	5.9	
Amino acid score – finfish	66	22	70	87	103	122	55	127	209	-	143	123	
Amino acid score – shrimp	40	29	90	115	94	116	86	133	165	-	137	137	
Chinese water spinach leaf meal (g/100g protein)	3.3	0.5	1.5	3.9	3.4	6.5	4.6	5.3	4.1	-	5.7	2.7	2
AA% Σ EAA	7.9	1.2	3.6	9.4	8.2	15.7	11.1	12.8	9.9	-	13.7	6.5	
Amino acid score – finfish	68	44	67	89	109	116	66	135	152	-	144	135	
Amino acid score – shrimp	41	58	85	118	100	111	104	141	120	-	138	151	
Acacia leaf meal (g/100g protein) (<i>Acacia</i> sp.)	2.2	0.5	0.9	2.7	2.4	4.8	2.9	3.5	3.5	-	3.8	3.9	2
AA% Σ EAA	7.1	1.6	2.9	8.7	7.7	15.4	9.3	11.2	11.2	-	12.2	12.5	
Amino acid score – finfish	61	59	54	82	103	114	55	105	172	-	128	260	
Amino acid score – shrimp	37	78	68	109	94	108	87	123	136	-	123	290	
Alfalfa leaf meal (22% protein) (<i>M. sativa</i>)	0.96	0.30	0.34	0.97	1.06	1.63	0.97	1.29	0.64	0.49	1.13	0.44	1
AA% Σ EAA	9.4	2.9	3.3	9.5	10.4	15.9	9.5	12.6	6.3	4.8	11.1	4.3	
Amino acid score – finfish	81	107	61	90	139	118	56	133	97	282	117	90	
Amino acid score – shrimp	49	141	78	119	126	112	89	138	76	265	112	100	

¹ Individual amino acids are expressed as % of total EAA and compared with the EAA requirement profile of farmed fish (Arg 11.6%, Cys 2.7%, Met 5.4%, Thr 10.6%, Iso 7.5%, Leu 13.5%, Val 9.5%, Tyr 6.5%, Try 1.7%, Phe 9.5% and His 4.8%; Ogino, 1980) and shrimp (Arg 19.3%, Cys 2.0%, Met 4.2%, Thr 8.0%, Iso 8.2%, Leu 14.2%, Val 9.1%, Tyr 8.2%, Try 1.8%, Phe 9.9% and His 4.3%; Tacon *et al.* 2002), respectively.

² The data shown represent mean values from various sources, including: 1 – Tacon (1987); 2 – Catacutan (2002).

TABLE 37

Major feeding studies conducted with miscellaneous protein sources in compound aquafeeds

ALFALFA (*M. sativa*)

Leaf protein concentrate: Tilapia: Olvera-Novoa *et al.* (2002b);

CASSAVA (*M. esculenta*)

Leaf meal: African catfish: Bureau *et al.* (1995); Shrimp: Eusebio and Coloso (1998);

GREEN MUNG BEAN (*Vigna radiata*)

Leaf meal: Shrimp: Eusebio and Coloso (1998);

HORSERADISH TREE/MALUNGGAY (*M. oliefera*)

Leaf meal: Abalone: Reyes and Fermin (2003);

JACQUIN (*Gliricidia sepium*)

Leaf meal: Tilapia: Gebeyehu *et al.* (2004);

LEAD TREE/IPIL-IPIL (*L. leucocephala*)

Leaf meal: Abalone: Reyes and Fermin (2003); Common carp: Hasan *et al.* (1997b); Rohu: Bairagi *et al.* (2004); Hasan *et al.* (1994); Tilapia: Osman *et al.* (1996);

PAPAYA (*C. papaya*)

Leaf meal: Abalone: Reyes and Fermin (2003); African catfish: Akinwande *et al.* (2007); Shrimp: Eusebio and Coloso (1998); Penaflores (1995);

POTATO PROTEIN CONCENTRATE

Gibel carp: Zhou *et al.* (2002); Gilthead seabream: Amerio *et al.* (1998); Trout: Refstie and Tiekstra (2003); Xie and Jokumsen (1997a, 1997b, 1998a, 1998b, 1999);

ROQUETTE (*Eruca sativa* Miller)

African catfish: Fagbenro (2004);

SWEET POTATO (*I. batatas*)

Leaf meal: Shrimp: Penaflores (1995);

WHITE COWPEA (*Vigna unguiculata*)

Leaf meal: Shrimp: Eusebio and Coloso (1998); Millamena and Trino (1997); Tilapia: Olvera-Novoa *et al.* (1997).

4.3 SINGLE CELL PROTEIN SOURCES

Official definitions (AAFCO, 2008b)

Active dry yeast (IFN 7-05-524 Yeast active dehydrated) is yeast which has been dried in such a manner as to preserve a large portion of its fermenting power. It must contain no added cereal or filler and must contain not less than 15 billion live yeast cells per gram.

Brewers dried yeast (IFN 7-05-527 Yeast brewers dehydrated) is the dried, non-fermentative, non-extracted yeast of the botanical classification *Saccharomyces* resulting as a by-product from the brewing of beer and ale. It must contain not less than 35 percent crude protein. It must be labelled according to its crude protein content.

Brewers liquid yeast (IFN 7-20-878 Yeast brewers liquid) is the non-fermentative, non-extracted yeast of the botanical classification *Saccharomyces* resulting as a by-product from the brewing of beer and ale. It must contain not less than 35 percent crude protein on a dry weight basis. The guaranteed analysis shall include the maximum moisture.

Direct-fed microorganisms – the following microorganisms were reviewed by the US Food and Drug Administration, Center for Veterinary Medicine and found to present no safety concerns when used in direct-fed microbial products:

<i>Aspergillus figer</i>	<i>Lactobacillus curvatus</i>
<i>Aspergillus oiyzae</i>	<i>Lactobacillus delbruekii</i>
<i>Bacillus coagulans</i>	<i>Lactobacillus fermentum</i>
<i>Bacillus lentus</i>	<i>Lactobacillus helveticus</i>
<i>Bacillus licheniformis</i>	<i>Lactobacillus lactis</i>
<i>Bacillus pumilus</i>	<i>Lactobacillus plantarum</i>
<i>Bacillus subtilis</i>	<i>Lactobacillus reuteri</i>
<i>Bacteroides amylophilus</i>	<i>Leuconostoc mesenteroides</i>
<i>Bacteroides capillosus</i>	<i>Pediococcus acidilacticii</i>
<i>Bacteroides ruminicola</i>	<i>Pediococcus cerevisiae</i> (damnosus)
<i>Bacteroides suis</i>	<i>Pediococcus pentosaceus</i>
<i>Bifidobacterium adolescentis</i>	<i>Propionibacterium acidipropionici</i>
<i>Bifidobacterium animalis</i> (cattle only)	<i>Bifidobacterium bifidum</i>
<i>Propionibacterium freudenreichii</i>	<i>Bifidobacterium infantis</i>
<i>Propionibacterium shermanii</i>	<i>Bifidobacterium longum</i>
<i>Saccharomyces cerevisiae</i>	<i>Bifidobacterium thermophilum</i>
* <i>Enterococcus cremoris</i>	<i>Lactobacillus acidophilus</i>
* <i>Enterococcus diacetylactis</i>	<i>Lactobacillus brevis</i>
* <i>Enterococcus faecium</i>	<i>Lactobacillus buchneri</i> (cattle only)
* <i>Enterococcus intermedius</i>	<i>Lactobacillus bulgaricus</i>
* <i>Enterococcus lactis</i>	<i>Lactobacillus casei</i>
* <i>Enterococcus thermophilus</i>	<i>Lactobacillus farciminis</i> (swine only)
<i>Yeast</i> (as defined elsewhere)	<i>Lactobacillus cellobiosus</i>

* Formerly catalogued as *Streptococcus*.

Dried fermentation biomass is a non viable biomass product resulting from the production of amino acids by the fermentation of nonpathogenic, nontoxic, risk group 1 *Escherichia coli*. The product must contain a minimum of 75 percent crude protein on a dry matter basis. The product is intended as a source of protein. Non-protein nitrogen content must be guaranteed when present.

Dried fermentation product (IFN 5-06-150 *Bacillus subtilis* fermentation product dehydrated, IFN 5-06-151 *Aspergillus niger* fermentation product dehydrated,

IFN 5-06-152 *Aspergillus oryzae* fermentation product dehydrated, IFN 5-06-153 *Lactobacillus acidophilus* fermentation product dehydrated, IFN 5-06-154 *Lactobacillus bulgaricus* fermentation product dehydrated, IFN 5-06-155 *Enterococcus* (formerly *Streptococcus*) *faecium* fermentation product dehydrated, *Corynebacterium glutamicum* fermentation product dehydrated) is the product derived by culturing on appropriate nutrient media for the production of one or more of the following: enzymes, fermentation substances, or other microbial metabolites, and dried in accordance with approved methods and good manufacturing practices. Protein, amino acids, fat, fibre, coli count, enzyme activity or nutrient metabolite level shall be guaranteed where applicable. If *Corynebacterium glutamicum* is used as a source of L-lysine, the label must provide a minimum guarantee for L-lysine and directions for use advising a maximum use limitation of one percent in swine and poultry complete diets. Use of *Lactobacillus buchneri* is limited to silage and high moisture corn grain in plant inoculant products. (For label identification, the source must be indicated such as *B. subtilis*, *A. oryzae*, *A. figer*, *Corynebacterium glutamicum*, *Lactobacillus acidophilus*, *Lactobacillus buchneri*, *Lactobacillus bulgaricus* or *Streptococcus faecium*, or as permitted by FDA.)

Grain distillers dried yeast is the dried, non-fermentative yeast of the botanical classification *Saccharomyces* resulting from the fermentation of grains and yeast, separated from the mash, either before or after distillation. It must contain not less than 40 percent crude protein.

Hydrolysed yeast is a concentrated, non-extracted, partially soluble, yeast digest. Solubilization is accomplished by enzymatic hydrolysis of whole *Saccharomyces cerevisiae* cells. Salts may be added as processing aids in accordance with good manufacturing practice. It must not contain less than 35 percent crude protein.

Primary dried yeast or dried yeast (IFN 7-05-533 Yeast primary dehydrated) is the dried, non-fermentative yeast of the botanical classification *Saccharomyces* which has been separated from the medium in which propagated. It must consist of yeast cells with no fillers and contain not less than 40 percent crude protein.

Selenium yeast is a dried non-viable yeast, *Saccharomyces cerevisiae*, cultivated in a fed-batch fermentation which provides incremental amounts of cane molasses and selenium salts in a manner which minimizes the detrimental effects of selenium salts on the growth rate of the yeast and allows for optimal incorporation of inorganic selenium into cellular organic material. Residual inorganic selenium is eliminated in a rigorous washing process and must not exceed 2 percent of the total selenium content in the final selenium yeast product. Guaranteed organic selenium content must be declared on the product label. The additive selenium yeast is added in complete feed for chickens, turkeys, swine, beef cattle, dairy cattle, sheep, goats, llamas, alpacas and horses at a level not to exceed 0.3 parts per million of selenium, and to complete dog foods at a level not to exceed 0.333 parts per million of selenium on a dry matter basis. Selenium yeast shall be incorporated into each ton of complete feed by adding no less than 1 pound of a premix containing no more than 272.4 milligrams of added selenium per pound.

Torula dried yeast or *Candida* dried yeast (IFN 7-05-534 Yeast torula dehydrated) is the dried, non-fermentative yeast of the botanical classification (torulopsis) *Candida utilis* (formerly *Torulopsis utilis*) which has been separated from the medium in which propagated. It must contain not less than 40 percent crude protein.

Vitamin B₁₂ supplement (IFN 7-05-146 Vitamin B₁₂ supplement) is a feeding material used for its vitamin B₁₂ activity. It must contain a minimum vitamin B₁₂ activity of

1.5 milligrams per pound. The term must not be applied to products for which there are accepted names and definitions.

Yeast extract is the concentrated solubles of mechanically ruptured cells of a selected strain of the yeast, *Saccharomyces cerevisiae*. It may be dried or concentrated. It must contain not less than 9 percent crude protein.

Reported proximate and essential amino acid composition and usage

The average reported proximate and essential amino acid composition of selected protein-rich dried single cell protein (SCP) meals which have been successfully used in compound aquafeeds is shown in Table 38, 39 and 40, respectively.

Single cell protein (SCP) is a term applied to a wide range of unicellular and filamentous algae, fungi and bacteria which can be produced by controlled fermentation processes. In contrast with conventional plant and animal feed proteins, these microorganisms offer numerous advantages as protein producers, including: (1) their production can be based on raw carbon substrates which are available in large quantities (i.e. coal, petrochemicals, natural gas) or on agricultural or cellulosic waste products which would otherwise cause an environmental hazard; (2) the majority of microorganisms cultured are highly proteinaceous (40–80 percent crude protein on a dry weight basis, depending on species); (3) they have a short generation time, with bacteria under optimum culture conditions doubling their cell mass within 0.5–2h, yeasts within 1–3h, and algae within a 3–6h period; (4) they can be cultivated in a limited land space and produced continuously with good control, independently of climate; and (5) to a certain extent their nutritional composition can be manipulated and/or controlled during the fermentation process through nutrient addition and/or deletion/limitation (Barbarito, 2007; El-Sheekh and Fathy (2009); Garcia-Galano, 2007; Guil-Guerrero and Reboloso-Fuentes, 2008; Tacon, 1987).

In addition to the use of monocultures of SCP for protein production, there is also the possibility of using mixed SCP cultures such as activated sludges (i.e. mixed suspension of bacteria, algae and unicellular organisms) resulting from the biological oxidation and/or fermentation of specific waste streams such as brewery waste and food processing wastes.

In general these microbial products are good sources of dietary protein, with methionine generally being the first limiting essential amino acid within algae, yeast and activated sludges, and to a lesser extent lysine within bacterial SCP (Table 39). In contrast to conventional plant and animal feedstuffs, a significant proportion of the nitrogen contained within SCP is present in the form of non-protein compounds, including nucleic acids and their decomposition products. In general SCP are poor sources of dietary lipid and calcium, but are an excellent source of dietary vitamins (i.e. B-vitamins, inositol and choline) and are good sources of dietary phosphorus (Barbarito, 2007; Garcia-Galano, 2007; Tacon, 1987). In particular, activated sludges (bacterial-based SCP) are one of the richest sources of dietary vitamin B₁₂, with levels as high as 12 mg/kg reported in activated bacterial SCP produced from brewery and food processing waste streams (Andrew J. Logan, Oberon FMR, Inc. – personal communication).

TABLE 38

Reported average proximate composition of selected protein-rich dried single cell protein (SCP) meals – all values are expressed as percent by weight on as-fed basis: Water-H₂O; Crude Protein-CP; Lipid or Ether Extract-EE; Crude Fibre-CF; Nitrogen-Free Extractives-NFE; Ash; Calcium-Ca; Phosphorus-P

SCP / substrate used	Average composition (% by weight)									Ref. ¹
	H ₂ O	CP	EE	CF	NFE	Ash	Ca	P		
Bacterial SCP <i>Pseudomonas/Methylophilus</i> spp.										
Methanol substrate	6.4	73.1	5.7	0.4	2.7	11.7	0.54	2.33	1	
Bacterial SCP <i>Methylococcus capsulatus</i>, <i>Alcaligenes acidovorans</i>, <i>Bacillus brevis</i> and <i>B. firmus</i>										
Natural gas substrate	6.5	69.5	8.1	-	-	6.2	-	1.59	8	
Yeast SCP <i>Saccharomyces</i> spp.										
Brewers yeast (<i>S. cerevisiae</i>) / Malt 7-05-527	min	7.0	43.8	0.8	2.4	24.3	6.6	0.12	1.26	1-4
	max	8.6	49.4	1.7	3.9	39.4	12.1	0.25	1.45	
	mean	7.6	46.1	1.3	2.9	34.0	8.1	0.18	1.37	
Torula yeast (<i>Torulopsis utilis</i>) 7-05-534	min	7.0	45.9	1.6	2.1	28.7	7.7	0.45	1.42	1,2,4
	max	7.7	49.1	4.1	2.3	32.2	8.1	0.50	1.59	
	mean	7.2	47.8	2.8	2.2	30.4	7.9	0.48	1.51	
Extracted yeast (Nupro: <i>S. cerevisiae</i>)	6.0	51.1	0.2	0.4	37.7	4.6	0.05	1.53	5	
Molasses yeast (<i>S. cerevisiae</i>) / Molasses	9.2	46.8	5.7	1.6	30.5	6.2	0.45	0.65	1,4	
<i>Candida utilis</i> / Sulphite liquor	8.3	47.3	5.2	1.1	30.8	7.3	-	-	1	
<i>Candida boidinii</i> / Methanol	6.2	36.4	7.2	10.0	34.5	5.7	-	-	1	
<i>Candida lipolytica</i> / n-Paraffin	6.0	58.8	7.2	3.9	16.4	7.7	0.01	0.80	1	
<i>Candida lipolytica</i> / Gas-oil	9.0	53.3	7.1	3.8	19.1	7.7	-	-	1	
<i>Candida pseudotrophus</i> / Whey	10.0	57.6	5.0	4.5	13.9	9.0	-	-	1	
<i>Candida</i> spp./ Citrus molasses	7.6	43.3	0.2	8.1	33.7	7.1	0.20	1.42	1	
Filamentous fungal SCP										
<i>Aspergillus oryzae</i> / Soybean waste	6.3	44.1	3.5	13.2	25.0	7.9	0.34	1.63	1	
<i>Aspergillus tomarii</i> / Fish waste water	8.5	44.4	9.4	16.9	16.1	4.7	0.10	0.95	1	
Mixed fungal SCP culture / Whisky wash	3.1	53.7	4.5	1.8	31.4	5.5	-	-	1	
Algal SCP										
<i>Spirulina maxima</i> 5-19-931	min	6.7	58.6	2.3	0.5	22.7	6.7	1.14	0.08	1-6
	max	9.0	70.0	8.5	-	-	12.0	-	-	
	mean	6.4	62.1	4.8	0.5	17.3	8.9	1.14	0.08	
<i>Chlorella vulgaris</i>	5.7	47.2	7.4	8.3	20.8	10.6	-	-	1	
<i>Scenedesmus obliquus</i>	6.0	52.6	13.0	6.5	13.5	8.0	0.16	1.76	1	
<i>Scenedesmus acutus</i>	8.1	43.6	10.5	6.0	24.4	7.4	0.59	3.66	1	
<i>Cladophora glomerata</i>	1.6	31.0	5.2	1.0	28.0	23.2	-	-	1	
Mixed bacterial-based SCP cultures										
Activated sludge / domestic sewage	5.6	39.6	2.6	11.3	19.8	21.1	1.84	1.65	1	
Activated sludge / brewery waste	5.0	44.4	8.0	-	-	12.6	-	-	1	
Activated sludge / paper processing waste	3.0	42.3	0.4	10.6	16.0	27.7	11.4	2.3	1	
Activated bacterial SCP / brewery waste	<5.0	65.6	2.0	1.2	13.7	12.5	0.61	1.11	7	

¹ 1 – Tacon (1987); 2 – NRC (1982); 3 – Catacutan (2002); 4 – Hertrampf and Pascual (2000); 5 – NuPro product specifications (www.alltech.com); 6 – Barbarito (2007); 7 – Andrew J. Logan, Oberon FMR, Inc. (personal communication); 8 – Crude protein (N x 6.25) reported as 69.5%, sum of total amino acids as 49.2%, RNA + DNA 11.1%: Aas et al. (2006a).

TABLE 39

Reported essential amino acid (EAA) composition of selected protein-rich single cell proteins (SCP) – all values are expressed as % by weight on as-fed basis: Arginine-Arg; Cystine-Cys; Methionine-Met; Threonine-Thr; Isoleucine-Iso; Leucine-Leu; Lysine-Lys; Valine-Val; Tyrosine-Tyr; Tryptophan-Try; Phenylalanine-Phe; Histidine-His

SCP	Average EAA composition (%)												Ref. ²	
	Arg	Cys	Met	Thr	Iso	Leu	Lys	Val	Tyr	Try	Phe	His		
Bacterial SCP														
<i>Pseudomonas/Methylophilus</i> spp.	3.67	0.41	1.75	3.29	3.34	5.43	4.30	4.16	2.70	0.80	3.07	1.50	1	
	AA%ΣEAA	10.7	1.2	5.1	9.6	9.7	15.8	12.5	12.1	7.8	2.3	8.9		4.4
	Amino acid score – finfish ¹	92	44	94	90	129	117	74	127	120	135	94		92
	Amino acid score – shrimp ¹	55	58	120	120	118	111	117	133	95	127	90		102
<i>M. capsulatus</i> , <i>A. acidovorans</i> , <i>B. brevis</i> and <i>B. firmus</i>	3.93	0.38	1.52	2.50	2.48	4.35	3.15	3.22	1.97	0.76	2.32	1.24	7	
	AA%ΣEAA	14.1	1.4	5.5	9.0	8.9	15.6	11.3	11.6	7.1	2.7	8.3		4.4
	Amino acid score – finfish	121	52	102	85	119	115	67	122	109	159	87		92
	Amino acid score – shrimp	73	68	130	113	108	110	106	127	86	149	84		102

TABLE 39 – CONTINUED

SCP	Average EAA composition (%)												Ref. ²	
	Arg	Cys	Met	Thr	Iso	Leu	Lys	Val	Tyr	Try	Phe	His		
Fungal SCP														
Brewers yeast (<i>S. cerevisiae</i>)	min	2.14	0.49	0.67	2.04	1.98	2.85	2.97	2.36	1.50	0.52	1.62	1.09	1–3
	max	2.25	0.60	0.83	2.32	2.22	3.25	3.31	2.48	1.51	0.62	1.95	1.14	
	mean	2.20	0.53	0.75	2.16	2.14	3.11	3.13	2.40	1.50	0.55	1.80	1.11	
	AA%ΣEAA	10.3	2.5	3.5	10.1	10.0	14.5	14.6	11.2	7.0	2.6	8.4	5.2	
	Amino acid score – finfish	89	92	65	95	133	107	87	118	108	153	88	108	
Amino acid score – shrimp	53	122	82	127	121	102	137	123	85	144	85	121		
Extracted yeast (<i>S. cerevisiae</i>)	min	1.98	0.53	0.76	2.00	2.00	3.72	2.82	2.54	1.54	0.51	1.93	1.00	4
	max	2.64	0.61	0.79	2.64	2.88	3.52	3.77	2.96	2.00	0.52	2.93	1.36	
	mean	2.63	0.60	0.78	2.63	2.86	3.51	3.75	2.94	2.00	0.51	2.89	1.34	
	AA%ΣEAA	9.3	2.5	3.6	9.4	9.4	17.4	13.2	11.9	7.2	2.4	9.0	4.7	
	Amino acid score – finfish	80	93	67	89	125	129	79	125	111	141	95	98	
Amino acid score – shrimp	48	122	85	118	114	123	124	131	87	133	91	109		
Torula yeast (<i>T. utilis</i>)	min	2.62	0.60	0.77	2.62	2.85	3.51	3.74	2.93	2.00	0.51	2.85	1.32	1–2
	max	2.64	0.61	0.79	2.64	2.88	3.52	3.77	2.96	2.00	0.52	2.93	1.36	
	mean	2.63	0.60	0.78	2.63	2.86	3.51	3.75	2.94	2.00	0.51	2.89	1.34	
	AA%ΣEAA	9.9	2.3	2.9	9.9	10.8	13.3	14.2	11.1	7.6	1.9	10.9	5.1	
	Amino acid score – finfish	85	85	54	93	144	98	84	117	117	112	115	106	
Amino acid score – shrimp	51	112	68	124	131	94	133	122	92	105	110	119		
<i>Candida</i> spp. (alkane substrate)	min	2.10	0.57	1.02	2.67	2.50	3.92	3.30	2.79	1.88	0.68	2.10	1.02	1
	max	8.5	2.3	4.1	10.9	10.2	16.0	13.4	11.4	7.7	2.8	8.5	4.1	
	mean	7.3	85	76	103	136	118	80	120	118	165	89	85	
	AA%ΣEAA	44	112	97	137	124	113	126	125	93	155	86	95	
	Amino acid score – finfish	73	85	76	103	136	118	80	120	118	165	89	85	
Amino acid score – shrimp	44	112	97	137	124	113	126	125	93	155	86	95		
<i>Aspergillus oryzae</i> (waste starch)	min	1.91	0.34	0.49	1.57	1.54	2.55	1.95	1.87	2.14	0.49	1.20	0.82	1
	max	11.3	2.0	2.9	9.3	9.1	15.1	11.5	11.1	12.7	2.9	7.1	4.9	
	mean	97	74	54	88	121	112	68	117	195	171	75	102	
	AA%ΣEAA	58	98	68	117	111	106	108	122	154	160	72	114	
	Amino acid score – finfish	58	98	68	117	111	106	108	122	154	160	72	114	
Amino acid score – shrimp	58	98	68	117	111	106	108	122	154	160	72	114		
<i>Rhodotorula pilimanae</i>	min	3.53	0.11	1.19	2.52	2.01	3.32	4.11	2.53	1.27	0.15	1.60	1.25	1
	max	15.0	0.5	5.0	10.7	8.5	14.1	17.4	10.7	5.4	0.6	6.8	5.3	
	mean	129	18	93	101	113	104	104	113	83	35	72	110	
	AA%ΣEAA	78	24	118	134	103	99	163	118	66	33	69	123	
	Amino acid score – finfish	129	18	93	101	113	104	104	113	83	35	72	110	
Amino acid score – shrimp	78	24	118	134	103	99	163	118	66	33	69	123		
Algal SCP														
<i>Spirulina maxima</i>	min	3.93	0.24	0.85	2.79	3.63	4.84	2.79	3.75	2.42	0.85	2.41	0.95	1,5
	max	4.25	0.47	1.33	3.00	3.81	5.40	2.95	3.93	2.90	0.89	3.02	1.09	
	mean	4.09	0.35	1.09	2.89	3.72	5.12	2.87	3.84	2.66	0.87	2.71	1.02	
	AA%ΣEAA	13.1	1.1	3.5	9.2	11.9	16.4	9.2	12.3	8.5	2.8	8.7	3.3	
	Amino acid score – finfish	113	41	65	87	159	121	55	129	131	165	92	69	
Amino acid score – shrimp	68	54	82	115	145	115	86	135	103	155	88	77		
Mixed bacterial-based SCP cultures														
Activated sludge / sewage	min	1.60	0.25	0.25	1.85	1.41	2.46	1.67	2.21	0.72	-	2.07	0.69	1
	max	10.5	1.6	1.6	12.2	9.3	16.2	11.0	14.5	4.7	-	13.6	4.5	
	mean	90	59	30	115	124	120	65	223	276	-	143	94	
	AA%ΣEAA	54	78	38	153	113	114	103	176	260	-	137	105	
Activated sludge / brewers waste	min	1.95	0.0	0.98	1.82	1.64	2.62	1.55	2.31	1.11	-	1.60	0.40	1
	max	12.2	-	6.1	11.4	10.3	16.4	9.7	14.4	6.9	-	10.0	2.5	
	mean	105	-	113	107	137	121	58	152	106	-	105	52	
	AA%ΣEAA	63	-	144	143	125	115	91	158	84	-	101	58	
Activated sludge / paper waste	min	3.07	0.14	1.20	2.23	2.05	3.50	2.07	2.69	1.51	-	2.02	0.90	1
	max	14.4	0.6	5.6	10.4	9.6	16.4	9.7	12.6	7.1	-	9.4	4.2	
	mean	124	22	104	98	128	121	58	133	109	-	99	87	
	AA%ΣEAA	74	29	132	130	117	115	91	138	86	-	95	98	
Activated bacterial SCP / brewery	min	3.60	0.55	1.41	3.11	3.38	5.06	4.34	3.52	2.83	0.98	3.29	1.46	6
	max	10.7	1.6	4.2	9.3	10.1	15.1	12.9	10.5	8.4	2.9	9.8	4.3	
	mean	92	59	78	88	135	112	77	110	129	171	103	90	
	AA%ΣEAA	55	78	99	117	123	106	121	115	102	160	99	100	
Amino acid score – finfish	92	59	78	88	135	112	77	110	129	171	103	90		
Amino acid score – shrimp	55	78	99	117	123	106	121	115	102	160	99	100		

¹ Individual amino acids are expressed as % of total EAA and compared with the EAA requirement profile of farmed fish (Arg 11.6%, Cys 2.7%, Met 5.4%, Thr 10.6%, Iso 7.5%, Leu 13.5%, Val 9.5%, Tyr 6.5%, Try 1.7%, Phe 9.5% and His 4.8%; Ogino, 1980) and shrimp (Arg 19.3%, Cys 2.0%, Met 4.2%, Thr 8.0%, Iso 8.2%, Leu 14.2%, Val 9.1%, Tyr 8.2%, Try 1.8%, Phe 9.9% and His 4.3%; Tacon et al. 2002), respectively.

² The data shown represent mean values from various sources, including: 1 – Tacon (1987); 2 – NRC (1983); 3 – NRC (1993); 4 – NuPro product specifications (www.alltech.com); 5 – Barbarito (2007); 6 – Andrew J. Logan, Oberon FMR, Inc. (personal communication); 7 – Sum of total amino acids as 49.2%: Aas et al. (2006a).

TABLE 40

Major feeding studies conducted with protein-rich dried single cell protein (SCP) sources in compound aquafeeds**ALGAL SCP**

Blue-green algae meal: Gibel carp: Zhao *et al.* (2006);

***Chlorella ellipsoidea* meal:** Japanese flounder: Kim *et al.* (2002);

Freshwater algae meals: *Chaetoceros muelleri*, *C. calcitrans*, *Skeletonema sp.* and *Thalassiosira pseudonana* – Shrimp: D'Souza *et al.* (2000, 2002);

General – Mustafa and Nakagawa (1995);

***Isochrysis galbana* meal** – Goldfish: Coutinho *et al.* (2006);

Marine algae – freeze-dried diatom (*Thalassiosira weissflogii*) and *Nannochloropsis* cultures (partially extracted with acetone into a carotenoid fraction and a residue fraction): Shrimp: Ju *et al.* (2009); Patnaik *et al.* (2006); freeze-dried *Nannochloropsis oculata* – Gilthead seabream: Navarro and Sarasquete (1998);

***Spirulina/Spirulina platensis* meal:** **General:** Habib *et al.* (2008); Iay and Ota (1996); **Abalone:** Bautista-Teruel *et al.* (2003b); Britz (1996); Shipton and Britz (2001); **Common carp:** Nandeeshha *et al.* (1998); **Indian major carp:** Nandeeshha *et al.* (2001); **Shrimp:** Jaime-Ceballos *et al.* (2004, 2005, 2006); **Sturgeon:** Palmegiano *et al.* (2005, 2008); **Tilapia:** Olvera-Novoa *et al.* (1998); Takeuchi *et al.* (2002);

BACTERIAL SCP

***Methylococcus capsulatus*, *Alcaligenes acidovorans*, *Bacillus brevis* and *B. firmus* meal:** Halibut: Aas *et al.* (2007); Salmon: Aas *et al.* (2006a); Berge *et al.* (2005); Øverland *et al.* (2007); Skrede *et al.* (1998); Storebakken *et al.* (1998a, 2004); Trout: Aas *et al.* (2006b); Øverland *et al.* (2006);

Rhodopseudomonas palustris – **General:** Kim and Lee (2000);

FUNGAL SCP

Brewers yeast/*S. cerevisiae*: African catfish: Hoffman *et al.* (1997); Cobia: Lunger *et al.* (2006, 2007a, 2007b); Grass carp: Lin *et al.* (2001); European seabass: Oliva-Teles and Goncalves (2001); Peres and Oliva-Teles (2003); Gilthead seabream: Oliva-Teles *et al.* (2006); Hybrid striped bass: Gaylord *et al.* (2004); Li and Gatlin (2003, 2004, 2005); Redclaw crayfish: Muzinic *et al.* (2004); Pavasovic *et al.* (2007); Red drum: Li *et al.* (2005); Rockfish: Lee (2002); Trout: Cheng *et al.* (2004); Fournier *et al.* (2002); Rumsey *et al.* (1991a, 1991b, 1992); Yamamoto *et al.* (1995); Turbot: Fournier *et al.* (2002);

Dried yeast (general): Channel catfish: Welker *et al.* (2007); Common carp: Cahu *et al.* (1998); Carvalho *et al.* (1997); European seabass: Cahu *et al.* (1998); Grouper: Lin *et al.* (2004); Pacu (*Piaractus mesopotamicus*): Abimorad *et al.* (2008); Ozorio *et al.* (2005); Shrimp: Gallardo *et al.* (2002); Striped/grey mullet: Wassef *et al.* (2001); Tilapia: Liu *et al.* (1995); Wu *et al.* (2000); Trout: Barnes *et al.* (2006); Yellow croaker: Mai *et al.* (2006b);

Recombinant vitellogenin yeast *Pichia pastoris*: Tilapia: Lim *et al.* (2005);

Red yeast/*Phaffia rhodozyma*: Trout: Nakano *et al.* (1995, 1999);

Torula yeast: Abalone: Britz (1996); Shipton and Britz (2001); Grey mullet: Luzzana *et al.* (2005); Shrimp: Fraga *et al.* (1996); Garcia *et al.* (1997); Tilapia: Olvera-Novoa *et al.* (2002b);

***Aspergillus oryzae*:** Parrot fish: Kim *et al.* (2009).

4.4 LIPID SOURCES**4.4.1 Marine oils**

Official definitions (AAFCO, 2008b)

Fish oil (IFN 7-01-965 Fish oil) is the oil from rendering whole fish or cannery waste.

Reported fatty acid composition, quality criteria and usage

The reported fatty acid content of selected marine oils which have been successfully used and/or tested within compound aquafeeds is shown in Table 41 and 42, respectively. Marine oils are rich dietary sources of essential fatty acids (EFA), and in particular of the long chain polyunsaturated fatty acids (lcPUFA) belonging to the linolenic or *n*-3 series, namely eicosapentaenoic acid (EPA; 20:5*n*-3) and docosahexaenoic acid (DHA; 22:6*n*-3). These fatty acids are dietary essential nutrients for most carnivorous marine finfish species (Glencross, 2009; Higgs and Dong, 2000). In general, the fatty acid profile of marine fish oils reflects the particular feeding habit of the fish species in question, with the relative proportion of EPA usually being higher within planktonic

feeders (krill, anchoveta, herring, menhaden, sardine) and DHA highest within those more piscivorous or carnivorous fish species (skipjack tuna, horse mackerel, salmon, cod; Table 41, 42). It also follows from the above that the fatty acid composition of marine fish and mollusc (squid) oils can be quite variable, depending on natural food availability, the fishing season, fish size and the reproductive condition of the species in question (Glencross, 2009; Higgs and Dong, 2000). Feeding studies have shown that the digestibility of marine fish oils increases with increasing fatty acid unsaturation; being lowest for saturated fatty acids (Glencross, 2009; Menoyo *et al.*, 2003).

Finally, it is important to mention here that apart from supplying EFA, dietary marine oils are also excellent dietary sources of highly digestible energy and (depending upon the animal species and source) may also be good dietary sources of phospholipids (phosphatidylcholine: Table 41), fat soluble vitamins (depending on the animal species includes choline, inositol, vitamin A, tocopherols, vitamin D₃: Table 41; Hardy and Roley, 2000; Hertrampf and Pascual, 2000; NRC, 1983, 1982), cholesterol (Table 20, 41, 42; Higgs and Dong, 2000), phosphorous, steroid hormones (depending on animal species and sexual maturity), and carotenoids (particularly within crustacean oils: Table 41: Sclabos Katevas, 2008; Tou *et al.*, 2007; Nordrum, AkerBioMarine, Oslo, Norway [personal communication]; see also www.krill.com/#/products/2/3/).

Table 43 shows the recommended quality criteria for fish oils used in aquaculture feeds. As mentioned previously (section 2.1.4), standard laboratory quality control methods for assessing the quality of marine oils measure the concentration of

TABLE 41
Fatty acid composition of selected marine oil sources used in compound aquafeeds – fatty acid values expressed as percent total fatty acids

Fatty acid	Anchovy	Jack mackerel	Cod liver	Capelin	Menhaden	Squid	Krill ¹	Thraust-ichthyrid ²	Algal SCP ³	Algal SCP ⁴
14:0	8	6	6	8	8	4	9	9	11	5
16:0	18	17	14	11	19	18	22	26	14	28
16:1n-7	11	8	8	11	9	5	4	1	-	36
18:0	6	4	3	1	4	3	1	1	-	2
18:1n-9	15	25	19	17	13	18	16	2	15	6
18:2n-6	1	4	2	2	2	2	2	1	3	1
18:3n-3	1	1	1	1	1	2	2	-	-	5
18:4n-3	3	2	3	2	3	4	4	1	-	-
20:0	4	-	-	-	-	1	-	-	-	-
20:1n-9	3	4	10	19	2	9	1	-	-	-
20:4n-3	1	1	1	-	-	2	1	1	-	-
20:4n-6	1	1	1	-	1	1	0.5	3	-	2
20:5n-3	12	13	9	5	11	11	22	2	-	13
22:0	1	-	1	-	-	2	-	-	-	-
22:1n-11	2	-	13	15	1	4	-	-	-	-
22:5n-3	2	2	2	1	2	1	1	1	-	-
22:6n-3	12	8	9	3	9	12	13	37	45	-
SFA	36	26	23	20	31	28	32	36	25	35
MUFA	30	37	49	62	25	35	22	3	15	44
PUFA	5	6	6	4	5	8	3	1	3	21
lcPUFA	26	25	21	8	23	26	43	44	45	15
n-3 FA	30	26	24	11	26	31	43	42	45	17
n-6 FA	2	5	3	2	2	3	3	3	3	4

Source: adapted from Glencross (2009).

¹ Krill oil containing (expressed as g/100g oil) on average 0.3-0.4% AA, 12.3-13.9% EPA, 7.0-7.9% DHA, 36-45% phosphatidylcholine, 1.1-1.4% cholesterol, 166-311 mg/kg vitamin E, 35.9-45 mg/kg Vitamin A, and 69-135 mg/kg astaxanthin (Sigve Nordrum, AkerBioMarine, Oslo, Norway – personal communication); ² Thraustochytrids are marine single-cell organisms rich in n-3 lcPUFA and in particular *Schizochytrium* sp.; ³ Heterotrophically grown alga (*Cryptocodinium* sp) containing 35% crude lipid and a minimum of 15% DHA by weight (Advanced BioNutrition, www.abn-corp.com); ⁴ Autotrophically grown alga (*Nannochloropsis gaditana*) containing 23.5% lipid, 188.4 mg/g total fatty acids and 2.37% EPA by weight (Clean Algae S.A., www.cleanalgae.es).

Note: 18:1n-7 data is combined with 18:1n-9, 20:1n-11 data is combined with 20:1n-9, 22:1n-9 data is combined with 22:1n-12; lcPUFA, long-chain polyunsaturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; SFA, saturated fatty acids (Glencross, 2009).

intermediate products of lipid oxidation, namely aldehydes (thiobarbituric acid reactive compound concentration [TBARS] or anisidine value [AV]) or peroxides (peroxide value [PV]; Hardy and Roley, 2000). Table 44 shows the major feeding studies which have been conducted with marine oils in compound aquafeeds for the major cultivated finfish and crustacean species since 1995.

TABLE 42

Content of selected fatty acids and cholesterol in marine fish oils – values expressed as g/100g edible portion

Fatty acid	Cod liver oil	Herring oil	Menhaden oil	Salmon oil	Sardine oil
Saturated	22.61	21.29	30.43	19.87	29.89
12:0	NR	0.16	NR	NR	0.10
14:0	3.57	7.19	7.96	3.28	6.52
16:0	10.63	11.70	15.15	9.84	16.65
18:0	2.80	0.82	3.77	4.24	3.89
Monosaturated	46.71	56.56	26.69	29.04	33.84
16:1	8.31	9.64	10.48	4.82	7.51
18:1	20.65	11.95	14.53	16.98	14.75
20:1	10.42	13.62	1.33	3.86	5.99
22:1	7.33	20.61	0.35	3.38	5.59
Polyunsaturated	22.54	15.60	34.20	40.32	31.87
18:2	0.93	1.15	2.15	1.54	2.01
18:3	0.93	0.76	1.49	1.06	1.33
18:4	0.93	2.30	2.74	2.80	3.02
20:4	0.93	0.29	1.17	0.67	1.76
20:5	6.90	6.27	13.17	13.02	10.14
22:5	0.93	0.62	4.91	2.99	1.97
22:6	10.97	4.21	8.56	18.23	10.66
Cholesterol (mg)	570	766	521	485	710

Source: adapted from Higgs and Dong (2000).

NR – Not reported.

TABLE 43

Recommended quality control criteria for fish oils used in aquafeeds

Parameter	Value
Free fatty acids	< 3%
Moisture	<1%
Nitrogen	<1%
Thiobarbituric acid reactive substances (TBARS)	<25 nm malonaldehyde equivalents/g
Peroxide value (PV)	<5 meq/kg
Anisidine value (AV)	<15 meq/kg
Totox (2 x PV + AV)	<20

Source: Dong and Hardy (2000).

TABLE 44

Major feeding studies conducted with marine oils in compound aquafeeds since 1995

MARINE ALGAL/THRAUSTOCHYTRID OILS

General: Harel *et al.* (2002); Otleş and Pire (2001); *Crypthecodinium sp* – Atlantic cod: Park *et al.* (2006); Shrimp: Browdy *et al.* (2006); Patnaik *et al.* (2006); *Crypthecodinium cohnii*, *Phaeodactylum tricorutum*, *Thraustochytrids* – European seabream: Atalah *et al.* (2007); Ganuza *et al.* (2008); *Thraustochytrids Schizochytrium sp* – Atlantic cod: Park *et al.* (2006); Channel catfish: Li *et al.* (2009); Atlantic salmon: Carter *et al.* (2003); Miller *et al.* (2007); *Schizochytrium limacinum* – Turbot: Song *et al.* (2007);

CRUSTACEAN OILS

Calanus oil: Atlantic salmon: Hynes *et al.* (2009); Olsen *et al.* (2004); Trout: Oxley *et al.* (2005);

Krill oil: Marine fish larvae: Bustos *et al.* (2003);

TABLE 44 – CONTINUED

FISH OILS

Anchovy oil: European seabass: Montero *et al.* (2005b); Richard *et al.* (2006a); Gilthead seabream: Caballero *et al.* (2003, 2004, 2006a, 2006b); Fountoulaki *et al.* (2009); Ganga *et al.* (2005); Izquierdo *et al.* (2003, 2005); Montero *et al.* (2003, 2005b, 2008); Salmon: Grant *et al.* (2008); Huang *et al.* (2008); Menoyo *et al.* (2002); Wagner *et al.* (2004); Wilson *et al.* (2007); Trout: Caballero *et al.* (2002); Richard *et al.* (2006b);

Capelin oil: Gilthead seabream: Schuchardt *et al.* (2008); Salmon: Stubhaug *et al.* (2005); Torstensen *et al.* (2000, 2004a, 2004b, 2005); Trout: Caballero *et al.* (2002);

Catfish oil: Channel catfish: O'Neal and Kohler (2008); Robinette *et al.* (1997);

Cod liver oil – African catfish: Legendre *et al.* (1995); Mukhopadhyay and Mishra (1998); Mukhopadhyay and Rout (1996); Ng *et al.* (2003); Asian seabass: Catacutan and Coloso (1997); Eel: Gunasekera *et al.* (2002); Grouper: Shapawi *et al.* (2008); Wu *et al.* (2002); Milkfish: Alava (1998); Murray cod: Francis *et al.* (2006, 2007a, 20076b, 2007c); Rohu: Mishra and Samantaray (2004); South American catfish: Arslan *et al.* (2008); Sturgeon: Kennari *et al.* (2007); Tilapia: Chou and Shiau (1996, 1999); Ng *et al.* (2001); Tropical bagrid catfish: Ng *et al.* (2000); Trout: Ballestrazzi *et al.* (2003, 2006);

Fish oil (general): Arctic charr: Lodemel *et al.* (2001); Atlantic cod: Grisdale-Helland *et al.* (2008); Hansen *et al.* (2008); Jobling *et al.* (2008); Mørkøre (2006); Black seabream: Peng *et al.* (2008); Catfish (*Heterobranchus longifilis*): Babalola *et al.* (2009); Chinese mitten crab: Wu *et al.* (2007); Cobia: Wang *et al.* (2005); Common carp: Zhou *et al.* (2008); Crayfish: Fotedar (2004); Hernandez-Vergara *et al.* (2003); European seabass: Alvarez *et al.* (1998); Mourente *et al.* (2005b); Navas *et al.* (1998); Parpoura and Alexis (2001); Yildiz and Sener (2003, 2004); Gilthead seabream: Benedito-Palos *et al.* (2007, 2008); Dias *et al.* (2009); Grigorakis *et al.* (2009); Grass carp: Du *et al.* (2006); Grouper: Lin and Shiau (2003); Halibut: Martins *et al.* (2007b); Jundia (*Rhamdia*): Vargas *et al.* (2008); Mud crab: Holme *et al.* (2007); Salmon: Bell *et al.* (1996); Bendiksen *et al.* (2003); Gjoen *et al.* (2004); Helland and Grisdale-Helland (1998); Jobling and Bendiksen (2003); Jobling *et al.* (2002); Jordal *et al.* (2005, 2006); Kennedy *et al.* (2006); Menoyo *et al.* (2005); Miller *et al.* (2007b, 2008); Olsvik *et al.* (2007); Pratoomyot *et al.* (2008); Rennie *et al.* (2005); Seierstad *et al.* (2005, 2008, 2009); Schlechtriem *et al.* (2007); Solberg (2004); Torstensen *et al.* (2008); Zheng *et al.* (2004); Shrimp: Ouraji *et al.* (2009); Sole: Morais *et al.* (2006); Sturgeon: McKenzie *et al.* (1997); Tilapia: El-Sayed *et al.* (2005); Hsieh *et al.* (2007a, 2007b); Karapanagiotidis *et al.* (2007); Ribeiro *et al.* (2008); Trout: Alvarez *et al.* (1998); Bureau *et al.* (2008); Geurden *et al.* (2009); Ng *et al.* (2003b); Nielsen *et al.* (2005); Panserat *et al.* (2002, 2008); Parova and Rehulka (1997); Rehulka and Parova (2000); Rodriguez *et al.* (1997); Sener and Yildiz (2003); White sea bream: Sa *et al.* (2008); Yellow catfish (Han *et al.* 2005);

Herring oil – Atlantic halibut: Martins *et al.* (2009); European seabass: Ballestrazzi and Lanari (1996); Halibut: Haugen *et al.* (2006); Salmon: Menoyo *et al.* (2002); Olsen *et al.* (2005); Trout: Ballestrazzi *et al.* (2003, 2006);

Jack mackerel oil: Abalone: Van Barneveld *et al.* (1998);

Menhaden fish oil - Brook charr: Guillou *et al.* (1995); Channel catfish: Fracalossi and Lovell (1995); Klinger *et al.* (1996); Manning *et al.* (2007); O'Neal and Kohler (2008); Robinette *et al.* (1997); Sink and Lochmann (2008); Yildirim-Aksoy *et al.* (2007b, 2009); European eel: McKenzie *et al.* (2000); Eurasian perch: Kestemont *et al.* (2001); Largemouth bass: Subhadra *et al.* (2006b); Red drum: Craig and Gatlin (1995); Craig *et al.* (1995, 1999); Davis *et al.* (1999); Tucker *et al.* (1997); Red snapper: Papanikos *et al.* (2008); River chub: Huang *et al.* (2001); Salmon: McKenzie *et al.* (1998); Welker and Congleton (2003); Sea urchins: Castell *et al.* (2004); Gonzalez-Duran *et al.* (2008); Shrimp: Cheng and Hardy (2004); González-Félix *et al.* (2002); Izquierdo *et al.* (2006); Re-Araujo and Ruiz (2003); Summer flounder: Gaylord *et al.* (2003); Sunshine bass: Lane *et al.* (2006); Lewis and Kohler (2008b); Wonnacott *et al.* (2004); Tilapia: Huang *et al.* (1998); Yildirim-Aksoy *et al.* (2007a); Trout: Chaiyapechara *et al.* (2003); Liu *et al.* (2004); Walleye: Clayton *et al.* (2008); White seabass: Lopez *et al.* (2006, 2009); Yellow perch: Twibell *et al.* (2001);

Northern hemisphere fish oil – European sea bass: Asturiano *et al.* (2001); Bell *et al.* (1997);

Oxidized fish oil: Atlantic halibut: Lewis-McCrea and Lall (2007); Martins *et al.* (2007); Atlantic cod: Zhong *et al.* (2008); Common carp: Ye *et al.* (2006); Gilthead seabream: Mourente *et al.* (2000); Salmon: Hamre *et al.* (2001); Sturgeon: Bergot (2006); Daskalov *et al.* (2000); Gao *et al.* (2005); Trout: Kiron *et al.* (2004);

Pollock fish/liver oil – Ivory shell (*Babylonia* sp.): Zhou *et al.* (2007b); Japanese flounder: Kikuchi *et al.* (2002); Tiger puffer: Takii *et al.* (1995); Shrimp: Zhou *et al.* (2007); Trout: Kiron *et al.* (2004); Yamamoto *et al.* (2002);

Ray liver oil: Shrimp: Perez-Valezquez *et al.* (2008);

Sardine oil: Gilthead seabream: Izquierdo *et al.* (2008); Liu *et al.* (2003); Shrimp: Kumaraguru Vasagam *et al.* (2005);

Trout offal oil: Murray cod: Turchini *et al.* (2003a);

Tuna fish oil/tuna orbital oil: Common carp: Appelford and Anderson (1997b); European sea bass: Asturiano *et al.* (2001);

MOLLUSCAN OILS

Cuttlefish oil: Freshwater prawn: Shyla *et al.* (2009);

Squid lecithin: Shrimp: Re-Araujo and Ruiz (2003);

Squid/liver oil: Abalone: Lee (2004); Flounder: Kim *et al.* (2006); Lim *et al.* (2004); Japanese flounder: Kim *et al.* (2002); Shrimp: Re-Araujo and Ruiz (2003).

4.4.2 Livestock fats

Official definitions (AAFCO, 2008b)

Animal fat (IFN 4-00-409 Animal poultry fat) is obtained from the tissues of mammals and/or poultry in the commercial processes of rendering or extracting. It consists predominantly of glyceride esters of fatty acids and contains no additions of free fatty acids or other materials obtained from fats. It must contain, and be guaranteed for, not less than 90 percent total fatty acids, not more than 2.5 percent unsaponifiable matter and not more than one percent insoluble impurities. Maximum free fatty acids and moisture must also be guaranteed. If the product bears a name descriptive of its kind or origin i.e. “beef”, “pork”, “poultry”, it must correspond thereto. If an antioxidant is used, the common name or names must be indicated, followed by the words “used as a preservative”.

Hydrolysed animal fat, or oil, feed grade (IFN 4-00-376 Animal fat hydrolysed) is obtained in the fat processing procedures commonly used in edible fat processing or soap making. It consists predominately of fatty acids and must contain, and be guaranteed for, not less than 85 percent total fatty acids, not more than 6 percent unsaponifiable matter and not more than 1 percent insoluble impurities. Maximum moisture must also be guaranteed. Its source must be stated in the product name i.e. “hydrolysed animal fat”, “hydrolysed vegetable fat”, or “hydrolysed animal and vegetable fat”. If an antioxidant(s) is used, the common name or names must be indicated, followed by the words “used as a preservative”.

Industrial tallow: animal tissue containing fat is converted to tallow by a process called rendering. Basically, rendering is a procedure by which lipid material is separated from meat tissue and water under the influence of heat and pressure. There are two principal methods of rendering. In the wet rendering process (old method) the animal tissue is placed in an enclosed pressure vessel (cooker) and superheated steam is injected to provide both heat and agitation. The mixture is cooked at 110–120 °C (230–250 °F) for three to six hours. At the end of this period, the mixture settles into three phases: a top fat layer that is drawn off, an intermediate water layer and a bottom layer consisting primarily of proteinaceous material. This method is no longer in wide usage. Protein and fat quality were more easily compromised during the extended cooking time. In the dry rendering process, the fatty tissue is heated in jacketed containers, mechanical agitation is provided and the water is evaporated either at atmospheric or at increased pressure.

Renderers process a variety of raw materials from various sources, including: (1) packing house by-products, such as organ fats, offal, bones and blood; (2) boning house material that consists of bones and meat trimmings; (3) meat market trimmings, including adipose and intermuscular fats, bone, cartilage and meat trimmings; (4) restaurant greases and recovered cooking oils (these are processed and stored separately); and (5) fallen animals (Anon, 2009).

Lard: Lard is the fat rendered from fresh, clean, sound tissues of swine in good health at the time of slaughter. The composition, characteristics and consistency of lard vary greatly according to the feeding regime. The higher the level of unsaturated fats in the diets of pigs, the softer (higher iodine value) the fat (Anon, 2009).

Yellow grease: This material is usually made from restaurant greases (fats and oils from cooking). Another source could be from rendering plants producing lower quality greases. The specifications for yellow grease are as follows: (1) free fatty acids – 15 percent maximum; (2) fat analysis committee (FAC) – 39 maximum; and (3) moisture, unsaponifiables and impurities – 2 percent maximum (Anon, 2009).

Feed grade fats: Feed grade fats are often stabilized blends of animal and vegetable fats. They are produced in the commercial processes of rendering offal from livestock and poultry tissues. Feed fats consist predominantly of triglyceride of fatty acids and contain no added free fatty acids. Any tallow or grease could come under this category although only the low-grade tallow or greases are used since they are less expensive. With the expanding use of fats in feed, some feed grade fats may include acidulated vegetable soapstock blended with tallow/greases (Anon, 2009).

Reported fatty acid composition, quality criteria and usage

The reported fatty acid content of selected livestock fats which have been successfully used and/or tested within compound aquafeeds is shown in Table 45. In marked contrast to marine oils, livestock fats are composed primarily of saturated and monounsaturated fatty acids and are poor dietary sources of long chain polyunsaturated fatty acids. However, depending on the source, livestock oils may contain significant quantities of linolenic acid (18:2n-6) and to a much lesser extent, linoleic acid (18:n-3: Table 45). As with marine oils, the fatty acid composition of livestock fats can be quite variable, depending on the feeding regime of the animal concerned and raw material processed (Anon, 2009).

As with fish oils, livestock fats are also good dietary sources of cholesterol (Table 20, 46; Hertrampf and Pascual, 2000; Higgs and Dong, 2000). Table 46 shows the reported quality criteria for feed grade terrestrial fats. Table 47 shows the major feeding studies which have been conducted with terrestrial livestock fats in compound aquafeeds for the major cultivated finfish and crustacean species since 1995.

TABLE 45

Fatty acid composition of different terrestrial animal oil sources used in compound aquafeeds – fatty acid values expressed as percent total fatty acids

Fatty acid	Bovine ¹	Ovine ¹	Avian ¹	Porcine ¹	Tallow ²	Yellow grease ²
14:0	4	2	1	2	2.9	0.5 – 3.0
16:0	25	18	22	24	25.8	14.0 – 24.5
16:1n-7	4	2	6	3	2.0	-
18:0	19	16	6	14	21.5	7.0 – 15.5
18:1n-9	36	38	38	41	42.6	43.0 – 46.0
18:2n-6	3	13	20	10	2.3	8.0 – 29.0
18:3n-3	1	4	1	1	0.2	0.6 – 2.5
18:4n-3	-	-	1	-	-	-
20:0	-	-	-	-	-	-
20:1n-9	1	1	1	1	-	-
20:4n-3	-	-	-	-	-	-
20:4n-6	-	-	-	-	-	-
20:5n-3	-	-	-	-	-	-
22:0	-	-	-	-	-	-
22:1n-11	-	-	-	-	-	-
22:5n-3	-	-	-	-	-	-
22:6n-3	-	-	-	-	-	-
SFA	48	35	29	39	50.2	21.5 – 43.0
MUFA	41	41	44	45	44.9 ³	43.0 – 46.0
PUFA	4	17	22	11	2.5	8.6 – 31.5
lcPUFA	0	0	0	0	0	0
n-3 FA	1	4	2	1	0.2	0.6 – 2.5
n-6 FA	3	13	20	10	2.3	8.0 – 29.0
Cholesterol ⁴ (mg/100g)	109	-	58	93	-	-

¹ Glencross (2009); ² Anon (2009); ³ Also includes myristoleic acid 14:1n-5; ⁴ Higgs and Dong (2000).

Note: 18:1n-7 data combined with 18:1n-9, 20:1n-11 data combined with 20:1n-9, 22:1n-9 data combined with 22:1n-12; lcPUFA, long-chain polyunsaturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; SFA, saturated fatty acids (Glencross, 2009).

TABLE 46
Reported quality criteria for feed grade fats (FGF) from animal livestock

Criteria	FGF – for all feeds	FGF – for milk replacer	Beef tallow	Pork fat	Poultry fat
Titre (°C) ¹	29 – 45	38 – 41	38 – 43	32 – 37	28 – 33
MIU (%) ²	2 – 4	1	1	2	2
Free fatty acids (max)	40	5	5	15	15
Iodine value ³	40 – 100	47	47	68	85
Unsaturate/saturate ratio	1.0 – 3.0	1.0	1.0	1.6	2.6
Saturated fatty acids (% total)	25 – 50	50	50	38	28
Unsaturated fatty acids (%)	50 – 75	50	50	62	72
Linoleic	4 – 40	4	4	12	20

Source: Anon (2009).

¹ Titre is a measure of the solidification point of a fat after it has been saponified and the soaps reacidulated to free fatty acids – under the accepted United States trading rules, inedible fats with titres below 40 degrees centigrade are classed as grease and those with higher titres are classed as tallow. In general the higher the degree of unsaturation, the lower the titre (Anon, 2009).

² Moisture, Impurities, Unsaponifiables (MIU): the recommended moisture level is one percent or less; impurities are non-hazardous filterable materials not soluble in petroleum ether, and could be meat and bone particles remaining in the tallow after the rendering process even though it is filtered, or it could be foreign materials such as sand or metal particles picked up after processing due to storage and/or transport; unsaponifiables refers to any material within the tallow that will not saponify (convert into soap) when mixed with alkali, including non-triglycerides such as plant sterols and pigments (Anon, 2009).

³ Iodine value: the iodine number is a measure of the chemical unsaturation of the fat and the results are expressed as the number of grams of iodine absorbed by 100 grams of fat sample; unsaturated fats have higher iodine values than saturated fats, so the higher the value, the softer the fat and lower the titre (Anon, 2009).

TABLE 47
Major feeding studies conducted with terrestrial livestock fats in compound aquafeeds

BEEF/BOVINE FATS: African catfish: Appelbaum and Raj (2008); Red drum: Craig and Gatlin (1995); Beef tallow – Channel catfish: Fracalossi and Lovell (1995); Klinger *et al.* (1996); O'Neal and Kohler (2008); Eel: Luzzana *et al.* (2003); Japanese seabass: Xue *et al.* (2006); Tilapia: Yildirim-Aksoy *et al.* (2007); Trout: Bureau *et al.* (2008);

CHICKEN/POULTRY FATS: Atlantic halibut: Martins *et al.* (2009); Catfish (*Heterobranchus longifilis*): Babalola *et al.* (2009); Channel catfish: Sink and Lochmann (2008); Japanese seabass: Xue *et al.* (2006); Largemouth bass: Subhadra *et al.* (2006b); Salmon: Higgs *et al.* (2006); Huang *et al.* (2008); Rosenlund *et al.* (2001); Wagner *et al.* (2004); Wilson *et al.* (2007); Shrimp: Cheng and Hardy (2004); Trout: Liu *et al.* (2004); Turchini *et al.* (2003b, 2004, 2005);

PORK/SWINE FATS/LARD: Catfish (*Heterobranchus longifilis*): Babalola *et al.* (2009); Chinese mitten crab: Wu *et al.* (2007); Grass carp: Du *et al.* (2006, 2008); Jundia (*Rhamdia quelen*): Parra *et al.* (2008); Salmon: Olsen *et al.* (2005); Shrimp: Zhou *et al.* (2007); Sturgeon: Gao *et al.* (2005); Surubim: Campos *et al.* (2006); Martino *et al.* (2002); Tilapia: Huang *et al.* (1998); Chou and Shiau (1996, 1999); Trout: Turchini *et al.* (2003b, 2004, 2005);

TALLOW/GREASES (GENERAL): General: Bureau (2006); Bureau and Gibson (2004); Bureau *et al.* (2002); Yellow grease: Common carp: Yilmaz and Genc (2006).

4.4.3 Vegetable oils

Official definitions (AAFCO, 2008b)

Vegetable fat or oil (IFN 4-05-077 Vegetable oil) is the product of vegetable origin obtained by extracting the oil from seeds or fruits which are commonly processed for edible purposes. It consists predominantly of glyceride esters of fatty acids and contains no additions of free fatty acids or other materials obtained from fats. It must contain, and be guaranteed for, not less than 90 percent total fatty acids, not more than 2 percent unsaponifiable matter and not more than 1 percent insoluble impurities. Maximum free fatty acids and moisture must also be guaranteed. If the product bears a name descriptive of its kind or origin i.e. “soybean oil”, “cottonseed oil”, it must correspond thereto. If an antioxidant(s) is used, the common name or names must be indicated, followed by the words “used as a preservative”.

Hydrolysed vegetable fat, or oil, feed grade (IFN 4-05-076 Vegetable oil hydrolysed) is obtained in the fat processing procedures commonly used in edible fat processing or soap making. It consists predominately of fatty acids and must contain, and be

guaranteed for, not less than 85 percent total fatty acids, not more than 6 percent unsaponifiable matter and not more than 1 percent insoluble impurities. Maximum moisture must also be guaranteed. Its source must be stated in the product name i.e. “hydrolysed animal fat”, “hydrolysed vegetable fat”, or “hydrolysed animal and vegetable fat”. If an antioxidant(s) is used, the common name or names must be indicated, followed by the words “used as a preservative”.

Corn endosperm oil (IFN 4-02-852 Maize endosperm oil) is obtained by the extraction of oil from corn gluten. It consists predominantly of free fatty acids and glycerides and must contain not less than 85 percent total fatty acids, not more than 14 percent unsaponifiable matter, and not more than 1 percent insoluble matter. If an antioxidant(s) is used, the common name or names must be indicated followed by the word “preservative(s)”.

Soy lecithin (IFN 4-04-562 Soybean lecithin) is the mixed phosphatide product obtained from soybean oil by a degumming process. It contains lecithin, cephalin, and inositol phosphatides, together with glycerides of soybean oil and traces of tocopherols, glucosides and pigments. It must be designated and sold according to conventional descriptive grades with respect to consistency and bleaching.

Vegetable oil refinery lipid, feed grade (IFN 4-05-078 vegetable oil refinery lipid) is obtained in the alkaline refining of a vegetable oil for edible use. It consists predominantly of the salts of fatty acids, glycerides and phosphates. It may contain water and not more than 22 percent ash on a water-free basis. It may or may not be acidulated before using in commercial feeds, but if acidulated, it should be neutralized.

Reported fatty acid composition, quality criteria and usage

The reported fatty acid content of selected terrestrial plant oils which have been successfully used and/or tested within compound aquafeeds is shown in Table 48. With the exception of coconut oil and palm oil, where saturated fatty acids constitute the bulk of the fatty acids present, the majority of plant oils derived from oilseeds, pulses and cereal grains are rich dietary sources of monounsaturated and polyunsaturated fatty acids, and in particular of the essential fatty acids linolenic acid 18:2n-6 (safflower oil > sunflower oil > corn oil > soybean oil > cottonseed oil > sesame oil > peanut oil > rapeseed oil > echium oil) and to a lesser extent linoleic acid 18:n-3 (linseed oil > echium oil > rapeseed oil > soybean oil; Glencross, 2009; Table 48).

Depending on species, source and processing method, terrestrial plant oils are generally rich sources of phytosterols and lipid antioxidants, including tocopherols and carotenoids (Hardy and Roley, 2000; Hertrampf and Pascual, 2000; Higgs and Dong, 2000; Pickova and Mørkøre, 2007). Table 49 shows the major feeding studies which have been conducted with terrestrial plant oils in compound aquafeeds for the major cultivated finfish and crustacean species since 1995 (for general review, see also Turchini *et al.* 2009).

TABLE 48

Fatty acid composition of different terrestrial plant oil sources used in compound aquafeeds – fatty acid values expressed as % total fatty acids

Fatty acid	Soybean	Palm	Rapeseed	Sunflower	Coconut	Safflower	Linseed	Sesame	Olive	Corn	Cottonseed	Peanut
8:0	-	-	-	-	9	-	-	-	-	-	-	-
10:0	-	-	-	-	7	-	-	-	-	-	-	-
12:0	-	-	-	-	47	-	-	-	-	-	-	-
14:0	1	1	-	-	18	-	-	-	-	-	1	1
16:0	8	44	6	7	9	7	5	10	11	11	23	10
16:1n-7	2	1	1	-	-	-	-	-	1	-	1	1
18:0	3	5	3	6	3	3	4	6	4	2	3	2
18:1n-9	21	39	54	23	7	16	16	41	76	24	17	45
18:2n-6	57	11	20	64	-	73	19	43	7	58	52	32
18:3n-3	7	-	13	-	-	1	56	-	1	1	1	-
18:4n-3	-	-	-	-	-	-	-	-	-	-	-	-
20:0	1	-	1	-	-	-	-	1	-	-	-	-
20:1n-9	2	-	2	-	-	-	-	-	-	-	-	-
20:4n-3	-	-	-	-	-	-	-	-	-	-	-	-
20:4n-6	-	-	-	-	-	-	-	-	-	-	-	-
20:5n-3	-	-	-	-	-	-	-	-	-	-	-	-
22:0	-	-	-	1	-	-	-	-	-	-	-	-
22:1n-11	-	-	1	-	-	-	-	-	-	-	-	-
22:5n-3	-	-	-	-	-	-	-	-	-	-	-	-
22:6n-3	-	-	-	-	-	-	-	-	-	-	-	-
SFA	13	50	9	13	94	10	9	17	15	13	27	12
MUFA	24	40	57	23	7	16	16	41	77	24	18	46
PUFA	64	11	33	64	0	74	75	43	8	59	52	32
lcPUFA	0	0	0	0	0	0	0	0	0	0	0	0
n-3 FA	7	0	13	0	0	1	56	0	1	1	1	0
n-6 FA	57	11	20	64	0	73	19	43	7	58	52	32

Source: after Glencross (2009).

Note: 18:1n-7 data is combined with 18:1n-9, 20:1n-11 data is combined with 20:1n-9, 22:1n-9 data is combined with 22:1n-12; lcPUFA, long-chain polyunsaturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; SFA, saturated fatty acids (Glencross, 2009).

TABLE 49

Major feeding studies conducted with terrestrial plant oils in compound aquafeeds since 1995

Coconut/copra oil: African catfish: Legendre *et al.* (1995); European eel: McKenzie *et al.* (2000); Milkfish: Alava (1998); Red drum: Craig and Gatlin (1995); Craig *et al.* (1995); Shrimp: González-Félix *et al.* (2002); Sturgeon: McKenzie *et al.* (1997); Tilapia: Hsieh *et al.* (2007b); Trout: Ballestrazzi *et al.* (2003, 2006);

Corn/maize oil: Channel catfish: Fracalossi and Lovell (1995); Manning *et al.* (2007); Crayfish: Hernandez-Vergara *et al.* (2003); European seabass: Bell *et al.* (1997); Yildiz and Sener (2004); Flounder: Lim *et al.* (2004); Grass carp: Du *et al.* (2006, 2008); Grouper: Lin and Shiau (2003, 2007); Lin *et al.* (2007); Japanese seabass: Xue *et al.* (2006); Jundia (Rhamdia): Vargas *et al.* (2008); Mud crab: Holme *et al.* (2007); Sea urchins: Castell *et al.* (2004); Gonzalez-Duran *et al.* (2008); Sunshine bass: Lane *et al.* (2006); Surubim: Campos *et al.* (2006); Martino *et al.* (2002); Tilapia: Chou and Shiau (1996, 1999); Hsieh *et al.* (2007a, 2007b); Karapanagiotidis *et al.* (2007); Ribeiro *et al.* (2008); Yildirim-Aksoy *et al.* (2007); Tropical bagrid catfish: Ng *et al.* (2000);

Corn-germ oil: Common carp: Steffens *et al.* (1995);

Corn lecithin: Trout: Liu *et al.* (2004);

Cottonseed oil: African catfish: Legendre *et al.* (1995); Gilthead seabream: Wassef *et al.* (2007);

Echium oil: Atlantic cod: Bell *et al.* (2006); Salmon: Miller *et al.* (2008);

Hydrogenated coconut oil: Sea urchin: Gonzalez-Duran *et al.* (2008);

Hydrogenated vegetable oil: African catfish: Mukhopadhyay and Mishra (1998);

Linseed/flax oil: Abalone: Xu *et al.* (2004); Arctic charr: Lodemel *et al.* (2001); Olsen *et al.* (1999, 2000); Ringo *et al.* (2002); Asian seabass (barramundi): Raso and Anderson (2003); Atlantic cod: Jobling *et al.* (2008); Atlantic halibut: Martins *et al.* (2009); Eel: Gunasekera *et al.* (2002); European seabass: Montero *et al.* (2005b); Mourente and Dick (2002); Mourente and Bell (2006); Mourente *et al.* (2005a, 2005b); Richard *et al.* (2006a); Lim *et al.* (2004); Gilthead seabream: Benedito-Palos *et al.* (2007); Caballero *et al.* (2003, 2004); Ganga *et al.* (2005); Izquierdo *et al.* (2003, 2005, 2008); Menoyo *et al.* (2004); Montero *et al.* (2003, 2005, 2008); Wassef

TABLE 49 – CONTINUED

et al. (2007); **Grass carp**: Du *et al.* (2008); **Grouper**: Wu *et al.* (2002); **Japanese flounder**: Kim *et al.* (2002); **Jundia (*Rhamdia*)**: Vargas *et al.* (2008); **Murray cod**: Francis *et al.* (2006, 2007a, 2007b, 2007c); Turchini *et al.* (2006); **Pikeperch**: Molnar *et al.* (2006); **Salmon**: Bell *et al.* (1996, 2003b, 2004); Bendiksen *et al.* (2003); Menoyo *et al.* (2005); Regost *et al.* (2004); Rollin *et al.* (2003); Rosenlund *et al.* (2001); Schlechtriem *et al.* (2007); Stubhaug *et al.* (2006, 2007); Tocher *et al.* (2000, 2001, 2002, 2003a, 2003b); Torstensen *et al.* (2005, 2008); Wagner *et al.* (2004); Welker and Congleton (2003); Wilson *et al.* (2007); Zheng *et al.* (2004); **Sea urchins**: Castell *et al.* (2004); Gonzalez-Duran *et al.* (2008); **Sharpnose seabream**: Almada-Pagan *et al.* (2007); Piedecausa *et al.* (2007); **Shrimp**: González-Félix *et al.* (2002); Surubim: Campos *et al.* (2006); Martino *et al.* (2002); **Tilapia**: Aguiar *et al.* (2007); de Souza *et al.* (2008); Karapanagiotidis *et al.* (2007); Ribeiro *et al.* (2008); Yildirim-Aksoy *et al.* (2007); **Trout**: Drew *et al.* (2007); Drobna *et al.* (2006); Geurden *et al.* (2007, 2009); Kiron *et al.* (2004); Richard *et al.* (2006b); Robin *et al.* (2003); Serot *et al.* (2002); Tocher *et al.* (2001); Zelenka *et al.* (2003); **Turbot**: Regost *et al.* (2003a, 2003b); Robin *et al.* (2003); Serot *et al.* (2001);

Olive oil: **Abalone**: Van Barneveld *et al.* (1998); **African catfish**: Yilmaz *et al.* (2004); **European seabass**: Mourente and Dick (2002); Mourente *et al.* (2005); Parpoura and Alexis (2001); Yildiz and Sener (2003, 2004); **Salmon**: Rollin *et al.* (2003); Stubhaug *et al.* (2005); Torstensen *et al.* (2004a); **Shrimp**: Glencross *et al.* (1998); Izquierdo *et al.* (2006); **Tilapia**: Ribeiro *et al.* (2008); **Trout**: Caballero *et al.* (2002); Choubert *et al.* (2006); Rodriguez *et al.* (1997); **Yellowtail**: Seno *et al.* (2008);

Palm oil: **General**: Ng (2007); **Abalone**: Toledo-Aguero and Viana (2009); **African catfish/mudfish**: Legendre *et al.* (1995); Lim *et al.* (2001); Ng *et al.* (2003, 2004b); Olurin *et al.* (2004); **Atlantic cod**: Jobling *et al.* (2008); **European seabass**: Mourente and Bell (2006); Mourente *et al.* (2005b); Richard *et al.* (2006a); **Gilthead seabream**: Benedito-Palos *et al.* (2007); Fountoulaki *et al.* (2009); Ganga *et al.* (2005); Grigorakis *et al.* (2009); **Grouper**: Shapawi *et al.* (2008); **Salmon**: Bell *et al.* (2002); Jordal *et al.* (2007); Ng *et al.* (2004a, 2007); Rosenlund *et al.* (2001); Schlechtriem *et al.* (2007); Stubhaug *et al.* (2006); Torstensen *et al.* (2000, 2005, 2008); **Shrimp**: Kumaraguru Vasagam *et al.* (2005); **Tilapia**: Bahurmiz and Ng (2007); Ng *et al.* (2001, 2006); Karapanagiotidis *et al.* (2007); **Tropical bagrid catfish**: Ng *et al.* (2000); **Trout**: Caballero *et al.* (2002); Fonseca-Madriral *et al.* (2005); Ng *et al.* (2003b); Richard *et al.* (2006b); Tocher *et al.* (2004);

Palm kernel oil: **African catfish**: Ng *et al.* (2003); **Catfish (*Heterobranchus longifilis*)**: Babalola *et al.* (2009); **Tilapia**: Ng *et al.* (2001);

Peanut oil: **African catfish**: Legendre *et al.* (1995); **Grouper**: Lin *et al.* (2007); **Shrimp**: González-Félix *et al.* (2002); Kumaraguru Vasagam *et al.* (2005); Zhou *et al.* (2007);

Rapeseed/canola oil: **General**: Opsahl-Ferstad *et al.* (2003); **Abalone**: Toledo-Aguero and Viana (2009); **Asian seabass (*barramundi*)**: Raso and Anderson (2003); **Atlantic cod**: Jobling *et al.* (2008); **Atlantic halibut**: Martins *et al.* (2009); **Brook charr**: Guillou *et al.* (1995); **Channel catfish**: Manning *et al.* (2007); **Common carp**: Steffens *et al.* (1995); **European seabass**: Montero *et al.* (2005b); Mourente and Dick (2002); Mourente and Bell (2006); Mourente *et al.* (2005a, 2005b); Richard *et al.* (2006a); **Gilthead seabream**: Benedito-Palos *et al.* (2007); Caballero *et al.* (2003, 2004, 2006a, 2006b); Dias *et al.* (2009); Fountoulaki *et al.* (2009); Ganga *et al.* (2005); Grigorakis *et al.* (2009); Izquierdo *et al.* (2003, 2005, 2008); Montero *et al.* (2003, 2005); **Grouper**: Shapawi *et al.* (2007); **Jundia (*Rhamdia quelen*)**: Losekann *et al.* (2008); Parra *et al.* (2008); **Largemouth bass**: Subhadra *et al.* (2006b); **Murray cod**: Francis *et al.* (2006, 2007a, 2007b, 2007c); Turchini *et al.* (2006); **Red seabream**: Glencross *et al.* (2003c, 2003d); Huang *et al.* (2007); **Salmon**: Bahaud *et al.* (2009); Bell *et al.* (2001, 2003a, 2003b); Bendiksen *et al.* (2003); Grant *et al.* (2008); Higgs *et al.* (2006); Huang *et al.* (2008); Jordal *et al.* (2005, 2006, 2007); Karalazos *et al.* (2007); McKenzie *et al.* (1998); Miller *et al.* (2007b, 2008); Ng *et al.* (2004a); Pratoomyot *et al.* (2008); Rennie *et al.* (2005); Rosenlund *et al.* (2001); Schlechtriem *et al.* (2007); Seierstad *et al.* (2005, 2008, 2009); Stubhaug *et al.* (2005, 2006, 2007); Tocher *et al.* (2000, 2001, 2003a, 2003b); Todorcevic *et al.* (2009); Torstensen *et al.* (2004a, 2004b, 2005, 2008); Wilson *et al.* (2007); **Shrimp**: Zhou *et al.* (2007); **Sunshine bass**: Lewis and Kohler (2008b); Wonnacott *et al.* (2004); **Trout**: Caballero *et al.* (2002); Drew *et al.* (2007); Geurden *et al.* (2007, 2009); Nielsen *et al.* (2005); Parova and Rehulka (1997); Rehulka and Parova (2000); Richard *et al.* (2006b); Tocher *et al.* (2001); Turchini *et al.* (2003b, 2004, 2005);

Rice oil: **Jundia (*Rhamdia quelen*)**: Losekann *et al.* (2008);

Safflower oil: **Grouper**: Wu *et al.* (2002); **Trout**: Kiron *et al.* (2004);

Shea butter oil: **Catfish (*Heterobranchus longifilis*)**: Babalola *et al.* (2009);

Soybean oil: **Abalone**: Toledo-Aguero and Viana (2009); **Arctic charr**: Ringo *et al.* (2002); **Asian seabass (*barramundi*)**: Catacutan and Coloso (1997); Raso and Anderson (2003); **Atlantic cod**: Mørkøre (2006); Mørkøre *et al.* (2007); **Black seabream**: Peng *et al.* (2008); **Brook charr**: Guillou *et al.* (1995); **Channel catfish**: Klinger *et al.* (1996); **Common carp**: Geurden *et al.* (2008); Zhou *et al.* (2008); **European catfish**: Has-Schon *et al.* (2004); **European seabass**: Figueiredo-Silva *et al.* (2005); Martins *et al.* (2006); Montero *et al.* (2005b); Parpoura and Alexis (2001); Yildiz and Sener (2003, 2004); **Gilthead seabream**: Caballero *et al.* (2003, 2004, 2006a, 2006b); Dias *et al.* (2009); Fountoulaki *et al.* (2009); Grigorakis *et al.* (2009); Izquierdo *et al.* (2003, 2005, 2008); Martinez-Llorens *et al.* (2007b); Menoyo *et al.* (2004); Montero *et al.* (2003, 2005a, 2008); Wassef *et al.* (2007); **Grouper**: Lin *et al.* (2007); Shapawi *et al.* (2008); **Halibut**: Haugen *et al.* (2006); **Japanese flounder**: Kim *et al.* (2002); **Japanese seabass**: Xue *et al.* (2006); **Jundia (*Rhamdia quelen*)**: Losekann *et al.* (2008); **Red drum**: Tucker *et al.* (1997); **River chub**: Huang *et al.* (2001); **Salmon**: Gjoen *et al.* (2004); Grisdale-Helland *et al.* (2002b); Jordal *et al.* (2007); Pratoomyot *et al.* (2008); Regost *et al.* (2004); Røra *et al.* (2003); Rosenlund *et al.* (2001); Welker and Congleton (2003); **Sharpnose seabream**: Almada-Pagan *et al.* (2007); Piedecausa *et al.* (2007); **Shrimp**: Cheng and Hardy (2004); González-Félix *et al.* (2002); Zhou *et al.* (2007); **Sole**: Morais *et al.* (2006); **Sturgeon**: Sener *et al.* (2005); **Surubim**: Campos *et al.* (2006); Martino *et al.* (2002); **Tilapia**: El-Syaed *et al.* (2005); Huang *et al.* (1998); Lanna *et al.* (2004); Ribeiro *et al.* (2008); **Tropical bagrid catfish**: Ng *et al.* (2000); **Trout**: Caballero *et al.* (2002); Figueiredo-Silva *et al.* (2005); Martins *et al.* (2006); Olsen *et al.* (2003); Serot *et al.* (2002); Sener and Yildiz (2003); **Turbot**: Regost *et al.* (2003a, 2003b); Serot *et al.* (2001); **Walleye**: Clayton *et al.* (2008); **Yellow catfish**: Han *et al.* (2005); **Yellow perch**: Twibell *et al.* (2001);

Soy acid oil: **Common carp**: Yilmaz and Genc (2006);

TABLE 49 – CONTINUED

Soy lecithin: General: Coutteau *et al.* (1997); **Arctic char:** Olsen *et al.* (1999); **Chinese mitten crab:** Sui *et al.* (2009); Wu *et al.* (2007); **Cobia:** Niu *et al.* (2008); **Common carp:** Geurden *et al.* (1995a, 1995c, 2008); **Crayfish:** Thompson *et al.* (2003a, 2003b); **European seabass:** Geurden *et al.* (1995b); **Flounder:** Kim *et al.* (2006); **Gilthead seabream:** Benedito-Palos *et al.* (2008); Liu *et al.* (2003); ***Pelteobagrus fulvidraco*:** Lu *et al.* (2008); **Red drum:** Craig and Gatlin (1997); **Salmon:** Olsen *et al.* (2005); **Sea urchins:** Gibbs *et al.* (2009); Gonzalez-Duran *et al.* (2008); **Shrimp:** Coutteau *et al.* (1996, 1997, 2000); Gong *et al.* (2000a, 2000b, 2001, 2004); González-Félix *et al.* (2002); Kontara *et al.* (1997); Kumaraguru vasagam *et al.* (2005); Paibulkichakul *et al.* (1998); Re-Araujo and Ruiz (2003); Thongrod and Boonyaratpulin (1998); **South American catfish:** Arslan *et al.* (2008); **Trout:** Liu *et al.* (2004); Olsen *et al.* (2003); Rehulka and Minarik (2003); Salvador *et al.* (2007);

Sunflower oil: **Abalone:** Toledo-Aguero and Viana (2009); **African catfish:** Mukhopadhyay and Mishra (1998); Mukhopadhyay and Rout (1996); Ng *et al.* (2003); **Atlantic halibut:** Martins *et al.* (2009); **Catfish (*Heterobranchus longifilis*):** Babalola *et al.* (2009); **Common carp:** Steffens *et al.* (1995); **Crayfish:** Fotedar (2004); **Eel:** Gunasekera *et al.* (2002); **European seabass:** Yildiz and Sener (2003, 2004); **Gilthead seabream:** Wassef *et al.* (2007); **Grouper:** Lin *et al.* (2007); **Jundia (*Rhamdia quelen*):** Parra *et al.* (2008); **Rohu:** Mishra and Samantaray (2004); **Salmon:** Bell *et al.* (1996); Bransden *et al.* (2003); Jutfelt *et al.* (2007); Rollin *et al.* (2003); Torstensen *et al.* (2000); Wagner *et al.* (2004); **Sturgeon:** Gao *et al.* (2005); Sener *et al.* (2005); **Tilapia:** Aguiar *et al.* (2007); de Souza *et al.* (2008); Ng *et al.* (2001); **Trout:** Drobna *et al.* (2006); Parova and Rehulka (1997); Rehulka and Parova (2000); Sener and Yildiz (2003); Zelenka *et al.* (2003).

4.5 OTHER PLANT INGREDIENTS

4.5.1 Terrestrial plant products

Official definitions (AAFCO, 2008b)

Almond hulls (IFN 4-00-358 Almond hulls ground) are obtained by drying the pericarp which surrounds the nut. Almond hulls shall contain not more than 13 percent moisture, 15 percent crude fibre and 9 percent ash. Total soluble sugars expressed as invert shall not be less than 18 percent. Almond hulls shall be processed in accordance with good manufacturing practices and be reasonably free of foreign material.

Almond hulls with almond shells (IFN 1-27-475 Almond hulls with shells) must not contain more than 29 percent crude fibre, 9 percent ash and 13 percent moisture. They shall be processed in accordance with good manufacturing practice and be reasonably free of foreign material.

Almond shells, ground (IFN 4-00-358 Almond hulls ground) is obtained by drying and grinding that portion of the almond fruit which surrounds the nut. It must be reasonably free of the nut shell and other foreign material.

Apple pomace, dried (IFN 4-00-423 Apple pomace dehydrated) is the sound, dried residue obtained by the removal of cider from apples.

Apple pectin pulp, dried (IFN 4-00-425 Apple pomace without pectin dehydrated) is the sound, dried residue obtained by the removal of pectin from apple products.

Aspirated grain fractions (IFN 4-12-208 Cereals-oilseeds grain and seed fractions aspirated) are obtained during the normal aspiration of cereal grains and/or oilseeds for the purpose of environmental control and safety within a grain handling facility. It shall consist primarily of seed parts and may not contain more than 15 percent ash. It shall not contain aspirations from medicated feeds.

Bagasse (IFN 1-04-686 Sugarcane bagasse dehydrated) is that portion of the stalk of sugar cane, after removal of leaves and tops, remaining after extraction of the juice.

Bakery product, dried (IFN 1-32-188 Beet, sugar-fibre, dehydrated) is the refined plant material derived from sugar beet pulp after sugar extraction which has been further refined by washing, drying and milling. It shall contain a total dietary fibre (crude fibre) content of not less than 80 percent and an ash content of not more than 3 percent.

Beet fibre, dried, plain (IFN 1-32-188 Beet, sugar-fibre, dehydrated) is the refined plant material derived from sugar beet pulp after sugar extraction which has been further refined by washing, drying and milling. It shall contain a total dietary fibre (crude fibre) content of not less than 80 percent and an ash content of not more than 3 percent.

Beet molasses (IFN 4-30-289 Beet sugar molasses) is a by-product of the manufacture of sucrose from sugar beets. It must contain not less than 48 percent total sugars expressed as invert and its density determined by double dilution must not be less than 79.5 Brix.

Beet pulp, dried, molasses (IFN 4-00-672 Beet sugar pulp with molasses dehydrated) is the dried residue from sugar beets which has been cleaned and freed from crowns, leaves and sand, and which has been extracted in the process of manufacturing sugar to which has been added (beet) molasses obtained in the extraction of sugar.

Beet pulp, dried, plain (IFN 4-00-669 Beet sugar pulp dehydrated) is the dried residue from sugar beets which has been cleaned and freed from crowns, leaves and sand, and which has been extracted in the process of manufacturing sugar.

Beet pulp, dried product (IFN 4-00-675 Beet sugar pulp with Steffen's filtrate dehydrated) is the dried residue from sugar beets which has been cleaned and freed from crowns, leaves and sand, and which has been extracted in the process of manufacturing sugar to which has been added the concentrated Steffens filtrate obtained in the extraction of the sugar from the beets.

Beet molasses, dried product (IFN 4-20-866 Beet sugar pulp with molasses dehydrated with more than 45 percent invert sugar) is the properly dried mixture of molasses and molasses dried beet pulp containing not less than 45 percent total sugar expressed as invert.

Buckwheat hulls (IFN 1-12-238 Buckwheat hulls) is the product consisting primarily of the outer covering of the buckwheat obtained in the milling of buckwheat flour.

Buckwheat middlings (IFN 5-12-23 7 Buckwheat flour by-product without hulls) is that portion of the buckwheat grain immediately under the hull after separation of the flour. It must contain no more hulls than is obtained in the usual process of buckwheat milling and must contain not more than 10 percent crude fibre.

Cane molasses (IFN 4-13-251 Sugarcane molasses) is a by-product of the manufacture of sucrose from sugar cane. It must contain not less than 43 percent total sugars expressed as invert. If its moisture content exceeds 27 percent, its density determined by double dilution must not be less than 79.5 Brix.

Cereal food fines (IFN 5-0 1-199 Cereals food fines) consists of particles of breakfast cereals obtained as a by-product of their processing.

Chaff and/or dust (IFN 4-02-149 Cereals-legumes chaff and/or dust) is material that is separated from grains or seeds in the usual commercial cleaning processes. It may include hulls, joints, straw, mill or elevator dust, sweepings, sand, dirt, grains or seeds. It must be labeled, "chaff and/or dust". If it contains more than 15 percent ash the words "sand" and "dirt" must appear on the label.

Citrus molasses (IFN 5-01-241 Citrus syrup) is the partially dehydrated juices obtained from the manufacture of dried citrus pulp. It must contain not less than 45 percent total sugars expressed as invert and its density determined by double dilution must not be less than 17.0 Brix.

Clipped oat by-product (IFN 1-03-269 Oats grain clipped by-product) is obtained in the manufacture of clipped oats. It may contain the light chaffy material broken from the end of the hulls, empty hulls, light immature oats and dust. It must not contain an excessive amount of oat hulls.

Cottonseed hulls (IFN 1-01-599 Cottonseed hulls) consist primarily of the outer covering of the cottonseed.

Cottonseed screenings (IFN 4-12-023 Cottonseed screenings) is obtained in the commercial processing of cottonseeds for planting purposes. It consists of lint, stems, leaves, small and immature seeds, sand and/or dirt. It must contain a minimum of 12 percent crude protein and not more than 30 percent crude fibre. It must be labelled with minimum guarantees for crude protein and crude fat and maximum guarantees for crude fibre and ash. If it contains more than 6.5 percent ash, the words “sand” and/or “dirt” must appear in the product name.

Dairy food by-products (IFN 5-30-260 Cattle mill process residue) are the products resulting from the collection of solids contained in the wash water from the normal processing and packaging of various food manufacturing plants. Dairy products are the primary source but non-dairy products may occasionally constitute a minor amount of the total volume. No sanitary sewer wastes may be included. This product is to be fed at levels less than 25 percent of the animal’s total dry matter intake. Minimum percent of solids, crude protein and crude fat and maximum percent ash must be prominently declared on the label.

Feeding oat meal (IFN 4-03-303 Oats cereal by-product less than 4% fibre) is obtained in the manufacture of rolled oat groats or rolled oats and consists of broken oat groats, oat groat chips and floury portions of the oat groats, with only such quantity of finely ground oat hulls as is unavoidable in the usual process of commercial milling. It must not contain more than 4 percent crude fibre.

Food processing waste is composed of any and all animal and vegetable products from basic food processing. This may include manufacturing or processing waste, cannery residue, production over-run and otherwise unsaleable material. The guaranteed analysis shall include the maximum moisture, unless the product is dried by artificial means to less than 12 percent moisture and designated as “Dehydrated Food Processing Waste”. If part of the grease and fat is removed, it must be designated as “Degreased”.

Forage products may include one or more of the following: Alfalfa meal (dehydrated), Flax plant product, Alfalfa hay (ground), Ground grass, Alfalfa meal (sun cured), Lespedeza meal, Coastal bermuda grass hay, Lespedeza stem meal, Corn plant (dehydrated), Soybean hay (ground), and Dehydrated silage (ensilage pellets).

Grain products (in any of the normal forms such as whole, ground, cracked, screen cracked, flaked, kibbled, toasted or heat processed): barley, wheat, corn, rice-ground brown, ground paddy, ground rough, grain sorghum, broken or chipped rice, mixed feed oats, rice (brewers), oats, rye and triticale.

Grain screenings (IFN 4-00-542 Barley screenings, IFN 4-20-687 Maize screenings, IFN 4-03-329 Oats screenings, IFN 4-08-085 Rice screenings, IFN 4-27-721 Sorghum screenings, IFN 4-05-216 Wheat screenings) are those screenings containing 70 percent or more grains, including light and broken grains. It may contain wild buckwheat and wild oats. The term “Grain Screenings” may be used for unspecified kinds of grain or the predominating kind of grain (if in excess of 50 percent) may be declared as the first word or words in the name. It may contain no more than 6.5 percent ash.

Grass, ground (IFN 1-02-215 Grass hay sun-cured ground) is obtained by drying and grinding grass which has been cut before formation of the seed. If a species name is used, the produce must correspond thereto.

Mixed feed nuts are the residue of the normal packaging and processing for human consumption of shelled tree nut and peanut products. This residue shall consist of broken, small, shriveled and cull edible tree nuts or peanuts of two or more kinds and shall be suitable for animal consumption. If salt has been added during processing, a guarantee must be made for maximum sodium.

Mixed feed oats (IFN 4-08-026 Oats wild-oats grain) consists of a mixture of grain containing at least 30 percent of cultivated oats provided that the mixture consists of either (a) not less than 65 percent of cultivated and wild oats combined or (b) not less than 65 percent of wild oats. It must contain more than 25 percent of other grains, not more than 6 percent heat damaged kernels of oats, wild oats and other grains, and not more than 10 percent foreign material which may include 4 percent foreign seeds.

Molasses products may include one or more of the following: beet molasses, cane molasses, citrus molasses and starch molasses.

Oat groats (IFN 4-03-331 Oats groats) are cleaned oats with the hulls removed.

Oat hulls (IFN 1-03-28 1 Oats hulls) consists primarily of the outer covering of oats, obtained in the milling of table cereals or in the groating of oats from clean oats.

Oat mill by-product (IFN 1-03-332 Oats groats by-product less than 22 percent fibre) is the by-product obtained in the manufacture of oat groats, consisting of oat hulls and particles of the groat, and containing not more than 25 percent crude fibre.

Pasta product is a mixture of dry, whole and broken particles of noodles, macaroni, spaghetti, etc., or a mixture of these resulting from the manufacturing and packaging of edible pasta products and which has been mechanically separated from any non-edible materials.

Paunch product, dehydrated (IFN 1-09-3 27 Animal rumen contents dehydrated) is a product composed of the contents of the rumen of slaughtered cattle, dehydrated at temperatures over 100 °C to a moisture content of 12 percent or less, such dehydration designed to destroy any pathogenic bacteria. It shall be dehydrated promptly after removal from the rumen to prevent decomposition.

Peanut hulls (IFN 1-08-028 Peanut hulls or Peanut pods) consists of the outer hull of the peanut shell.

Peanut skins (IFN 1-03-631 Peanut seed coats) is the outer covering of the peanut kernel, exclusive of hulls, as obtained in ordinary commercial processing. The product may contain broken peanut kernels.

Potato products, dried (IFN 4-03-775 Potato process residue dehydrated) is the dried residue of potato pieces, peeling, hulls, etc., obtained from the manufacture of processed potato products for human consumption. The residue may contain up to 3 percent hydrate of lime which may be added to aid in processing.

Rice bran (IFN 4-03-928 Rice bran with germs) is the pericarp or bran layer and germ of the rice, with only such quantity of hull fragments, chipped, broken, or brewers' rice, and calcium carbonate as is unavoidable in the regular milling of edible rice. It must contain not more than 13 percent crude fibre. When the calcium carbonate exceeds 3 percent, the percentage must be declared in the brand name i.e. "Rice Bran with Calcium Carbonate not exceeding %".

Rice bran solvent extracted (IFN 4-03-930 Rice bran with germ meal solvent extracted) is obtained by removing part of the oil from rice bran by the use of solvents and must contain not less than 14 percent crude protein and not more than 14 percent crude fibre.

Rice by-products fractions (IFN 1-08-03 3 Rice hull fines) is obtained by screening and aspirating ground rice hulls. It is used primarily as a pelleting aid and is composed of such fine particles of ground rice hulls, spongy parenchyma and minute amounts of rice flour, rice germ, pericarp and rice starch as will pass an 80 mesh screen and contain not less than 5 percent crude protein, 1.5 percent crude fat and not more than 25 percent crude fibre.

Rice grain ground (IFN 4-03-938 Rice grain ground) ground rough rice or ground paddy is the entire product obtained in grinding the whole rice grain including the hulls.

Rice groats brown (IFN 4-03-935 Rice groats ground) is the entire product obtained in grinding the rice kernels after the hulls have been removed.

Rice groats polished broken (IFN 4-03-932 Rice groats polished broken), chipped rice, broken rice or brewers rice is the small fragments of rice kernels that have been separated from the larger kernels of milled rice.

Rice hulls (IFN 1-08-075 Rice hulls) consists primarily of the outer covering of the rice.

Rice mill by-product (IFN 1-03-941 Rice mill run) is the total offal obtained in the milling of rice. It consists of rice hulls, rice bran, rice polishings and broken rice grains. Its crude fibre content must not exceed 32 percent.

Rice polishings (IFN 4-03-943 Rice polishing) is a by-product of rice obtained in the milling operation of brushing the grain to polish the kernel.

Restaurant food waste is composed of edible food waste collected from restaurants, cafeterias, and other institutes of food preparation. Processing and/or handling must remove any and all undesirable constituents including crockery, glass, metal, string and similar materials. The guaranteed analysis shall include maximum moisture, unless the product is dried by artificial means to less than 12 percent moisture and designated as "Dehydrated Restaurant Food Waste". If part of the grease and fat is removed, it must be designated as "Degreased".

Roughage products may include one or more of the following: almond hulls (ground), apple pectin pulp (dried), malt hulls, apple pomace (dried), oat mill by-product, bagasse, oat hulls, barley hulls, oat mill by-product, barley mill by-product, peanut hulls, beet pulp (dried), rice hulls, buckwheat hulls, rice mill by-product, citrus meal (dried), rye mill run, citrus pulp (dried), soybean hulls, citrus seed meal, soybean mill feed, corn cob fractions, soybean mill run, cottonseed hulls, sunflower hulls, flax straw by-products, straw (ground) and tomato pomace (dried).

Rye middlings consist of rye feed and rye red dog combined in the proportions obtained in the usual process of milling rye flour and must not contain more than 8.5 percent crude fibre.

Rye mill run (IFN 4-04-03 4 Rye mill run) is obtained in the usual process of milling rye flour from cleaned and scoured rye, consisting principally of the mill run of the outer covering of the rye kernel and the rye germ with small quantities of rye flour and aleurone, and must not contain more than 9.5 percent crude fibre.

Silage (ensilage) pellets, dehydrated (IFN 3-08-812 Alfalfa silage dehydrated pelleted) are pellets made from wholesome silage (ensilage) which has been dried by thermal means and formed into pellets by compacting and forcing through die openings by a mechanical process. The product should bear a name descriptive of the type of silage (ensilage) pelleted, such as “Dehydrated Alfalfa Silage (ensilage) Pellets”.

Soybean hay ground (IFN 1-04-559 Soybean hay sun-cured ground) is the ground soybean plant including the leaves and beans. It must be reasonably free of other crop plants and weeds and must contain not more than 33 percent crude fibre.

Soybean hulls (IFN 1-04-560 Soybean seed coats [hulls]) consist primarily of the outer covering of the soybean.

Soybean mill feed (IFN 4-04-594 Soybean flour by-product) is composed of soybean hulls and the offal from “the tail of the mill” which results from the manufacture of soy grits or flour. It must contain not less than 13 percent crude protein and not more than 32 percent crude fibre.

Soybean mill run (IFN 4-04-595 Soybean mill run) is composed of soybean hulls and such bean meats that adhere to the hulls which result from normal milling operations in the production of dehulled soybean meal. It must contain not less than 11 percent crude protein and not more than 35 percent crude fibre.

Starch molasses (IFN 4-08-037 Maize-sorghum grain starch molasses) is a by-product of the manufacture of dextrose from starch derived from corn or grain sorghums in which the starch is hydrolysed by use of enzymes and/or acid. It must contain not less than 43 percent reducing sugars expressed as dextrose and not less than 50 percent total sugars expressed as dextrose. It shall contain not less than 73 percent total solids.

Straw, ground (IFN 1-04-682 Cereals straw ground, IFN 1-12-232 Alfalfa straw ground, IFN 1-12-233 Bluegrass straw ground) is the ground product remaining after separation of the seed from mature forage plants. The source of the material shall constitute a part of the name of the product i.e. “Ground Bluegrass Straw”, “Ground Alfalfa Straw”.

Sunflower hulls (IFN 1-04-720 Sunflower hulls) consists of the outer covering of sunflower seed.

Tapioca/manioc and cassava root (IFN 4-18-896 Cassava tubers, sun-cured pelleted) is the whole root chipped mechanically into small pieces and sun dried on concrete surfaces for two to three days and then the chips are pelleted.

Tomato pomace, dried (IFN 5-05-041 Tomato pomace dehydrated) is the dried mixture of tomato skins, pulp and crushed seeds. If the pomace contains spices used in the production of the tomato product, this must be shown in the name as “Dried Spiced Tomato Pomace”.

Wheat bran (IFN 4-05-190 Wheat bran) is the coarse outer covering of the wheat kernel as separated from cleaned and scoured wheat in the usual process of commercial milling.

Wheat flour (IFN 4-05-199 Wheat flour less than 1.5 percent fibre) consists principally of wheat flour together with fine particles of wheat bran, wheat germ and the offal from the “tail of the mill”. This product must be obtained in the usual process of commercial milling and must contain not more than 1.5 percent crude fibre.

Wheat germ meal (IFN 5-05-218 Wheat germs ground) consists chiefly of wheat germ together with some bran and middlings or shorts. It must contain not less than 25 percent crude protein and 7 percent crude fat.

Wheat middlings (IFN 4-05-205 Wheat flour by-product less than 9.5 percent fibre) consists of fine particles of wheat bran, wheat shorts, wheat germ, wheat flour and some of the offal from the “tail of the mill”. This product must be obtained in the usual process of commercial milling and must contain not more than 9.5 percent crude fibre.

Wheat mill run (IFN 4-05-206 Wheat mill run less than 9.5 percent fibre) consists of coarse wheat bran, fine particles of wheat bran, wheat shorts, wheat germ, wheat flour and the offal from the “tail of the mill”. This product must be obtained in the usual process of commercial milling and must contain not more than 9.5 percent crude fibre.

Wheat red dog (IFN 4-05-203 Wheat flour by-product less than 4 percent fibre) consists of the offal from the “tail of the mill” together with some fine particles of wheat bran, wheat germ and wheat flour. This product must be obtained in the usual process of commercial milling and must contain not more than 4 percent crude fibre.

Wheat shorts (IFN 4-05-201 Wheat flour by-product less than 7 percent fibre) consists of fine particles of wheat bran, wheat germ, wheat flour and the offal from the “tail of the mill”. This product must be obtained in the usual process of commercial milling and must contain not more than 7 percent crude fibre.

Reported proximate composition and usage

The reported proximate composition of selected terrestrial low-protein feed ingredient sources commonly used and/or tested within compound aquafeeds is shown in Table 51. In general, the nutritional value and digestibility of these carbohydrate-rich ingredients greatly improves with heat processing or cooking either due to the cell wall disruption/gelatinization of the starch component present and/or due to the destruction of the heat sensitive anti-nutritional factors present (Allan and Booth, 2004; Podoskina *et al.* 1997; Francis *et al.*, 2001; Gatlin *et al.* 2007; Hertrampf and Pascual, 2000; Tacon, 1997). Table 52 shows some of the major reported feeding studies which have been

conducted with these ingredients in compound aquafeeds for the major cultivated finfish and crustacean species since 1995.

TABLE 50

Reported average proximate composition of selected terrestrial low-protein terrestrial plant products – all values are expressed as % by weight on as-fed basis: Water-H₂O; Crude Protein-CP; Lipid or Ether Extract-EE; Crude Fibre-CF; Nitrogen-Free Extractives-NFE; Ash; Calcium-Ca; Phosphorus-P

Product	Average composition (% by weight)								Ref. ¹
	H ₂ O	CP	EE	CF	NFE	Ash	Ca	P	
CEREAL PRODUCTS									
Barley products (<i>Hordeum vulgare</i>/H. <i>distichum</i>)									
Grain	12.4	10.5	1.8	5.6	67.1	2.6	0.05	0.37	1
Bran	10.0	11.6	3.4	14.6	55.4	5.0	0.36	0.70	1
Middlings	11.0	14.5	4.5	9.3	56.4	4.3	-	-	1
Mill run	10.0	10.5	2.5	14.1	58.8	4.1	-	-	1
Grain screenings (sweepings)	11.0	11.2	2.3	8.4	64.0	3.1	0.33	0.29	1
Pearl by-product	10.4	13.2	3.5	10.7	57.1	5.1	0.04	0.41	1
Malt, dehydrated	9.0	14.1	1.7	2.6	70.4	2.2	0.07	0.46	1
Corn/maize (<i>Zea mays</i>)									
Grain, ground	12.2	9.6	3.9	2.0	70.8	1.5	0.02	0.28	1
Grain, flaked	11.0	10.0	3.6	1.2	73.2	1.0	-	-	1
Hominy feed	9.7	10.7	5.8	5.0	66.2	2.6	0.05	0.50	1
Feed meal	12.5	9.0	4.5	3.5	68.0	2.5	0.05	0.40	1
Corn-and-cob meal (corn ears)	12.8	7.8	3.1	8.6	66.2	1.5	0.05	0.22	1
Cobs, ground meal	9.7	2.5	0.6	34.5	51.2	1.5	0.10	0.06	1
Cobs (Egypt)	11.3	2.4	0.3	31.4	51.8	2.9	-	-	4
Cannery process residue (fresh)	77.0	2.0	0.6	5.1	13.9	1.4	0.18	0.14	1
Cannery process residue (silage)	69.5	2.5	1.2	9.5	15.7	1.6	0.10	0.24	1
Millet (<i>P. typhoideum</i>; <i>S. italica</i>; <i>E. crusgalli</i>; <i>P. miliaceum</i>; <i>E. coracana</i>; <i>P. scrobiculatum</i>)									
Grain	10.7	11.2	3.9	6.3	64.6	3.3	0.06	0.30	1
Hulls	8.7	4.8	1.3	38.3	41.2	5.7	0.60	0.30	1
Oats (<i>Avena sativa</i>)									
Grain	11.5	10.4	4.8	11.5	58.4	3.4	0.10	0.32	1
Dehulled grain (naked, groats)	10.9	13.6	6.4	2.8	64.0	2.3	0.09	0.39	1
Hulls	7.7	3.5	1.4	31.4	49.5	6.5	0.21	0.12	1
Oatmeal/middlings (feeding)	9.5	15.9	5.7	2.9	63.8	2.2	0.06	0.43	1
Oat-mill feed	7.7	5.0	1.6	28.5	51.1	6.1	0.12	0.12	1
Oat shorts	9.0	12.8	5.6	13.5	54.3	4.8	-	-	1
Oat sprouts, fresh	86.8	2.4	0.7	2.6	7.0	0.5	-	-	1
Rice (<i>Oryza sativa</i>)									
Rough (paddy) rice	11.2	8.3	1.6	9.4	65.1	4.4	0.07	0.26	1
Brown (cargo) rice, dehulled	9.0	9.1	1.6	1.0	78.2	1.0	0.07	0.65	1
Broken (brewers) rice (rice meal)	11.3	7.5	0.6	0.3	79.7	0.6	0.19	0.13	1
Polished (milled) rice	11.8	7.1	0.3	0.3	79.7	0.8	0.06	0.18	1
Hulls (husk, chaff)	9.4	3.7	1.0	36.9	32.6	16.4	0.09	0.07	1
Hulls (China)	8.5	3.0	0.7	39.3	-	22.8	-	-	5
Bran (full-fat)	10.0	12.2	11.8	12.3	40.6	13.1	0.12	1.38	1
Bran (solvent extracted)	10.5	12.3	2.1	14.6	47.9	12.6	0.20	1.33	1
Bran (defatted, China)	11.0	15.5	1.0	8.5	-	8.0	0.10	1.40	5
Bran (full fat, China)	10.5	13.0	14.0	12.0	-	16.7	0.10	1.60	5
Bran (full-fat, Bangladesh)	10.0	12.6	16.5	16.3	40.9	13.6	-	-	3
Bran (India)	8.7	9.0	4.5	13.2	40.8	23.8	-	-	6
Bran type I (Viet Nam)	12.4	13.0	12.0	7.8	46.4	8.4	-	-	2
Bran type II (Viet Nam)	9.7	9.8	6.8	18.6	40.1	15.1	-	-	2
Bran type III (Viet Nam)	10.3	7.6	5.0	23.3	38.9	14.9	-	-	2
Bran (defatted) (Viet Nam)	11.0	14.9	3.6	11.2	47.6	10.4	-	-	2
Polishings	10.0	12.1	11.5	4.7	52.9	8.8	0.05	1.26	1
Pollards (mix of bran/polishings)	11.1	12.8	11.7	7.6	48.0	8.8	0.05	1.41	1
Rice-mill feed (mix of hulls/bran)	8.3	6.6	5.3	29.4	36.1	14.3	0.10	0.45	1

TABLE 50 – CONTINUED

Product	Average composition (% by weight)								Ref. ¹
	H ₂ O	CP	EE	CF	NFE	Ash	Ca	P	
Rye (<i>Secale cereale</i>)									
Grain	13.0	11.2	1.5	2.3	70.3	1.7	0.06	0.34	1
Bran	11.1	15.9	2.9	6.3	59.3	4.5	0.10	0.74	1
Middlings	10.5	16.4	3.3	5.0	61.2	3.6	0.06	0.62	1
Mill run	10.0	16.7	3.3	4.6	61.6	3.8	0.07	0.64	1
Sorghum (<i>Sorghum bicolor</i>/S. <i>vulgare</i>)									
Grain	11.2	10.6	3.0	1.9	71.4	1.9	0.08	0.27	1
Bran	12.0	7.8	4.8	7.6	65.7	2.1	-	-	1
Hominy feed	11.0	10.0	5.8	3.4	67.4	2.4	-	-	1
Wheat (<i>Triticum aestivum</i>/T. <i>vulgare</i>/T. <i>Sativum</i>/T. <i>durum</i>)									
Grain	12.1	12.0	1.7	2.5	70.0	1.7	0.05	0.36	1
Bran	12.1	14.7	4.0	9.9	53.5	5.8	0.12	1.28	1
Bran (China)	12.5	15.5	4.0	10.5	-	6.0	0.10	1.15	5
Bran (Bangladesh)	11.5	18.2	4.4	14.0	58.6	4.8	-	-	3
Bran (India)	10.6	10.8	2.5	9.7	6.4	3.0	-	-	6
Mill run	11.5	15.2	4.1	8.5	57.0	5.4	0.10	1.10	1
Grain screenings	9.5	13.2	3.7	9.1	58.9	5.6	0.18	0.35	1
Shorts (fine bran/feed flour mix)	11.8	16.3	4.3	6.1	56.7	4.8	0.10	0.70	1
Middlings (pollard)	10.5	17.4	4.3	7.5	55.4	4.9	0.14	0.91	1
Feed flour	12.0	11.7	1.2	1.3	73.3	0.5	0.03	0.18	1
OILSEED PRODUCTS									
Almond (<i>Prunus amygdalus</i>)									
Almond hulls	9.7	3.2	3.3	13.9	64.0	5.9	0.21	0.10	1
Cocoa (<i>Theobroma cacao</i>)									
Bean (seed, kernel), fresh	52.8	6.7	20.2	4.2	13.9	2.2	-	-	1
Bean (seed, kernel), dried	10.4	13.1	35.7	6.6	30.7	3.5	0.07	0.33	1
Shell (pericarp), dried	9.3	18.8	7.0	13.5	43.5	7.9	0.15	0.21	1
Pods (without beans), fresh	85.1	1.2	0.1	4.3	8.0	1.3	-	-	1
Pods (without beans), dried	11.5	5.8	0.7	21.5	52.9	7.6	0.17	0.07	1
Coconut (<i>Cocos nucifera</i>)									
Kernel (endosperm), fresh	47.9	4.2	34.0	2.6	9.8	1.5	0.01	0.13	1
Kernel (endosperm, meat, copra), dried	4.0	7.2	64.6	3.8	18.5	1.9	0.03	0.19	1
Coir dust (husk processing dust)	12.9	2.0	0.6	29.8	48.1	6.6	-	-	1
Cotton (<i>Gossypium</i> spp.)									
Hulls	9.6	4.2	1.9	44.5	37.3	2.5	0.14	0.09	1
Groundnut/peanut (<i>Arachis hypogaea</i>)									
Hulls	11.4	6.2	1.6	54.3	21.4	5.1	1.10	0.91	1
Linseed/flax (<i>Linum usitatissimum</i>)									
Hulls	9.0	7.7	1.4	28.7	43.7	9.5	-	-	1
Seed screenings	9.0	16.2	9.6	12.5	46.0	6.7	0.35	0.43	1
Olives (<i>Olea europaea</i>)									
Seed (kernel)	8.0	1.1	0.7	68.2	20.9	1.1	-	-	1
Pulp with seed, dried	8.0	5.9	15.5	36.5	31.6	2.5	-	-	1
Pulp, dried	5.0	13.9	27.4	19.3	31.0	3.4	-	-	1
Pulp, solvent extracted	7.8	11.4	3.1	28.5	43.1	6.1	0.31	0.11	1
Oilcake (kernel plus pulp)	14.8	5.4	10.1	34.1	32.0	3.6	-	-	1
African oil palm (<i>Elaeis guineensis</i>)									
Seed (kernel/nut)	7.2	9.4	47.8	5.1	28.6	1.9	0.08	0.28	1
Press fibre bunch, fresh	34.5	4.5	7.7	21.0	28.1	4.2	0.20	0.09	1
Press fibre bunch, dried	13.8	4.8	18.1	31.4	24.2	7.7	0.27	0.11	1
Palm oil sludge, dried	10.2	9.4	18.1	10.8	40.5	11.0	0.36	0.47	1
Safflower (<i>Carthamus tinctorius</i>)									
Hulls	8.7	3.5	4.1	53.1	29.1	1.5	-	-	1
Soybean (<i>Glycine max</i>)									
Hulls	9.1	9.8	1.7	36.4	38.1	4.9	0.49	0.18	1
Mill run	12.0	11.9	1.2	35.8	34.6	4.5	0.37	0.18	1
Mill feed (flour by-product)	10.3	12.9	1.7	32.5	37.9	4.7	0.41	0.18	1

TABLE 50 – CONTINUED

Product	Average composition (% by weight)								Ref. ¹
	H ₂ O	CP	EE	CF	NFE	Ash	Ca	P	
Sunflower (<i>Helianthus annuus</i>)									
Hulls	12.0	3.1	1.6	65.0	13.0	5.3	-	-	1
Sunflower heads with seed	9.5	13.1	12.6	23.4	32.8	8.6	-	-	1
Sunflower heads without seed	10.0	8.2	3.7	19.4	47.7	11.0	-	-	1
GRAIN LEGUME PRODUCTS									
Pigeon pea/red gram/dahl (<i>Cajanus cajan</i>)									
Seed (pea), fresh	67.4	7.0	0.6	3.5	20.2	1.3	-	-	1
Seed flour	9.3	11.5	8.2	7.5	60.0	3.5	-	-	1
Pod husks	7.0	6.2	0.3	35.3	47.4	3.8	1.02	0.08	1
Jack/sword bean (<i>Canavalia ensiformis</i>)									
Pod husks	8.0	4.1	1.4	44.3	38.7	3.5	0.28	0.01	1
Carob/locust bean (<i>Ceratonia siliqua</i>)									
Seed (bean), mature, dry	13.5	7.7	0.9	7.7	67.6	2.6	0.34	0.08	1
Bean pods with seeds, dry	12.1	5.4	1.4	8.3	69.7	3.1	0.50	0.11	1
Chickpea/Egyptian pea/Gram pea/Bengal gram (<i>Cicer arietinum</i>)									
Bean pods with seeds, dry	4.9	16.2	2.8	23.8	43.2	9.1	1.32	0.23	1
Bran	11.6	13.9	3.7	21.5	43.1	6.2	1.38	0.27	1
Cluster bean (<i>Cyamopsis tetragonoloba</i>)									
Bean pods with seeds, green	82.5	3.7	0.2	2.3	9.9	1.4	0.13	0.25	1
Grass pea (<i>Lathyrus sativus</i>)									
Bran (Bangladesh)	12.5	11.0	1.8	38.8	40.4	8.1	-	-	3
Egyptian bean/Hyacinth bean (<i>Lablab purpureus/Dolichos lablab</i>)									
Bean pods with seeds, immature	82.4	4.5	0.1	2.0	10.0	1.0	0.05	0.06	1
Lentil/Red dahl (<i>lens esculenta</i>)									
Pod husks	12.0	11.1	0.7	25.5	47.6	3.1	-	-	1
Bran (Bangladesh)	15.7	19.5	0.5	25.9	46.9	7.3	-	-	3
Velvet bean (<i>Mucana pruriens/M. utilis</i>)									
Bean pods with seeds, dry	10.7	17.6	4.4	12.8	50.0	4.5	0.24	0.37	1
Pod husks	11.1	4.2	0.7	33.9	44.0	6.1	-	-	1
African locust bean (<i>Parkia filicoidea</i>)									
Bean pods with seeds, dry	7.0	12.7	6.8	18.0	49.3	6.2	-	-	1
Pod husks	6.4	4.4	1.1	22.5	57.3	8.3	-	-	1
Lima bean (<i>Phaseolus lunatus</i>)									
Bean pods with seeds, dry	4.6	17.9	0.6	16.7	56.4	3.8	-	-	1
Pea/Field pea (<i>Pisum sativum</i>)									
Bean pods with seeds, dry	12.0	9.5	1.0	31.3	41.5	4.7	1.30	0.20	1
Bran (Bangladesh)	10.8	11.4	1.0	39.6	42.3	5.8	-	-	3
Velvet mesquite (<i>Prosopis velutina</i>)									
Bean pods with seeds, dry	6.9	11.6	1.8	23.0	52.2	4.5	-	-	1
Saman/Rain tree/Monkey pod/Cow tamarind (<i>Samanea saman</i>)									
Bean pods with seeds, dry	20.5	10.2	0.6	11.5	55.3	1.9	0.23	0.25	1
Bean pods, fresh	34.8	13.5	2.4	10.8	36.2	2.4	0.17	0.17	1
Urd/Black gram (<i>Vigna mungo</i>)									
Bran	11.2	16.2	3.2	21.3	50.2	7.9	-	-	1
Bran (Bangladesh)	12.5	17.9	2.4	24.3	48.0	7.4	-	-	3
Mung bean/Green gram/Golden gram <i>Vigna radiate</i> (<i>Phaseolus aureus</i>)									
Pod husks	9.7	7.4	0.5	32.3	43.1	7.0	1.97	0.18	1
Bran (Bangladesh)	12.1	8.1	2.9	37.5	41.0	10.6	-	-	3
Hull (Thailand)	10.8	18.4	1.7	17.8	47.8	3.4	-	-	7
Horse gram (<i>Vigna unguiculata/Macrotyloma uniflorum</i>)									
Bean pods, dry	8.0	6.6	1.1	34.5	39.2	10.6	1.53	0.12	1
Broad bean/Horse bean (<i>Vicia faba</i>)									
Bean pods with seeds, dry	11.6	11.6	1.0	26.8	43.0	6.0	0.78	0.10	1

TABLE 50 – CONTINUED

Product	Average composition (% by weight)								Ref. ¹
	H ₂ O	CP	EE	CF	NFE	Ash	Ca	P	
Winged bean (<i>Psophocarpus tetragonolobus</i>)									
Green pod, immature, fresh	84.0	2.4	0.3	1.9	10.3	1.1	0.04	0.05	1
Cowpea (<i>Vigna unguiculata/V. sinensis</i>)									
Pod husks	7.4	12.0	0.6	30.9	42.4	6.7	-	-	1
Bambara groundnut (<i>Voandzeia subterranea</i>)									
Seed pods, dry	3.4	17.6	5.3	13.7	54.8	5.2	-	-	1
ROOT CROP PRODUCTS									
Giant taro/Alocasia (<i>Alocasia macrorrhiza</i>)									
Fresh tuber	81.2	0.6	0.1	-	-	-	0.15	0.05	1
Elephant yam (<i>Amorphophallus</i> spp.)									
Fresh tuber	74.2	5.1	0.4	0.6	18.0	1.7	0.05	0.02	1
Mangold/Mangel (<i>Beta vulgaris macrorrhiza</i>)									
Fresh root	88.5	1.2	0.1	0.8	8.5	0.9	0.02	0.03	1
Sugar beet (<i>Beta vulgaris altissima</i>)									
Fresh root	83.6	1.4	0.1	0.9	13.0	1.0	0.04	0.04	1
Beet crowns	82.0	3.0	0.3	1.9	9.2	3.6	-	-	1
Beet pulp (sugar extracted), wet	87.0	1.4	0.2	3.1	7.8	0.5	0.10	0.01	1
Beet pulp (sugar extracted), dry	9.6	8.4	0.5	19.3	58.3	3.9	0.64	0.10	1
Pulp with molasses, dry	8.0	9.2	0.6	15.4	61.0	5.8	0.56	0.10	1
Beet molasses	20.4	7.3	0.1	0.0	62.6	9.6	0.10	0.02	1
Swede (<i>Brassica napus</i>)									
Fresh root	91.0	0.8	0.1	1.1	6.3	0.7	0.06	0.02	1
Turnip (<i>Brassica rapa rapa</i>)									
Fresh root	91.0	1.2	0.2	1.0	5.8	0.8	0.06	0.02	1
Queensland arrowroot (<i>Canna edulis</i>)									
Fresh tuber	70.9	1.1	0.2	0.8	25.1	1.9	-	-	1
Taro/Old cocoyam/Dasheen (<i>Colocasia esculenta</i>)									
Fresh tuber	74.0	1.7	0.2	0.7	22.4	1.0	0.06	0.60	1
Fresh tuber (peeled)	67.6	1.9	0.1	0.6	28.7	1.1	-	-	1
Fresh peelings	81.2	0.9	0.2	1.7	14.7	1.3	-	-	1
Swamp taro (<i>Cyrtosperma chamissonis</i>)									
Fresh tuber	60.0	1.0	0.5	1.0	36.5	1.0	-	-	1
Cufa/Tiger nut (<i>Cyperus esculentus</i>)									
Tuber	19.8	5.3	24.2	10.0	38.9	1.8	-	-	1
Carrot (<i>Daucus carota</i>)									
Fresh tuber	86.8	1.5	0.2	1.3	9.0	1.2	-	-	1
Pulp, fresh	86.0	0.9	1.1	2.6	8.2	1.2	-	-	1
Greater yam/Water yam/Winged yam (<i>Dioscorea alata</i>)									
Fresh tuber	70.0	2.0	0.2	1.0	25.4	1.4	0.04	0.06	1
Fresh tuber (peeled)	73.8	1.9	0.2	0.6	22.1	1.4	-	-	1
Fresh peelings	74.1	3.0	0.3	1.7	18.4	2.5	-	-	1
Potato yam (<i>Dioscorea bulbifera</i>)									
Fresh tuber	65.0	1.3	<0.1	0.7	31.6	1.3	-	-	1
Yellow yam (<i>Dioscorea cayenensis</i>)									
Fresh tuber	83.0	1.0	<0.1	0.4	15.0	0.5	-	-	1
Fresh tuber (peeled)	83.9	0.9	<0.1	0.1	14.6	0.5	-	-	1
Fresh peelings	78.3	1.6	0.2	1.6	16.7	1.6	-	-	1
Lesser yam (<i>Dioscorea esculenta</i>)									
Fresh tuber	74.0	1.6	0.2	0.8	22.5	0.9	0.03	0.03	1
Fresh tuber, peeled	81.4	1.4	<0.1	0.2	16.4	0.5	-	-	1
Fresh peelings	93.0	0.7	<0.1	0.5	5.3	0.4	-	-	1
Bitter yam (<i>Dioscorea dumetorum</i>)									
Fresh tuber	79.0	2.8	0.3	0.3	16.9	0.7	0.09	-	1

TABLE 50 – CONTINUED

Product	Average composition (% by weight)								Ref. ¹
	H ₂ O	CP	EE	CF	NFE	Ash	Ca	P	
Intoxicating yam (<i>Dioscorea hispida</i>)									
Fresh tuber	78.0	1.8	0.2	0.9	18.4	0.7	-	-	1
White yam (<i>Dioscorea rotundata</i>)									
Fresh tuber	65.5	1.5	0.1	0.6	30.7	1.6	-	-	1
Fresh tuber (peeled)	75.9	1.1	<0.1	0.4	21.8	0.7	-	-	1
Fresh peelings	82.3	2.0	0.2	1.7	12.1	1.7	-	-	1
Jerusalem artichoke (<i>Helianthus tuberosus</i>)									
Fresh tuber	77.9	2.1	0.2	1.2	16.4	1.7	0.02	0.10	1
Sweet potato/Spanish potato (<i>Ipomoea batatas</i>)									
Fresh tuber	70.9	1.5	0.3	0.8	25.6	0.9	0.05	0.06	1
Dried tuber meal	12.6	4.2	0.7	4.2	74.9	3.4	0.09	0.13	1
Fresh peelings	88.3	0.7	0.2	<0.1	10.2	0.5	-	-	1
Cassava/Tapioca/Manioc/Manihot (<i>Manihot esculenta</i>)									
Fresh tuber	65.9	0.9	0.2	1.0	30.9	1.0	0.03	0.05	1
Tuber, dehydrated	13.5	2.1	0.5	3.8	77.9	2.2	0.17	0.11	1
Fresh tuber (peeled)	68.8	0.9	0.2	0.5	28.6	1.0	0.03	0.01	1
Fresh peelings	72.1	1.6	0.4	4.4	20.1	1.4	-	-	1
Peelings (dry matter basis, Cameroon)	-	7.0	-	-	-	-	0.1	0.2	8
Cassava meal (starch extracted)	14.8	1.3	0.6	13.5	67.5	2.3	0.50	0.03	1
Arrowroot (<i>Maranta arundinacea</i>)									
Rhizome (root), fresh	70.5	1.6	0.1	1.0	25.4	1.4	-	-	1
Rhizome (starch extracted 'bittie', dry)	12.2	3.0	0.3	14.4	67.7	2.4	0.30	0.15	1
Oca (<i>Oxalis tuberosa</i>)									
Fresh tuber	84.0	1.1	0.8	1.0	12.3	0.8	-	-	1
Yam bean/Potato bean (<i>Pachyrrhizus erosus</i>)									
Fresh tuber	82.4	1.5	0.1	0.6	14.9	0.5	0.02	-	1
Young green pods	86.4	2.6	0.3	2.9	7.1	0.7	0.12	0.04	1
Yacon strawberry (<i>Polymnia sonchifolia</i>/P. <i>edulis</i>)									
Fresh tuber	75.2	1.4	0.1	1.5	20.2	1.6	-	-	1
Kudzu (<i>Pueraria lobata</i>)									
Fresh root, peeled	68.6	2.1	0.1	0.7	27.1	1.4	0.02	0.02	1
Radish (<i>Raphanus sativus</i>)									
Fresh root	92.4	0.8	0.1	0.7	5.2	0.8	0.04	0.02	1
Potato/Irish potato (<i>Solanum tuberosum</i>)									
Fresh tuber	76.7	2.3	0.1	0.7	19.1	1.1	0.02	0.05	1
Tuber, dry meal	9.9	7.9	0.3	1.7	75.5	4.7	0.07	0.20	1
Fresh peelings	78.8	2.1	0.1	0.7	17.0	1.3	-	-	1
Pulp residue (starch extracted)	11.6	7.9	0.3	5.9	70.7	3.6	0.14	0.23	1
Hausa potato (<i>Solenostemon rotundifolius</i>)									
Fresh tuber	75.2	1.4	0.4	0.6	21.4	1.0	0.02	-	1
African yam bean (<i>Sphenostylis stenocarpa</i>)									
Fresh tuber	64.7	3.7	0.1	0.4	30.4	0.7	0.01	-	1
New cocoyam/Tannia (<i>Xanthosoma sagittifolium</i>)									
Fresh tuber	70.0	2.1	0.2	0.9	25.8	1.0	0.04	0.06	1
Fresh tuber (peeled)	75.9	1.4	<0.1	0.3	21.1	1.2	-	-	1
Fresh peelings	70.5	2.4	0.4	3.4	20.8	2.5	-	-	1
FRUIT PRODUCTS									
Pineapple (<i>Ananas comosus</i>)									
Fruit, ripe, fresh	85.3	0.4	0.2	0.4	13.3	0.4	0.02	0.01	1
Stump meal, fresh	54.0	1.4	0.4	10.1	33.2	0.9	0.13	0.04	1
Juice presscake	79.0	1.1	0.2	5.5	13.6	0.6	0.06	0.02	1
Cannery residue (pulp/bran), dehydrated	11.7	3.6	1.1	15.9	64.2	3.5	0.21	0.12	1
Breadfruit (<i>Artocarpus altilis</i>)									
Fruit, ripe, fresh	70.2	1.7	0.3	1.5	24.3	2.0	0.04	0.04	1
Fruit, ripe, cooked and peeled	68.2	1.5	0.3	1.4	27.6	1.0	-	-	1
Fruit meal, dehydrated	15.1	2.7	0.8	4.7	74.1	2.6	0.07	0.14	1

TABLE 50 – CONTINUED

Product	Average composition (% by weight)								Ref. ¹
	H ₂ O	CP	EE	CF	NFE	Ash	Ca	P	
Breadnut tree (<i>Brosimum alicastrum</i>)									
Fruit pulp, fresh	84.9	3.1	0.8	1.8	8.4	1.0	-	-	1
Fruit seeds, fresh	63.0	4.7	1.6	3.4	25.9	1.4	-	-	1
Fruit fibre and skin, fresh	86.6	0.9	0.6	2.4	8.0	1.5	-	-	1
Papaya/Pawpaw (<i>Carica papaya</i>)									
Fruit, ripe, fresh	88.0	0.8	0.1	1.0	4.4	0.8	0.02	0.01	1
Fruit, immature, fresh	92.8	0.8	<0.1	0.9	4.9	0.5	-	-	1
Peels (dry matter basis, Cameroon)	-	18.0	-	-	-	-	0.2	0.3	8
Watermelon (<i>Citrullus lanatus</i>)									
Fruit, ripe, fresh	95.9	0.5	0.1	0.9	2.3	0.3	-	-	1
Seeds, dry	8.5	8.3	17.5	42.9	20.6	2.2	-	-	1
Lime (<i>Citrus aurantiifolia</i>)									
Whole fruit, ripe, fresh	68.1	3.6	3.0	13.5	9.7	2.1	-	-	1
Fruit skin (peel) and rag (fibre)	81.7	1.4	0.9	3.1	12.2	0.7	-	-	1
Seed, fresh	70.9	6.4	3.6	3.8	14.7	0.6	0.05	0.09	1
Silage of skins (peels)	77.0	2.4	1.5	4.8	12.1	2.2	-	-	1
Fruit pulp, dehydrated	15.0	7.7	2.9	15.2	-	-	-	-	1
Lemon (<i>Citrus limon</i>)									
Fruit pulp, dehydrated	7.0	6.4	1.4	14.8	65.1	5.3	-	-	1
Grapefruit (<i>Citrus paradisi</i>)									
Whole fruit, ripe, fresh	86.6	1.0	0.5	1.3	10.1	0.5	0.09	0.02	1
Fruit pulp, wet	79.7	1.3	<0.1	2.1	16.0	0.8	0.12	-	1
Fruit pulp, dehydrated	9.0	6.1	1.4	12.6	65.4	5.5	1.30	0.16	1
Fruit skin (peels), fresh	82.1	1.2	0.3	1.9	13.8	0.7	-	-	1
Silage of fruit peels, fresh	80.8	1.4	0.4	2.5	14.1	0.8	-	-	1
Tangerine (<i>Citrus reticulata</i>)									
Fruit pulp, dehydrated	13.0	7.0	4.9	9.6	61.1	4.4	1.40	0.12	1
Sweet orange (<i>Citrus sinensis</i>)									
Whole fruit, ripe, fresh	87.2	1.0	0.2	1.3	9.7	0.6	0.07	0.02	1
Fruit skin (peels), fresh	83.9	1.1	0.3	1.0	13.1	0.6	0.21	0.02	1
Silage of fruit peels, fresh	80.4	1.5	0.5	2.8	13.8	1.0	0.27	0.02	1
Fruit pulp, wet	75.0	2.2	0.4	3.3	18.2	0.9	0.05	0.07	1
Fruit pulp, silage	88.7	1.0	0.2	2.0	7.5	0.6	-	-	1
Fruit pulp, dehydrated	11.1	7.5	2.0	10.2	65.8	3.4	0.63	0.09	1
Citrus pulp (<i>Citrus</i> spp.)									
Citrus pulp, fresh	81.7	1.2	0.6	2.3	12.8	1.4	-	-	1
Citrus pulp, silage	80.0	1.5	2.1	3.2	12.1	1.1	0.42	0.03	1
Citrus pulp, dehydrated	9.1	6.3	3.3	12.4	62.9	6.0	1.80	0.11	1
Molasses (<i>Citrus</i> spp.)									
Citrus molasses, fresh	32.0	5.6	0.2	0.0	57.3	4.9	1.12	0.09	1
Coffee (<i>Coffea arabica/robusta</i>)									
Fruit pulp, fresh	76.8	2.4	0.5	4.6	13.8	1.9	0.13	0.03	1
Fruit pulp, sun dried	11.4	10.9	2.3	22.9	44.8	7.7	0.53	0.11	1
Seed hulls, dried	8.8	2.3	0.6	68.9	18.9	0.5	-	-	1
Pumpkin/Squash/Gourd (<i>Cucurbita</i> spp.)									
Fruit, ripe, fresh	91.5	1.2	0.4	1.0	5.2	0.7	0.02	0.04	1
Mango (<i>Mangifera indica</i>)									
Fruit pulp (immature fruit), fresh	82.3	6.2	<0.1	0.5	10.6	0.3	0.04	0.02	1
Fruit pulp (mature fruit), fresh	82.7	1.0	0.1	0.4	15.4	0.4	-	-	1
Fruit kernel (seed), fresh	50.0	4.2	4.4	1.4	37.3	2.7	-	-	1
Fruit silage, wet	84.0	0.8	1.0	2.7	10.0	1.5	0.03	0.01	1
Tomato (<i>Lycopersicon esculentum</i>)									
Whole fruit, ripe, fresh	93.8	1.0	0.2	0.6	3.7	0.7	0.01	0.03	1
Pomace (pulp), dehydrated	8.1	21.4	10.3	24.8	30.1	5.3	0.36	0.56	1
Pomace (pulp), silage, wet	70.5	5.7	4.3	13.2	5.0	1.3	0.15	0.14	1
Fruit skins with juice, dried	10.4	18.5	2.2	17.1	43.0	8.8	0.55	0.41	1

TABLE 50 – CONTINUED

Product	Average composition (% by weight)								Ref. ¹
	H ₂ O	CP	EE	CF	NFE	Ash	Ca	P	
Apple (<i>malus sylvestris</i>)									
Whole fruit, ripe, fresh	83.0	0.5	0.4	1.2	14.5	0.4	0.01	0.01	1
Fruit pomace (pulp), dried	11.0	4.4	4.5	15.1	63.0	2.0	0.12	0.11	1
Fruit pomace (pulp), silage, wet	78.6	1.7	1.3	4.4	13.0	1.0	0.02	0.02	1
Banana/Plantain (<i>Musa sapientum</i>/<i>M. paradisiaca</i>)									
Banana fruit, immature/green, fresh	80.6	0.9	0.5	0.6	16.5	0.9	-	-	1
Banana fruit, ripe, fresh	76.0	1.3	0.3	0.7	20.7	1.0	0.01	0.03	1
Peeled fruit, immature, fresh	74.9	0.9	0.4	0.2	22.8	0.8	-	-	1
Peeled fruit, ripe, fresh	69.5	1.3	0.2	<0.1	27.5	1.4	-	-	1
Green fruit with peel, meal	12.0	4.3	2.8	3.0	73.6	4.3	-	-	1
Ripe fruit, dried	14.0	3.5	0.5	1.0	78.4	2.6	0.03	0.09	1
Fruit skins (peels), ripe, fresh	85.9	1.1	1.6	1.1	8.4	1.9	-	-	1
Fruit skins (peels), ripe, dried	12.0	6.8	7.1	7.6	57.3	9.2	-	-	1
Fruit skins (peels), immature, dried	10.0	6.9	5.4	11.7	51.2	14.8	-	-	1
Peels, ripe (dry matter basis, Cameroon)	-	10.0	-	-	-	-	0.2	0.3	8
Plantain fruit, ripe, fresh	68.8	1.1	0.2	0.3	30.5	1.1	0.22	0.08	1
Plantain fruit, green with peel, meal	10.0	4.3	1.0	6.2	74.0	4.5	-	-	1
Plantain peels, mature, fresh	81.6	1.7	1.0	1.2	11.3	3.2	-	-	1
Avocado (<i>Persea americana</i>)									
Avocado seeds, fresh	59.0	2.0	1.6	2.4	-	-	0.02	0.08	1
Avocado skins, fresh	76.0	1.7	8.4	5.9	-	-	0.03	0.04	1
Avocado oil meal	9.0	18.5	1.1	17.6	42.5	11.3	-	-	1
Fruit, ripe (dry matter basis, Cameroon)	-	12.0	-	-	-	-	0.3	0.1	8
Date palm (<i>Phoenix dactylifera</i>)									
Whole fruit date, dried	25.7	2.2	0.7	4.8	62.4	4.2	-	-	1
Fruit seeds, ground, dried	9.8	5.9	8.1	14.1	59.2	2.9	-	-	1
Fruit pulp (sugar extracted)	11.8	4.8	0.3	10.4	70.3	2.4	-	-	1
Prune (<i>Prunus</i> spp.)									
Fruit with seeds	18.0	4.3	2.4	10.7	-	-	0.11	0.09	1
Fruit without seeds	20.0	3.3	1.1	1.8	-	-	0.03	0.09	1
Fruit (prune) mix	18.2	5.2	2.0	16.2	53.3	5.1	-	-	1
Pomegranate (<i>Punica granatum</i>)									
Fruit pulp, wet	74.0	2.2	1.3	4.3	17.2	1.0	-	-	1
Pear (<i>Pyrus communis</i>)									
Fruit pulp, ground, dried	8.5	5.6	1.9	21.8	58.5	3.7	2.20	0.11	1
Fruit cannery residue, wet	84.8	0.6	0.2	2.6	11.5	0.3	-	-	1
Raisin (<i>Vitis</i> spp.)									
Fruit pulp, dried	11.0	9.5	7.7	16.0	50.4	5.4	-	-	1
Grape (<i>Vitis vinifera</i>)									
Seeds	11.0	9.4	9.8	41.3	25.2	3.3	0.58	0.20	1
Fruit pomace, dried	9.0	11.6	6.9	30.0	37.5	5.0	0.46	0.36	1
Winery pomace (stalk, skin, seed), wet	59.4	4.7	4.0	10.4	18.4	3.1	-	-	1
Winery pomace (skin, seed), wet	53.5	6.4	3.2	11.0	19.9	6.0	0.38	0.09	1
Winery pomace (stalk, skin), dried	11.2	13.2	4.4	31.8	31.5	7.9	-	-	1
Winery pomace (skin), dried	11.1	16.3	5.7	28.4	31.4	7.1	1.45	0.29	1
GREEN LEAFY CROPS									
Fresh green pasture grass									
Very leafy	82.0	4.0	0.6	3.6	7.5	2.3	-	-	1
Leafy	81.0	3.3	0.5	4.5	8.5	2.2	-	-	1
Early flowering	79.0	3.0	0.7	5.4	9.8	2.1	-	-	1
Flowering	77.0	2.4	0.5	6.2	11.7	2.2	-	-	1
Seed set	75.0	2.1	0.6	7.4	13.1	1.8	-	-	1
Fresh green fodder crops									
Alfalfa/lucerne (<i>Medicago sativa</i>)									
Late vegetative	79.0	4.3	0.6	4.9	9.1	2.1	-	-	1
Early bloom (flowering)	77.0	4.4	0.7	5.8	9.9	2.2	-	-	1

TABLE 50 – CONTINUED

Product	Average composition (% by weight)								Ref. ¹
	H ₂ O	CP	EE	CF	NFE	Ash	Ca	P	
Mid bloom	76.0	4.5	0.6	6.8	10.0	2.1	-	-	1
Full bloom	75.0	3.5	0.7	7.7	11.0	2.1	-	-	1
Red clover (<i>Trifolium pratense</i>)									
Early vegetative	81.0	6.3	0.9	2.0	8.3	1.5	0.30	0.07	1
Late vegetative	78.0	5.5	0.6	3.5	10.7	1.7	-	-	1
Early bloom	79.0	3.9	0.8	5.2	9.2	1.9	0.33	0.05	1
Mid bloom	74.6	3.9	0.8	6.6	12.1	2.0	-	-	1
White clover (<i>Trifolium repens</i>)									
Early vegetative	81.0	5.3	0.5	2.7	7.9	2.6	-	-	1
Early bloom	81.0	4.4	0.8	4.3	7.4	2.1	-	-	1
Vetches (<i>Vicia</i> spp.)									
Mid bloom	82.0	3.2	0.5	5.1	7.7	1.5	-	-	1
Trefoil (<i>Lotus corniculatus</i>)									
Aerial part	77.4	4.0	0.8	5.8	9.9	2.1	0.34	0.05	1
Sesbania (<i>Sesbania</i> spp.)									
Leaves	77.0	6.6	0.5	2.6	11.0	2.3	0.52	0.10	1
Leadtrees (<i>Ipil-Ipil</i> (<i>L. glauca</i>))									
Leaves	68.4	8.8	1.0	3.3	17.4	1.1	0.17	0.10	1
Saman (<i>S. saman</i>)									
Leaves	60.9	8.7	2.7	11.5	13.9	2.3	0.55	0.08	1
Kale (<i>Brassica oleracea</i>)									
Aerial crop	85.9	2.4	0.5	2.2	7.2	1.8	0.18	0.08	1
Mangold (<i>B. vulgaris</i>)									
Leaves and crowns (tops)	87.4	2.1	0.5	1.4	6.2	2.4	-	-	1
Sugar beet (<i>B. vulgaris</i>)									
Leaves and crowns (tops)	85.2	2.2	0.4	1.8	6.8	3.0	0.17	0.03	1
Leaves	85.3	2.6	0.4	1.8	7.1	2.8	0.26	0.05	1
Cassava (<i>M. esculenta</i>)									
Leaves and stem	76.9	4.5	1.2	3.9	11.8	1.7	-	-	1
Leaves	74.4	7.7	1.3	7.7	7.1	1.8	0.17	0.10	1
Sweet potato (<i>I. batatas</i>)									
Leaves	89.2	2.1	0.4	1.1	4.4	2.8	-	-	1
Vines	89.0	2.2	0.3	1.9	5.0	1.6	0.16	0.02	1
Leaves and vines	84.9	2.5	0.5	2.5	7.2	2.4	-	-	1
Taro (<i>C. esculenta</i>)									
Leaves	89.8	2.2	0.8	1.2	4.7	1.3	0.14	0.05	1
Aerial crop	83.3	3.7	1.2	1.9	7.6	2.3	0.01	0.01	1
Swede (<i>B. napus</i>)									
Leaves and crowns (tops)	88.0	2.3	0.5	1.5	5.5	2.2	-	-	1
Turnip (<i>B. rapa rapa</i>)									
Leaves and crowns (tops)	87.0	2.8	0.3	1.3	6.4	2.2	0.38	0.07	1
Carrot (<i>D. carota</i>)									
Leaves and crowns (tops)	84.0	2.1	0.6	2.9	8.0	2.4	0.31	0.03	1
Cabbage (<i>Brassica oleracea</i> var. <i>capitata</i>)									
Leaves	87.4	2.1	0.5	2.0	6.4	1.6	0.07	0.03	1
Brussels sprouts (<i>Brassica oleracea</i> var.)									
Leaves	85.0	4.9	0.4	1.6	6.9	1.2	0.04	0.08	1
Broccoli (<i>Brassica oleracea</i> var. <i>italica</i>)									
Leaves and stems	89.0	3.6	0.3	1.5	4.5	1.1	0.10	0.08	1
Lettuce (<i>Lactuca sativa</i>)									
Leaves	95.0	1.1	0.2	0.6	2.3	0.8	0.04	0.02	1
Ramie (<i>Boehmeria nivea</i>)									
Leaves	84.9	2.0	0.6	4.2	5.9	2.4	0.60	0.05	1

TABLE 50 – CONTINUED

Product	Average composition (% by weight)								Ref. ¹
	H ₂ O	CP	EE	CF	NFE	Ash	Ca	P	
Jerusalem artichoke (<i>H. tuberosus</i>)									
Aerial parts (tops)	70.2	2.4	0.7	5.2	17.9	3.6	0.44	0.09	1
Leaves	78.3	4.5	0.5	2.7	10.5	3.5	0.44	0.08	1
Elephant yam (<i>Amorphophallus</i> spp.)									
Leaves	86.5	3.0	0.5	5.6	-	-	-	-	1
Queensland arrowroot (<i>C. edulis</i>)									
Aerial part, early vegetative	83.5	1.7	0.8	3.2	8.1	2.7	-	-	1
Radish (<i>R. sativus</i>)									
Leaves	87.4	2.2	0.4	1.5	6.1	2.4	0.40	0.30	1
Sugar cane (<i>Saccharum officinarum</i>)									
Stems	85.0	1.2	0.1	4.2	8.6	0.9	-	-	1
Cane tops	75.0	1.3	0.4	8.5	11.8	3.0	-	-	1
Guava (<i>Psidium guajava</i>)									
Leaves	62.5	3.8	2.8	7.2	20.8	2.9	0.41	0.10	1
Papaya (<i>C. papaya</i>)									
Leaves	77.4	5.3	1.1	3.6	9.7	2.9	0.31	0.06	1
Breadnut tree (<i>B. alicastrum</i>)									
Leaves	61.1	5.4	1.3	10.3	18.9	3.0	-	-	1
Pineapple (<i>A. comosus</i>)									
Leaves	79.4	1.9	0.3	4.9	12.5	1.0	-	-	1
Green tops	83.0	1.5	0.4	4.2	9.5	1.4	0.05	0.01	1
Pumpkin (<i>Cucurbita</i> spp.)									
Vine	82.5	1.5	0.9	5.6	6.6	2.9	-	-	1
Alocasia (<i>A. macrorrhiza</i>)									
Leaves	90.4	2.3	0.6	1.2	3.8	1.7	0.15	0.01	1
Banana (<i>Musa</i> spp.)									
Leaves	75.0	2.4	1.3	6.1	-	-	0.32	0.04	1
Pseudostem (trunk)	95.0	0.15	0.1	1.1	2.9	0.7	0.05	0.01	1
Jackfruit (<i>Artocarpus heterophyllus</i>)									
Leaves	60.3	6.8	1.7	8.3	18.2	4.7	0.74	0.08	1
Neem tree (<i>Azadirachta indica</i>)									
Leaves	64.2	4.8	2.2	5.3	19.8	3.7	0.69	0.06	1
Groundnut (<i>A. hypogaea</i>)									
Leaves	73.1	4.7	0.6	5.4	13.9	2.3	0.25	0.05	1
Pigeon pea (<i>C. cajan</i>)									
Aerial part (forage)	71.0	5.9	1.5	8.1	11.7	1.8	0.22	0.06	1
Jack/Sword bean (<i>C. ensiformis</i>)									
Aerial part (forage)	76.8	5.2	0.5	6.4	8.4	2.7	-	-	1
Carob (<i>C. siliqua</i>)									
Leaves and stem	75.7	5.4	0.6	7.5	8.5	2.3	-	-	1
Chickpea (<i>C. arietinum</i>)									
Young shoots	60.6	8.2	0.5	-	-	3.5	0.31	0.21	1
Cluster bean (<i>C. tetragonoloba</i>)									
Aerial part (fodder)	80.8	3.1	0.4	4.4	8.0	3.3	0.61	0.07	1
Egyptian bean/lablab/hyacinth bean (<i>L. purpureus</i>)									
Aerial part	81.6	2.5	0.9	5.8	6.9	2.3	0.30	0.06	1
Soybean (<i>G. max</i>)									
Aerial part	74.0	3.7	1.1	10.5	8.3	2.4	0.35	0.07	1
Grass pea (<i>L. sativus</i>)									
Aerial part, late vegetative	82.6	3.6	0.6	4.0	7.3	1.9	0.23	0.06	1
Aerial part, early bloom	78.2	3.2	0.6	6.5	8.4	3.1	0.34	0.08	1
Aerial part, mid bloom	72.0	5.0	0.7	8.5	10.3	3.5	0.28	0.06	1

TABLE 50 – CONTINUED

Product	Average composition (% by weight)								Ref.¹
	H ₂ O	CP	EE	CF	NFE	Ash	Ca	P	
Lupin (<i>Lupinus spp.</i>)									
Aerial part	88.3	3.1	0.3	2.2	4.5	1.6	0.15	0.03	1
Velvet bean (<i>M. pruriens</i>)									
Aerial part, vegetative	82.9	3.9	0.4	4.7	6.1	2.0	-	-	1
Aerial part, mid bloom	81.5	3.2	0.7	6.2	7.3	1.1	0.23	0.02	1
Broad bean (<i>V. faba</i>)									
Stems and leaves	85.0	2.5	0.4	4.9	5.4	1.8	0.22	0.04	1
Winged bean (<i>P. tetragonolobus</i>)									
Stems and leaves	78.9	6.3	1.0	4.1	7.9	1.8	0.37	0.12	1
Pea (<i>P. sativum</i>)									
Aerial part, late vegetative	86.6	2.3	0.4	3.6	5.4	1.7	0.25	0.05	1
Aerial part, mid bloom	84.8	2.2	0.4	4.3	6.3	2.0	0.28	0.06	1
Urd/Black gram (<i>V. mungo</i>)									
Aerial part	84.0	3.1	0.4	4.3	5.6	2.6	0.32	0.04	1
Horse gram (<i>V. unguiculata</i>)									
Aerial part	81.8	3.2	0.4	3.9	9.4	1.3	0.10	0.05	1
Red bean (<i>V. umbellata</i>)									
Aerial part, mid bloom	68.0	5.4	0.6	9.8	13.7	2.5	0.33	0.08	1
SILAGES									
Grass, leafy	80.0	3.5	1.0	5.0	8.7	1.8	-	-	1
Grass, early bloom	75.0	3.2	0.9	7.0	11.6	2.3	-	-	1
Grass, full bloom	75.0	2.9	0.7	7.9	10.8	2.7	-	-	1
Alfalfa/lucerne (<i>M. sativa</i>)	79.2	4.3	1.8	5.0	7.1	2.6	0.40	0.10	1
Red clover (<i>T. pratense</i>)	74.6	3.2	1.3	6.6	11.3	3.0	0.43	0.06	1
Maize/corn (<i>Z. mays</i>)	75.0	2.4	1.1	6.1	13.9	1.5	0.09	0.08	1
Oats (<i>A. sativa</i>)	76.0	2.5	0.7	7.9	11.2	1.7	0.10	0.07	1
Rye (<i>S. cereale</i>)	68.0	4.1	1.1	10.9	13.4	2.5	0.13	0.10	1
Sorghum (<i>S. bicolor</i>)	70.0	2.2	0.9	8.2	16.1	2.6	0.10	0.06	1
Wheat (<i>Triticum spp.</i>)	72.5	2.8	0.7	8.0	13.8	2.2	0.08	0.08	1
Soybean (<i>G. max</i>)	73.0	4.8	0.7	7.8	11.0	2.7	0.37	0.13	1
Pea (<i>P. sativum</i>), vines only	76.0	3.1	0.8	7.2	10.8	2.1	0.31	0.06	1
Urd (<i>V. mungo</i>)	72.7	3.8	1.3	5.2	9.8	7.2	-	-	1
Sugar beet (<i>B. vulgaris</i>), crowns with tops	79.0	2.8	0.6	2.9	7.6	7.1	0.38	0.05	1
Pineapple (<i>A. comosus</i>), leaves	80.9	1.1	0.5	4.4	11.2	1.9	-	-	1
HAYS (Sun-cured, S-C)									
Meadow grass, leafy	15.0	13.7	3.0	19.5	41.0	7.8	-	-	1
Meadow grass, early bloom	15.0	10.0	1.6	26.6	40.0	6.8	-	-	1
Meadow grass, full bloom	15.0	7.6	1.5	28.7	40.8	6.4	-	-	1
Meadow grass, seed set	15.0	4.8	1.2	30.6	43.1	5.3	-	-	1
Bahia grass (<i>Paspalum notatum</i>)	9.2	4.3	1.5	20.5	59.1	5.4	0.41	0.17	1
Orchard grass (<i>Dactylis glomerata</i>), early bloom	11.0	13.4	2.5	27.6	37.7	7.8	-	-	1
Orchard grass (<i>Dactylis glomerata</i>), late bloom	9.0	7.6	3.1	33.6	37.5	9.2	-	-	1
Pangola grass (<i>Digitaria decumbens</i>)	12.0	6.7	1.5	27.4	40.7	11.7	0.40	0.20	1
Rye grass (<i>Lolium perenne</i>)	14.0	7.4	1.9	26.1	40.7	9.9	0.56	0.28	1
Bermuda grass (<i>Cynodon dactylon</i>)	9.7	7.3	1.9	29.0	44.9	7.2	0.43	0.16	1
Alfalfa/lucerne (<i>M. sativa</i>)	9.5	12.3	1.4	31.6	38.2	7.0	1.33	0.24	1
Red clover (<i>T. pratense</i>)	11.9	12.9	2.8	26.2	39.6	6.6	1.11	0.17	1
White clover (<i>T. repens</i>)	12.5	17.6	2.9	20.9	38.1	8.0	1.21	0.28	1
Crimson clover (<i>T. incarnatum</i>)	13.0	16.1	2.1	26.3	32.9	9.6	1.22	0.19	1
Trefoil (<i>L. corniculatus</i>)	8.0	15.0	2.3	28.3	39.9	6.5	1.57	0.25	1
Barley (<i>H. vulgare</i>)	13.0	7.6	1.9	24.1	46.8	6.6	0.20	0.23	1
Oats (<i>A. sativa</i>)	12.0	8.2	2.5	27.6	42.8	6.9	0.22	0.20	1
Sorghum (<i>S. bicolor</i>), early vegetative	8.0	14.7	3.0	25.8	36.5	12.0	0.46	0.17	1
Sorghum (<i>S. bicolor</i>), late vegetative	8.0	11.0	2.4	30.4	38.1	10.1	0.37	0.18	1

TABLE 50 – CONTINUED

Product	Average composition (% by weight)								Ref. ¹
	H ₂ O	CP	EE	CF	NFE	Ash	Ca	P	
Sorghum (<i>S. bicolor</i>), early bloom	7.0	7.0	1.9	35.3	40.4	8.4	0.28	0.13	1
Wheat (<i>Triticum</i> spp.)	12.0	7.4	1.9	24.6	47.9	6.2	0.13	0.17	1
Groundnut (<i>A. hypogaea</i>)	9.2	9.2	2.7	30.3	40.2	8.4	0.97	0.13	1
Pigeon pea (<i>C. cajan</i>)	11.2	14.8	1.7	28.9	39.9	3.5	-	-	1
Cluster bean (<i>C. tetragonoloba</i>)	9.3	16.5	1.3	19.3	41.2	12.4	-	-	1
Soybean (<i>G. max</i>)	10.0	15.3	3.9	27.0	36.8	7.0	1.10	0.22	1
Grass pea (<i>L. sativus</i>)	12.8	13.0	2.4	31.8	32.0	8.0	-	-	1
Lentil (<i>L. esculenta</i>)	10.2	4.4	1.8	21.4	50.0	12.2	-	-	1
Lupin (<i>Lupinus</i> spp.)	5.9	15.4	3.1	23.3	44.6	7.7	0.99	0.19	1
Velvet bean (<i>M. pruriens</i>)	9.4	13.4	2.4	27.8	38.9	8.1	-	-	1
Pea (<i>P. sativum</i>)	11.3	12.6	2.3	27.4	39.4	7.0	1.20	0.25	1
Mung bean (<i>V. radiata</i>)	9.7	9.8	2.2	24.0	46.6	7.7	-	-	1
Cowpea (<i>V. unguiculata</i>)	9.7	17.4	2.7	23.9	35.6	10.7	1.33	0.32	1
Pineapple (<i>A. comosus</i>), aerial part	11.0	6.9	2.5	26.3	47.8	5.5	0.35	0.21	1
Sweet potato (<i>I. batatas</i>), vines	13.4	14.2	4.5	23.7	33.3	10.9	-	-	1
STRAWS AND CHAFF									
Barley (<i>H. vulgare</i>)	11.8	3.4	1.6	37.5	40.4	5.3	0.30	0.07	1
Maize/corn (<i>Z. mays</i>)	10.0	5.3	1.2	33.4	44.9	5.2	0.44	0.08	1
Oats (<i>A. sativa</i>), straw	10.5	3.7	2.1	35.8	41.5	6.4	0.25	0.08	1
Oats (<i>A. sativa</i>), chaff	14.0	6.0	2.1	22.8	44.8	10.3	-	-	1
Rice (<i>O. sativa</i>)	8.0	3.9	1.0	31.8	40.5	14.8	0.24	0.08	1
Rye (<i>S. cereale</i>)	11.7	2.9	1.5	37.8	42.3	3.8	0.23	0.08	1
Wheat (<i>Triticum</i> spp.)	10.4	2.7	1.4	36.4	41.4	7.7	0.15	0.06	1
Soybean (<i>G. max</i>)	12.0	4.6	1.3	38.9	37.6	5.6	1.40	0.05	1
Chickpea (<i>C. arietinum</i>)	9.4	5.4	0.4	40.2	32.6	12.0	0.31	0.11	1
Lima bean (<i>P. lunatus</i>)	10.0	6.8	1.6	27.9	46.3	7.4	0.09	0.37	1
Kidney bean (<i>P. vulgaris</i>)	11.0	6.0	1.5	40.0	34.0	7.5	1.70	0.10	1
Pea (<i>P. sativum</i>)	13.0	8.1	1.5	34.4	37.0	6.0	0.85	0.09	1
Broad bean (<i>V. faba</i>)	12.0	5.3	1.1	41.5	34.1	6.0	1.70	0.13	1
ARTIFICIALLY DEHYDRATED LEAVES									
Grass, very leafy	10.0	18.7	3.0	17.7	40.6	10.0	-	-	1
Grass, leafy	10.0	15.0	2.6	20.9	40.7	10.8	-	-	1
Grass, early bloom	10.0	12.1	2.2	24.4	42.3	9.0	-	-	1
Alfalfa lucerne (<i>M. sativa</i>)	7.8	17.3	2.7	24.4	38.3	9.5	1.37	0.23	1
Cassava (<i>M. esculenta</i>)	10.0	27.0	4.6	27.1	25.0	6.3	0.60	0.35	1
Papaya (<i>C. papaya</i>)	7.5	21.7	3.9	9.8	45.7	11.4	-	-	1
Bambara groundnut (<i>V. subterranea</i>)	9.8	14.3	1.6	28.6	38.9	6.8	-	-	1
Cabbage (<i>B. oleracea</i> var. <i>capitata</i>)	11.7	14.9	3.9	8.4	54.1	7.0	-	-	1
Banana (<i>Musa</i> spp.)	5.9	9.3	11.1	22.6	42.8	8.3	0.71	0.23	1
Cluster bean (<i>C. tetragonoloba</i>)	14.2	19.3	3.0	8.3	42.8	12.4	-	-	1
MISCELLANEOUS PLANT-BASED FEEDSTUFFS									
Bakery waste, dried	8.8	10.0	12.4	0.8	64.8	3.2	0.10	0.23	1
Bread, dried	8.0	12.2	2.9	0.9	74.2	1.8	0.08	0.15	1
Pyrethrum (<i>C. cinerariifolium</i>), marc (fresh)	22.7	11.9	0.5	20.6	38.2	6.1	0.41	0.19	1
Pyrethrum (<i>C. cinerariifolium</i>), marc, sun cured	14.5	12.6	0.5	20.6	45.4	6.4	0.34	0.26	1
Sago palm (<i>Metroxylon sagu</i>), meal	14.0	1.8	1.1	4.9	74.4	3.8	0.05	0.04	1
Sago palm (<i>Metroxylon sagu</i>), refuse (starch extr.)	22.9	2.0	0.2	7.7	51.0	16.2	0.29	0.02	1
Sugar cane (<i>S. officinarum</i>), bagasse, dried	9.6	1.5	0.8	40.3	42.7	5.1	-	-	1
Sugar cane (<i>S. officinarum</i>), bagasse, fresh	45.0	0.8	0.2	26.9	24.1	3.0	0.19	0.15	1
Sugar cane (<i>S. officinarum</i>), filter press mud, fresh	75.5	2.7	2.6	3.0	10.9	5.3	0.64	0.27	1
Sugar cane (<i>S. officinarum</i>), molasses, final	25.0	3.0	trace	trace	63.5	8.5	0.70	0.10	1
Sugar cane (<i>S. officinarum</i>), strippings, fresh	55.0	1.6	0.4	20.3	18.1	4.6	0.16	0.12	1

¹ 1 – Tacon (1987); 2 – Hung and Huy (2007); 3 – Barman and Karim (2007); 4 – El-Sayed (2007); 5 – Weimin and Mengqing (2007); 6 – Ayyappan and Ahamad Ali (2007); 7 – Thongrod (2007); 8 – Pouomogne (2007).

TABLE 51

Major feeding studies conducted with selected low-protein terrestrial plant feedstuffs and by-products in compound aquafeeds**CEREAL PRODUCTS**

Acha: (*Digitaria exilis* stapf): Tilapia: Fagbenro *et al.* (2000);

Barley grain: Trout: Overturf *et al.* (2003); **Fermented barley-based grains:** Salmon: Skrede *et al.* (2002); Shrimp: Molina-Poveda *et al.* (2004);

Maize/corn bran: Tilapia: Chikafumbwa (1996); Liti *et al.* (2006b); Mataka and Kang'ombe (2007); **Maize/corn meal:** Bluespot mullet: Belal (2004); Common carp: Vacha *et al.* (2007); Pacu (*Piaractus mesopotamicus*): Abimorad *et al.* (2008); Red drum: McGoogan and Reigh (1996); Salmon: Sagstad *et al.* (2007); Shrimp: Hernandez *et al.* (2004b); Tilapia: Fagbenro *et al.* (2000); Al-Ogaily *et al.* (1996); Salmon: Arnesen *et al.* (1995); Hemre *et al.* (2007b); Shrimp: Bombeo-Tuburan *et al.* (1995); Sea urchin: Basuyaux and Blin (1998);

Oat meal: Salmon: Arnesen *et al.* (1995); **Whole oats, oat groats, rolled oats, oat meal and oat bran:** Trout: Arnsen and Krogdahl (1995);

Rice bran: Grass carp: Dongeza *et al.* (2009); Mud crab: Truong *et al.* (2009); Red drum: McGoogan and Reigh (1996); Streptocephalus proboscideus (Crustacea: Anostraca): Ali and Dumont (2002); Thai silver barb: Shah *et al.* (1998); Tilapia: Liti *et al.* (2006b); Pouomogne (1995); **Rice meal:** Tilapia: Al-Ogaily *et al.* (1996);

Rye meal: Common carp: Degani (2006); Salmon: Thodesen and Storebakken (1998);

Sorghum meal: Common carp: Degani (2006); Red drum: McGoogan and Reigh (1996); Silver perch: Rowland *et al.* (2007); Tilapia: Fagbenro *et al.* (2000); Al-Ogaily *et al.* (1996);

Wheat bran: Common carp: Degani (2006); Dourado (*Salminus brasiliensis*): Braga *et al.* (2008); Pacu (*Piaractus mesopotamicus*): Abimorad *et al.* (2008); Tilapia: AlAsgah and Ali (1996); Liti *et al.* (2006b); **Wheat meal:** Common carp: Vacha *et al.* (2007); Silver perch: Rowland *et al.* (2007); Salmon: Thodesen and Storebakken (1998); Tilapia: Al-Ogaily *et al.* (1996); **Wheat middlings:** Red drum: McGoogan and Reigh (1996); **Wheat meal fermented:** Salmon: Skrede *et al.* (2002);

Triticale meal: Common carp: Vacha *et al.* (2007);

FRUIT PRODUCTS

Apple pomace: Common Carp, Crucian Carp and Grass Carp: Zhou *et al.* (2006); Tilapia: Vendruscolo *et al.* (2009);

Breadfruit seed meal: African catfish: Tihamiyu *et al.* (2007);

Cocoa husks: Clariid catfish: Fagbenro (1995); Tilapia: Falaye and Jauncey (1999); Pouomogne *et al.* (1997);

Coffee pulp: Tilapia: Rojas and Verreth (2003); **Coffee pulp silage:** Colossoma: Bautista *et al.* (1999, 2005); Tilapia: Moreau *et al.* (2003); **Coffee pulp (bacteria-treated):** Tilapia: Ulloa and Verreth (2002);

Date fruit pit/waste: Tilapia: Azaza *et al.* (2009b); Belal (2008); Belal and AlJasser (1997);

Mango seeds: Labeo: Omoregie (2001);

Mangrove seeds: Bluespot mullet: Belal (2004);

Papaya/pawpaw seed: Tilapia: Ekanem and Basse (2003);

Plantain peel meal: African catfish: Falaye and Oloruntuyi (1998);

Tomato meal/waste: African catfish: Hoffman *et al.* (1997); Tilapia: Azaza *et al.* (2006); Soltan (2002);

FORAGE/GRASS/LEAF/ PRODUCTS

Bamboo leaves (*Bambusa vulgaris*): Grass carp: Dongeza *et al.* (2009);

Banana leaves (*Musa nana*): Grass carp: Dongeza *et al.* (2009);

Barnyard grass (*Echinochloa erusgalli*): Grass carp: Dongeza *et al.* (2009);

Cassava leaves: African catfish: Bureau *et al.* (1995); Grass carp: Dongeza *et al.* (2009);

Elephant grass (*Pennisetum purpureum*): Grass carp: Dongeza *et al.* (2009);

Mixed weeds from paddy fields: Grass carp: Dongeza *et al.* (2009);

Napier grass (*Pennisetum purpureum*): Tilapia: Chikafumbwa (1996);

Peanut vines: African catfish: Bureau *et al.* (1995);

Rice straw (fermented): General: Malek *et al.* (2008);

White clover (*Trifolium repens*): Crayfish: Jones *et al.* (2002);

ROOT PRODUCTS

Cassava meal: Mud crab: Truong *et al.* (2009); Shrimp: Bombeo-Tuburan *et al.* (1995); **Cassava peel:** Grass carp: Dongeza *et al.* (2009); Tilapia: Oresgun *et al.* (2004); **Cassava tubercles:** Grass carp: Dongeza *et al.* (2009);

TABLE 51 – CONTINUED

Maca tuber meal (*Lepidium meyenii*): **Trout**: Lee *et al.* (2004);
Taro (*Colocasia esculenta*): **Common carp**: Nandeesh *et al.* (2002);
Potato by-product meal: **Tilapia**: Soltan (2002); **Potato starch**: **Trout**: Podoskina *et al.* (1997);

MISCELLANEOUS

Condensed molasses fermentation soluble: **Milkfish**: Chien and Chen (2007); **Tilapia**: Chien *et al.* (2005);
Salicornia meal: (*Salicornia bigelovii*): **Tilapia**: Belal and Al-Dosari (1999);
Soybean molasses: **Salmon**: Knudsaen *et al.* (2007);
Winery by-product: **Abalone**: Nava Guerrero *et al.* (2004).

4.5.2 Aquatic plant products*Official definitions (AAFCO, 2008b)*

Algae meal (IFN 5-00-357 Algae whole meal), a colour additive, is a dried mixture of algae cells (genus *Sponecocccum* separated from its culture broth), molasses, corn steep liquor and a maximum of 0.3 percent ethoxyquin. (Reg. 73.275, Subpart D, Color Additives.)

Kelp, dried (IFN 1-08-073 Seaweed kelp whole dehydrated) is dried seaweed of the families Laminariaceae and Fucaeeae. The maximum percentage of salt (NaCl) and the minimum percentage of potassium (K) must be declared. If the kelp is sold as a source of iodine (I), the minimum percentage of iodine must be declared. If the product is prepared by artificial drying, it may be called “Dehydrated Kelp”.

Seaweed meal, dried (IFN 5-18-897 Algae whole meal) is the product resulting from drying and grinding non-toxic macroscopic marine algae (marine plants) of the following botanical divisions: Division RHODOPHYTA (Red Algae); Division PHAEOPHYTA (Brown Algae); Division CHLOROPHYTA (Green Algae). The maximum percentage of salt (NaCl), determined by sodium content, the minimum percentage of potassium (K) and the percentage of iodine (I) shall be guaranteed. If the product is prepared by artificial drying it must be labelled as “Dehydrated Seaweed Meal”. The family(ies) shall be identified on the label. Note: The following families are accepted for use under the definition Dried Seaweed Meal: RHODOPHYTA (Red Algae): Gelidiaceae, Endocladiaceae, Gigartinaceae, Gracilariaceae, Phyllophoraceae, Solieriaceae, Hypneaceae, Pahnariaceae, Bangiaceae; PHAEOPHYTA (Brown Algae): Chordaceae, Laminariaceae, Lessoniaceae, Alariaceae, Fucaceae, Sargassaceae, Durvillaeaceae; CHLOROPHYTA (Green Algae): Monostromataceae, Ulvaceae.

Reported proximate composition and usage

The reported proximate composition of selected aquatic plants and seaweeds that have been employed as feed ingredient sources within compound aquafeeds is shown in Table 52. Table 53 shows some of the major reported feeding studies which have been conducted with these ingredients in compound aquafeeds for the major cultivated finfish and crustacean species since 1995.

TABLE 52

Reported average proximate composition of selected aquatic plants and seaweeds – all values are expressed as percent by weight on as-fed basis: Water-H₂O; Crude Protein-CP; Lipid or Ether Extract-EE; Crude Fibre-CF; Nitrogen-Free Extractives-NFE; Ash; Calcium-Ca; Phosphorus-P

Product	Average composition (% by weight)								Ref. ¹
	H ₂ O	CP	EE	CF	NFE	Ash	Ca	P	
FRESHWATER AQUATIC MACROPHYTES									
Alligator weed (<i>Alternanthera philoxeroides</i>)									
Whole plant, fresh	84.1	2.4	0.4	2.4	7.5	3.2	-	-	1
Whole plant, fresh (Thailand)	77.5	3.2	0.8	2.6	11.6	-	-	-	2
Whole plant, dry matter basis	0	15.1	2.5	15.1	47.2	20.1	-	-	1
Aquatic fern (<i>Azolla</i> spp.)									
Whole plant, fresh	93.5	1.7	0.3	0.6	3.2	0.9	0.07	0.03	1
Whole plant, dry matter basis	0	25.3	3.8	9.3	49.1	12.5	1.16	0.59	1
Whole plant, dry basis (Philippines)	8.0	27.2	3.4	12.9	36.5	20.0	-	-	3
Azolla leaf meal, dry basis (Indonesia)	8.5	25.10	3.8	12.0	35.1	23.9	-	-	4
Coontail (<i>Ceratophyllum demersum</i>)									
Whole plant, fresh	93.1	1.3	0.3	1.7	2.0	1.6	0.06	0.04	1
Whole plant, dry matter basis	0	17.9	3.8	18.3	40.5	19.5	1.30	0.32	1
Chara (<i>Chara vulgaris/Chara</i> spp.)									
Whole plant, fresh	91.6	1.5	0.1	2.0	2.0	2.7	-	-	1
Whole plant, dry matter basis	0	8.8	0.8	14.0	48.1	28.3	-	-	1
Water hyacinth (<i>Eichhornia crassipes</i>)									
Whole plant, fresh	91.5	1.2	0.3	1.9	3.8	1.3	0.18	0.09	1
Whole plant, fresh (Viet Nam)	94.9	1.0	0.2	0.9	1.8	-	-	-	2
Whole plant, dried	10.9	14.8	2.9	22.9	26.4	22.1	1.69	0.37	1
Leaf meal (Bangladesh)	5.7	25.6	1.1	17.2	44.4	11.7	-	-	6
Whole plant, compost, dried	10.5	14.2	1.3	9.4	20.0	44.6	-	-	1
Whole plant, silage, fresh	89.9	1.0	0.1	2.0	5.1	1.9	-	-	1
Canadian pondweed (<i>Elodea canadensis</i>)									
Whole plant, fresh	91.1	1.9	0.3	2.0	3.1	1.6	0.19	0.04	1
Whole plant, dry matter basis	0	18.0	2.9	14.7	44.7	19.7	1.75	0.36	1
Hydrilla (<i>Hydrilla verticillata</i>)									
Whole plant, fresh	91.7	1.8	0.3	2.6	1.5	2.0	-	-	1
Whole plant, dry matter basis	0	23.1	4.1	30.2	15.6	27.0	4.40	0.28	1
Kangkong/water bind-weed (<i>Ipomoea aquatica/l. reptans</i>)									
Leaves and stem, fresh	92.5	2.1	0.2	0.9	2.9	1.4	0.09	0.03	1
Leaves and stem, dry matter basis	0	28.0	2.7	12.0	38.6	18.7	1.20	0.40	1
Water willow (<i>Justicia americana</i>)									
Whole plant, fresh	85.0	3.4	0.5	3.9	4.6	2.6	-	-	1
Whole plant, dry matter basis	0	17.6	3.5	24.0	38.8	16.1	0.82	0.12	1
Duckweed (<i>Lemna minor</i>)									
Whole plant, fresh	91.9	1.7	0.5	0.9	4.0	0.9	-	-	1
Whole plant, fresh (Viet Nam)	92.0	1.5	0.2	0.1	5.4	1.1	-	-	5
Whole plant, dry matter basis	0	20.9	4.1	13.2	48.2	13.6	1.75	0.17	1
Whole plant, dry meal (Bangladesh)	5.1	17.6	1.4	8.1	34.8	38.1	-	-	6
Milfoil (<i>Myriophyllum</i> spp.)									
Whole plant, fresh	88.7	2.0	0.3	1.9	5.3	1.9	-	-	1
Whole plant, dry matter basis	0	20.3	2.5	13.9	45.1	18.2	2.82	0.41	1
Najas (<i>Najas guadalupensis</i>)									
Whole plant, fresh	90.4	2.3	0.4	2.9	2.6	1.4	-	-	1
Whole plant, dry matter basis	0	23.9	4.2	30.2	27.1	14.6	0.98	0.15	1
Water lettuce (<i>Pistia stratiotes</i>)									
Whole plant, fresh	93.6	1.2	0.3	1.0	2.3	1.6	-	-	1
Whole plant, fresh (Thailand)	91.9	1.2	0.4	1.8	2.9	-	-	-	2
Whole plant, dry matter basis	0	15.9	4.2	20.8	36.1	23.0	2.35	0.30	1
Whole plant, dry meal (India)	4.9	19.5	1.3	11.7	37.0	25.6	-	-	7

TABLE 52 – CONTINUED

Product	Average composition (% by weight)								Ref. ¹
	H ₂ O	CP	EE	CF	NFE	Ash	Ca	P	
Pond weed (<i>Potamogeton</i> spp.)									
Whole plant, fresh	85.0	2.0	0.4	3.1	7.1	2.4	-	-	1
Whole plant, dry matter basis	0	13.1	2.1	20.0	46.1	18.7	1.68	0.24	1
Sagittaria (<i>Sagittaria</i> spp.)									
Whole plant, fresh	85.0	2.6	1.0	4.1	5.8	1.5	-	-	1
Whole plant, dry matter basis	0	18.2	6.6	23.9	42.4	8.9	0.83	0.35	1
Salvinia (<i>Salvinia auriculata</i>/S. <i>molesta</i>)									
Whole plant, fresh	77.2	1.8	0.6	7.7	11.2	1.5	-	-	1
Whole plant, dry matter basis	0	7.9	2.6	33.8	49.1	6.6	-	-	1
Burreed (<i>Sparganium americanum</i>)									
Whole plant, fresh	89.1	2.6	0.9	2.2	4.0	1.2	-	-	1
Whole plant, dry matter basis	0	23.8	8.3	20.2	36.7	11.0	-	-	1
Reed-mace (<i>Typha latifolia</i>)									
Whole plant, fresh	77.1	2.4	0.9	7.6	10.4	1.6	-	-	1
Whole plant, dry matter basis	0	10.7	3.9	30.3	47.0	8.1	0.64	0.17	1
Wolffia (<i>Wolffia</i> spp.)									
Whole plant, fresh	96.4	1.0	0.3	-	1.0	0.6	-	-	1
Whole plant, dry matter basis	0	27.8	8.3	-	47.2	16.7	-	-	1
MARINE AQUATIC MACROPHYTE									
<i>Chaetomorpha</i> spp., fresh (green seaweed)	90.4	3.1	0.6	1.1	2.5	2.3	-	-	1
<i>Enteromorpha intestinalis</i> , fresh (green seaweed)	81.4	3.7	0.5	-	-	6.0	-	-	1
<i>Enteromorpha</i> (lumot), dried (Philippines)	15.2	13.8	1.9	9.3	36.9	38.1	-	-	3
<i>Ulva</i> spp. (green seaweed), dried meal	11.5	8.0	0.15	-	-	26.4	-	-	7
<i>Laminariales/Fucales</i> spp. (brown seaweed) (d)	8.9	6.5	0.5	6.6	42.3	35.0	2.50	0.26	1
<i>Gracilaria</i> spp. (red seaweed), dried	7.0	10.2	0.4	5.8	44.8	38.8	-	-	3
<i>Kappaphycus</i> spp. (red seaweed), dried	6.1	5.4	0.8	6.1	57.3	30.4	-	-	3
Sargassum (brown seaweed), dried	10.4	9.0	0.8	9.6	46.4	34.2	-	-	3

¹ 1 – Tacon (1987); 2 – Thongrod (2007); 3 – Catacutan (2002); 4 – Nur (2007); 5 – Hung and Huy (2007); 6 – Barman and Karim (2007); 7 – Diler et al. (2007).

TABLE 53

Major feeding studies conducted with selected aquatic macrophyte and seaweed based low-protein feedstuffs in compound aquafeeds

FRESHWATER AQUATIC MACROPHYTES

Aquatic fern: (*Azolla pinnata*): Abalone: Reyes and Fermin (2003); Medium carp/*Osteobrama belangeri*: Basudham and Vishwanath (1997);

Duckweed: (*Lemna minor*): Catla catla/Cirrhinus mrigala: Kalita et al. (2007, 2008); Tilapia: El-Shafai et al. (2004); **Duckweed** (*Lemna polyrrhiza*) leaf meal (fermented): Rohu: Bairagi et al. (2002); **Duckweed** (*Spirodela polyrrhiza*): Grass carp: Pipalova (2003); Tilapia: Fasakin et al. (1999); **Duckweed** (*Spirodela* spp.): Crayfish: Fletcher and Warburton (1997);

Echinochloa stagnina: Crayfish: Sharshar and Haroon (2009);

Water spinach/*Ipomoea reptans*: Catla catla/Cirrhinus mrigala: Kalita et al. (2007, 2008);

Nymphoides cristatum: Indian major carp: Patra et al. (2002);

Polygonum timentosum: Crayfish: Sharshar and Haroon (2009);

Asian watermoss/*Salvinia cuculata*: Catla catla/Cirrhinus mrigala: Kalita et al. (2007, 2008);

Water chestnut/*Trapa natans*: Catla catla/Cirrhinus mrigala: Kalita et al. (2007, 2008);

Water hyacinth (*Echhornia crassipes*): Crayfish: Sharshar and Haroon (2009); Tilapia: Soliman (2000); **Water hyacinth/fermented**: Tilapia: El-Sayed (2003);

Water lettuce (*Pistia stratiotes*): Rohu: Ray and Das (1996).

MARINE AQUATIC MACROPHYTES

Green seaweeds

Ulva meal: Striped mullet: Wassef et al. (2001);

Ulva australis: Sea urchin: Senaratna et al. (2005);

TABLE 53 – CONTINUED

Ulva clathrata: Shrimp: Cruz-Suarez et al. (2008);
Ulva fasciata: Rohu: Bindu and Sobha (2004);
Ulva linza: Sea urchin: Daggett et al. (2005);
Ulvaria obscura/Ulva lactuca: Sea urchin: Daggett et al. (2005); Dlaza et al. (2008); Dworjanyn et al. (2007);
Ulva pertusa: Sea urchin: Osakao et al. (2006); Red sea bream: Mustafa et al. (1995);
Ulva rigida: Abalone: Tayloy and Tsvetnenko (2004); Common carp: Dilar et al. (2007); European sea bass: Valentea et al. (2006); Tilapia: Kut Guroy et al. (2007); Sebahattin et al. (2009);

Red seaweeds

Cryptonemia crenulata: Shrimp: Da Silva and Barbosa (2009);
Gracilaria cornea/Gracilaria bursa-pastoris: European sea bass: Valentea et al. (2006);
Gracilaria cervicornis: Shrimp: Marinho-Soriano et al. (2007);
Gracilariopsis bailinae: Abalone: Reyes and Fermin (2003);
Gracilaria heteroclada: Shrimp: Penafiorida and Golez (1996);
Hypnea cervicornis: Shrimp: Da Silva and Barbosa (2009);
Kappaphycus alvarezii: Shrimp: Penafiorida and Golez (1996);
Palmaria palmate: Sea urchin: Basuyaux and Blin (1998); Daggett et al. (2005);
Porphyra purpurea: Grey mullet: Davies et al. (1997b); Daggett et al. (2005); *Porphyra* spp: Atlantic cod: Walker et al. (2009); *Porphyra yezoensis*: Red sea bream: Mustafa et al. (1995);

Brown seaweeds

Ascophyllum meal: Red sea bream: Nakagawa et al. (1997); *Ascophyllum nodosum*: Red sea bream: Mustafa et al. (1995); Shrimp: Cruz-Suarez et al. (2008);
Cystoseira barbata: Tilapia: Kut Guroy et al. (2007);
Ecklonia cava: Olive flounder: Kim and Lee (2008); *Ecklonia radiata*: Sea urchin: Dworjanyn et al. (2007);
Ecklonia maxima: Sea urchin: Dlaza et al. (2008);
Kelp meal: Abalone: Garcia-Esquivel and Felbeck (2009); Kelp meal: *Macrocystis pyrifera*: Abalone: Nava Guerrero et al. (2004); Shrimp: Cruz-Suarez et al. (2008);
Laminaria digitata: Sea urchin: Basuyaux and Blin (1998); *Laminaria saccharina*: Sea urchin: Daggett et al. (2005);
Polysiphonia fucoides: Trout: Del Barga et al. (2006);
Sargassum linearifolium: Sea urchin: Dworjanyn et al. (2007)
Sargassum wightii: Rohu: Bindu and Sobha (2004);
Spyridia insignis: Rohu: Bindu and Sobha (2004).

4.6 FEED ADDITIVES

According to AAFCO a feed additive is defined as an ingredient or combination of ingredients added to a basic feed mix or parts thereof to fulfil a specific need; usually used in micro quantities and requiring careful handling and mixing (AAFCO, 2008a).

For the purpose of this report, feed additives may include (1) the addition of specific nutrients in synthetic or purified form (includes specific amino acids, vitamins, minerals and trace elements, cholesterol, phospholipids, etc.); (2) the addition of specific chemicals, nutrients or ingredients that aid in maintaining feed quality, stability, and/or attractability (includes chemical preservatives, antioxidants, emulsifiers, antimicrobial compounds, pellet binders and feeding stimulants); and (3) the addition of specific compounds or substances that target feed digestibility, animal performance, health and/or flesh quality (includes enzymes, acidifiers, growth promoters [hormones, antibiotics], pigments, immune enhancers, probiotics, etc. (for general review, see Barrows and Hardy, 2000; Hertrampf and Pascual, 2000; Singh et al., 2008).

4.6.1 Amino acids and related products

Official definitions (AAFCO, 2008b)

Glycine (IFN 5-02-127 Glycine) is a product which contains a minimum of 97 percent amino acetic acid. The percentage of glycine must be guaranteed.

L-Lysine (IFN 5-08-022 L-Lysine) is a product which contains a minimum of 95 percent L-2,6-diaminohexanoic acid. The percentage of L-lysine must be guaranteed.

L-Threonine (IFN 5-08-092 L-Threonine) is a product which contains a minimum of 95 percent L-2-amino-3-hydroxybutyric acid. The percentage of L-threonine must be guaranteed.

DL-Tryptophan (IFN 5-08-093 DL-Tryptophan) is a product which contains a minimum of 97 percent racemic 2-amino-3-(3'indolyl)-propionic acid. The percentage of DL-tryptophan must be guaranteed.

L-Tryptophan (IFN 5-18-776 L-Trptophan) is a product which contains a minimum of 97 percent L-2-amino-3-(3'indolyl)-propionic acid. The percentage of L-tryptophan must be guaranteed.

L-Lysine monohydrochloride (IFN 5-19-118 L-Lysine monohydrochloride) is a product which contains a minimum of 95 percent L-2, 6-diaminohexanoic acid monohydrochloride. The percentage of L-lysine must be guaranteed.

Taurine (IFN 5-09-821 Taurine) is a product which contains a minimum of 97 percent 2-aminoethanesulfonic acid. The percentage of taurine must be guaranteed. It is used as a nutritional supplement in cat foods (growth, reproduction and adult maintenance), dog foods (growth, reproduction and adult maintenance) and in the feed of growing chickens. When added to complete chicken feed, the total taurine shall not exceed 0.054 percent of the feed.

L-Arginine (IFN 5-32-043 L-Arginine) is a product which contains a minimum of 98 percent L-2-Amino-5-guanidinopentanoic acid. The percentage of L-Arginine must be guaranteed.

DL-Arginine (IFN 5-32-044 DL-Arginine) is a product which contains a minimum of 98 percent racemic 2-Amino-5-guanidinopentanoic acid. The percentage of DL-Arginine must be guaranteed.

L-Tyrosine (IFN 5-32-045 L-Tyrosine) is a product which contains a minimum of 98 percent L-2-amino-3-(4-hydroxyphenyl)-propanoic acid. The percentage of L-Tyrosine must be guaranteed.

L-Lysine liquid is a product that contains a minimum of 50 percent L-2, 6-diaminohexanoic acid by weight in a water solution. The L-lysine content must not be less than 85 percent on a moisture free basis. The percentage of L-lysine must be guaranteed.

DL-Methionine hydroxy analogue calcium (IFN 5-03-087 DL-Methionine Hydroxy Analogue Calcium) is a product which contains a minimum of 97 percent racemic 2-amino-4-(methylthio)butanoic acid calcium salt. The percentage of DL-methionine hydroxy analogue calcium must be guaranteed.

DL-Methionine (IFN 5-03-086 DL-Methionine) is a product which contains a minimum of 99 percent racemic 2-amino-4-(methylthio)butanoic acid. The percentage of DL-methionine must be guaranteed.

DL-Methionine hydroxy analogue (IFN 5-30-281 DL-Methionine Hydroxy Analogue) is a product which contains a minimum of 88 percent racemic 2-hydroxy-4-methylthiobutanoic acid. The percentage of DL-methionine hydroxy analogue must be guaranteed.

DL-Methionine sodium (IFN 5-16-730 DL-Methionine Sodium) is a product which contains a minimum of 45.9 percent racemic 2-amino-methylthiobutyric acid sodium salt. The percentage of DL-methionine must be guaranteed.

Reported usage

Purified amino acids are usually added to feed mixtures so as to improve the overall essential amino acid balance of a formulated diet, and in particular within those formulated feeds where the fishmeal content has been reduced and/or replaced with alternative protein sources which may be deficient in one or more essential amino acids. Moreover, recent evidence suggests that dietary supplementation with specific amino acids may also be beneficial for other reasons (depending upon the species), including: (1) increasing the chemo-attractive property and nutritional value of aquafeeds with low fishmeal inclusion; (2) optimizing efficiency of metabolic transformation in juvenile and sub-adult fishes; (3) suppressing aggressive behaviours and cannibalism; (4) increasing larval performance and survival; (5) mediating timing and efficiency of spawning; (6) improving fillet taste and texture; and (7) enhancing immunity and tolerance to environmental stresses (for review, see Li *et al.*, 2009).

Table 54 summarises some of the major studies which have been conducted since 1995 concerning the efficacy of dietary supplementation of rations with synthetic amino acids, either alone or in combination with trace elements. In general terms, synthetic uncoated free amino acids are usually soluble in water and thus may be prone to loss through leaching on prolonged immersion of amino acid supplemented feeds in water prior to feeding (especially in the case of feeds for crustaceans with slow cutting/rasping feeding habits). Moreover, because of their solubility, they are usually digested and absorbed more rapidly from the gastrointestinal tract than those amino acids contained within intact dietary protein sources.

TABLE 54

Major feeding studies showing the efficacy of dietary supplementation with synthetic amino acids

- I. **Studies showing the benefit of dietary supplementation with free amino acids on growth:** American lobster: Floreto *et al.* (2000); Asian seabass (Barramundi): Williams *et al.* (2001); Cobia: Lunger *et al.* (2007b); Red sea bream: Takagi *et al.* (2001); Rohu: Mukhopadhyay and Ray (1999b); Salmon: Sveier *et al.* (2001); Shrimp: Biswas *et al.* (2007b); Fernandez and Sukumaran (1995); Forster and Dominy (2006); Fox *et al.* (2009); Southern catfish: Ai and Xie (2005b); Sunshine bass: Keembiyehetty and Gatlin (1997); Tilapia: El-Saidy and Gaber (2002b); Trout: Cheng *et al.* (2003b, 2003c); Gaylord and Barrows (2009); Nang Thu *et al.* (2007); Rodehutsord *et al.* (2000a, 2000b); Yamamoto *et al.* (2005); Turbot: Peres and Oliva-Teles (2005);
- II. **Studies showing rapid absorption rates of amino acids from purified supplements compared with coated amino acids and/or intact protein sources:** Channel catfish: Ambardekar and Reigh (2007); Ambardekar *et al.* (2009); Zarate *et al.* (1999);
- III. **Studies showing little or no benefit on growth of dietary supplementation with crystalline amino acids:** Channel catfish: Gaylord *et al.* (2002); Li and Robinson (1998); Crucian carp: Wang *et al.* (2006); Trout: Davies and Morris (1997);
- IV. **Studies showing the effect of amino acid leaching from supplemented rations:** Channel catfish: Zarate and Lovell (1997); Crucian carp: Wang *et al.* (2006); Shrimp: Alam *et al.* (2004, 2005); Fish larvae/general: Yufera *et al.* (2002);

TABLE 54 – CONTINUED

- V. **Studies showing the benefit of using coated or protected amino acids compared with free unprotected amino acids:** Common carp: Zhiou *et al.* (2007c); Crucian carp: Wang *et al.* (2006); Fish larvae/general: Yufera *et al.* (2002); Grass carp: Liu *et al.* (1999); Shrimp: Alam *et al.* (2004, 2005); Cheng *et al.* (2003); Fox *et al.* (1995); Tilapia: Segovia-Quintero and Reigh (2004); Trout: Masumoto *et al.* (1999); Yellowtail: Masumoto *et al.* (1999);
- VI. **Studies showing other possible non-growth related beneficial effects of dietary supplementation with specific amino acids:** General: Li *et al.* (2009); Aggression/cannibalism: Atlantic cod: Hoglund *et al.* (2005); Groupers: Hseu *et al.* (2003); Rainbow trout: Winberg *et al.* (2001); Feeding attraction: Abalone: Allen *et al.* (2000, 2001); Atlantic cod: Yacoob *et al.* (2004); Atlantic halibut: Yacoob and Browman (2007a, 2007b); Common carp: Kasumyan and Morsi (1996); Li and Yamamoto (2000); Eel: Sola and Tongiorgi (1998); European seabass: Gomes *et al.* (1997); Dias *et al.* (1997); Freshwater prawn: Felix and Sudharsan (2004); Harpaz (1997); Rainbow trout: Tiril *et al.* (2008); Yamashita *et al.* (2006); Rohu: Shankar *et al.* (2008); Shrimp: Coman *et al.* (1996); Feng and Wang (2004); Nunes *et al.* (2006); Smith *et al.* (2005b); Snook: Borquez and Cerqueira (1998); Sole: Reig *et al.* (2003); Sturgeon: Shamusaki *et al.* (2007); Sudagar *et al.* (2005); Tilapia: Yacoob *et al.* (2001); Winter flounder: Fredette *et al.* (2000); Maturation: Ayu: Akiyama *et al.* (1996); Osmoregulation: Shrimp: Penaflores and Virtanen (1996); Stress control/management: Brown trout: Hoglund *et al.* (2007); European seabass: Herrero *et al.* (2007); Rainbow trout: Lepage *et al.* (2002, 2003); Papoutsoglou *et al.* (2005);
- VII. **Studies showing the beneficial effect of amino acid-mineral mixtures and chelates:** Abalone: Mai and Tan (2000a, 2000b); Tan and Mai (2001); Channel catfish: Lim *et al.* (1996); Micropterus salmoides: Yuan *et al.* (2003); Rainbow trout: Apines *et al.* (2001, 2003a, 2003b, 2004a, 2004b); Satoh *et al.* (2001); Red sea bream: Alam Sarker *et al.* (2005); Tilapia: Barros *et al.* (2004); Zhao *et al.* (1997).

4.6.2 Mineral products

Official definitions (AAFCO, 2008b)

Bone ash (IFN 6-00-401 Animal bone ash) is the ash obtained by burning bones with free access to air and containing a minimum of 15.3 percent phosphorus (P). The label must show a guarantee for calcium (Ca) and phosphorus (P).

Bone charcoal (IFN 6-00-402 Animal bone charcoal) is obtained by charring bones in closed retorts. It must contain a minimum of 14 percent phosphorus (P). It must be labelled with guarantees for calcium (Ca) and phosphorus (P).

Bone charcoal, spent (IFN 6-00-404 Animal bone charcoal spent) is the product resulting from the repeated charring of bone charcoal after use in clarifying sugar solutions. It must contain a minimum of 11.5 percent phosphorus (P). It must be labelled with guarantees for phosphorus (P) and calcium (Ca).

Bone meal, cooked (IFN 6-17-171 Animal bone meal boiled) is the dried and ground sterilized product resulting from wet cooking without steam pressure of undecomposed bones. Fat, gelatin and meat fibre may or may not be removed. When labeled as a commercial feed ingredient, it shall carry guarantees for protein, phosphorus (P), and calcium (Ca). “Cooked Bone Meal” shall be used in all labelling.

Bone meal, steamed (IFN 6-00-400 Animal bone meal steamed) is the dried and ground product sterilized by cooking undecomposed bones with steam under pressure. Grease, gelatin and meat fibre may or may not be removed. It must be labelled with guarantees for phosphorus (P) and calcium (Ca). “Steamed Bone Meal” must be used in all labelling.

Bone phosphate (IFN 6-00-406, Animal bone phosphate) is the residue of bones that have been treated first in a hydrochloric acid solution and thereafter precipitated with lime and dried. It must contain a minimum of 17 percent phosphorus (P). It must be labelled with guarantees for calcium (Ca) and phosphorus (P).

Calcite (IFN 6-01-067 Calcite ground) is an acceptable source of calcium carbonate. It must be true to name and contain not less than 33 percent calcium (Ca).

Calcium carbonate (IFN 6-01-069 Calcium carbonate) is a product true to name which contains a minimum of 38 percent calcium (Ca).

Calcium carbonate, precipitated (IFN 6-01-071 Calcium carbonate, precipitated CaCO₃) is an acceptable source of calcium carbonate. It must be true to name and contain not less than 33 percent calcium (Ca). "Precipitated Calcium Carbonate" must be used in all labelling.

Calcium iodate (IFN 6-16-610 Calcium iodate monohydrate Ca(IO₃)₂·H₂O) is the calcium salt of iodic acid generally expressed as Ca(IO₃)₂ and the monohydrate form. Minimum calcium (Ca) and iodine (I) must be specified.

Calcium oxide (IFN 6-14-003 Calcium oxide CaO) is the oxide form of calcium generally expressed as CaO (commonly called quicklime). It is the product of calcining limestone. A strong alkali requiring caution in its use. Minimum calcium (Ca) content must be specified.

Calcium periodate (IFN 6-09-355 Calcium periodate Ca₅(IO₆)₂) is an acceptable source of iodine. It is produced by reacting calcium iodate with calcium hydroxide or calcium oxide to form a substance consisting of not less than 60 percent by weight of penta calcium orthoperiodate containing 28 to 31 percent by weight of iodine. It is used or intended for use in salt for livestock as a source of iodine.

Calcium phosphate (IFN 6-12-311 Calcium phosphate) is a calcium phosphate product either calcined, fused, precipitated or reacted. It must contain not more than one part fluorine (F) to 100 parts of phosphorus (P). The minimum percent of calcium (Ca) and phosphorus (P) and maximum percent of fluorine (F) must be stated on the label.

Calcium sulfate (IFN 6-01-087 Calcium sulphate anhydrous CaSO₄; IFN 6-01-090 Calcium sulphate dihydrate CaSO₄·2H₂O) is the calcium salt of sulphuric acid generally expressed as CaSO₄ and its hydrated forms. Minimum calcium (Ca) and minimum sulphur (S) content must be specified.

Chalk, precipitated (IFN 6-01-201, Chalk precipitated) is an acceptable source of calcium carbonate. It must be true to name and contain not less than 33 percent calcium (Ca). "Precipitated Chalk" must be used in all labelling.

Chalk rock (IFN 6-01-202 Chalk rock ground) is an acceptable source of calcium carbonate. It must be true to name and contain not less than 33 percent of calcium (Ca).

Chromium tripicolinate is the product resulting from reaction of chromium chloride with picolinic acid. It is to be used as a source of supplemental chromium in swine diets, not to supply more than 200 ppb of chromium to the diet. Minimum chromium from chromium tripicolinate must be specified.

Clam shells, ground (IFN 6-01-259 Clam shells ground) is an acceptable source of calcium carbonate. It must be true to name and contain not less than 35 percent calcium (Ca).

Cobalt carbonate (IFN 6-01-566 Cobalt carbonate) is the cobalt salt of carbonic acid generally expressed as CoCO₃ and its hydrated forms. Minimum cobalt (Co) must be specified.

Cobalt chloride (IFN 6-01-556 Cobalt chloride anhydrous) is the cobalt salt of hydrochloric acid generally expressed as CoCl_2 and its hydrated forms. Minimum cobalt (Co) content must be specified.

Cobalt oxide (IFN 6-01-560 Cobalt oxide) is the oxide form of cobalt generally expressed as CoO . Minimum cobalt (Co) content must be specified.

Cobalt sulfate (IFN 6-01-562 Cobalt sulphate monohydrate $\text{CoSO}_4 \cdot \text{H}_2\text{O}$; IFN 6-01-564 Cobalt sulphate heptahydrate $\text{CoSO}_4 \cdot 7\text{H}_2\text{O}$) is the cobalt salt of sulphuric acid generally expressed as CoSO_4 and its hydrated forms. Minimum cobalt (Co) content must be specified.

Copper carbonate (IFN 6-01-703 Cupric carbonate) is the copper salt of carbonic acid generally expressed as CuCO_3 . Minimum copper (Cu) content must be specified.

Copper chloride (IFN 6-07-135 Cuprous chloride CuCl_2 ; IFN 6-01-705 Cupric chloride dihydrate, $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$) is the copper salt of hydrochloric acid generally expressed as CuCl or CuCl_2 and their hydrated forms. Minimum copper (Cu) content must be specified.

Copper oxide (IFN 6-28-224 Cuprous oxide Cu_2O ; IFN 6-01-711 Cupric oxide CuO) is the oxide form of copper generally expressed as CuO or Cu_2O . Minimum copper (Cu) content must be specified.

Copper sulphate (IFN 6-01-717 Cupric sulphate anhydrous; IFN 6-01-719 Cupric sulphate pentahydrate $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$) is the copper salt of sulphuric acid generally expressed as CuSO_4 and its hydrated forms. Minimum copper (Cu) content must be specified.

Dicalcium phosphate (IFN 6-01-080 Calcium phosphate dibasic from defluorinated phosphoric acid; IFN 6-26-335 Calcium phosphate dibasic from furnaced phosphoric acid) is a calcium salt of phosphoric acid generally expressed as CaHPO_4 and its hydrated forms. Minimum phosphorus (P), minimum calcium (Ca) and maximum fluorine (F) content must be specified. It must not contain more than 1 part of fluorine (F) to 100 parts phosphorus (P).

Disodium phosphate (IFN 6-04-286 Sodium phosphate dibasic) is a sodium salt of phosphoric acid generally expressed as Na_2HPO_4 and its hydrated forms. Minimum phosphorus (P), minimum sodium (Na) and maximum fluorine (F) content must be specified. It must not contain more than 1 part fluorine (F) to 100 parts phosphorus (P).

Ferric sulphate (IFN 6-30-086 Ferric sulfate) is the iron salt of sulphuric acid generally expressed as $\text{Fe}_2(\text{SO}_4)_3$ and its hydrated forms. Minimum iron (Fe) content must be specified.

Ferrous carbonate (IFN 6-01-863 Ferrous carbonate) is the iron salt of carbonic acid generally expressed as FeCO_3 . Minimum iron (Fe) content must be specified.

Ferrous chloride (IFN 6-30-090 Ferrous chloride) is the iron salt of hydrochloric acid generally expressed as FeCl_2 and its hydrated forms. Minimum iron (Fe) content must be specified.

Ferrous sulphate (IFN 6-01-869 Ferrous sulphate monohydrate $\text{FeSO}_4 \cdot \text{H}_2\text{O}$; IFN 6-20-734 Ferrous sulphate heptahydrate $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$) is the iron salt of sulphuric acid generally expressed as FeSO_4 and its hydrated forms. Minimum iron (Fe) content must be specified.

Iron oxide (IFN 6-02-431 Ferric oxide) is the oxide form of iron occurring both naturally and synthetically in various chemical valence compositions and colours – sometimes expressed as Fe_2O_3 . Minimum iron (Fe) content must be specified.

Limestone, ground (IFN 6-02-632 Limestone ground) is an acceptable source of calcium carbonate. It must be true to name and contain not less than 33 percent calcium (Ca). “Ground Limestone” must be used in all labelling.

Limestone, magnesium or dolomitic (IFN 6-02-633 Limestone dolomitic ground; IFN 6-06-934 Limestone magnesium ground) is an acceptable source of magnesium and calcium carbonate. The terms are synonymous and designate a native mineral composed of mixtures of magnesium carbonate (MgCO_3) and calcium carbonate (CaCO_3). It must contain not less than 10 percent magnesium (Mg) and must be declared as an ingredient as magnesium limestone or dolomitic limestone.

Magnesium carbonate (IFN 6-02-754 Magnesium carbonate, IFN 6-08-797 Magnesium carbonate trihydrate, IFN 6-29-798 Magnesium carbonate pentahydrate) is a magnesium salt of carbonic acid generally expressed as MgCO_3 , $\text{Mg}(\text{OH})_2$ and its hydrated forms. Minimum magnesium (Mg) content must be specified.

Magnesium chloride (IFN 6-20-872 Magnesium chloride) is the magnesium salt of hydrochloric acid generally expressed as MgCl_2 and its hydrated forms. Minimum magnesium (Mg) content must be specified.

Magnesium phosphate (IFN 6-23 -294 Magnesium phosphate) is the magnesium salt of phosphoric acid, generally expressed as MgHPO_4 and its hydrated forms. Minimum magnesium (Mg) and phosphorus (P) and maximum fluorine (F) must be specified. It must contain not more than one part fluorine (F) to 100 parts phosphorus.

Magnesium oxide (IFN 6-02-756 Magnesium oxide) is the oxide of magnesium generally expressed as MgO . Minimum magnesium (Mg) content must be specified.

Magnesium-mica (IFN 6-08-999 Magnesium-mica) is a naturally occurring magnesium, iron and potassium layer silicate. It must be labelled with guarantees for magnesium (Mg), iron (Fe) and potassium (K).

Magnesium sulphate (IFN 6-26-134 Magnesium sulphate, IFN 6-12-209 Magnesium sulphate monohydrate, IFN 6-02-758 Magnesium sulphate heptahydrate) is the magnesium salt of sulphuric acid generally expressed as MgSO_4 and its hydrated forms. Minimum magnesium (Mg) content must be specified.

Manganese carbonate (IFN 6-03-036 Manganous carbonate) is the manganese salt of carbonic acid generally expressed as MnCO_3 and its hydrated forms. Minimum manganese (Mn) content must be specified.

Manganese chloride (IFN 6-03-03 8 Manganous chloride tetrahydrate) is the manganese salt of hydrochloric acid generally expressed as MnCl_2 and its hydrated forms. Minimum manganese (Mn) content must be specified.

Manganese orthophosphate (IFN 6-03-047 Manganese orthophosphate trihydrate) is the manganese salt of phosphoric acid generally expressed as $\text{Mn}_3(\text{PO}_4)_2$ and its hydrated forms. Minimum manganese (Mn) content must be specified.

Manganese phosphate (dibasic) (IFN 6-03-048 Manganese phosphate dibasic) is the manganese salt of phosphoric acid generally expressed as $MnHPO_4$ and its hydrated forms. Minimum manganese (Mn) content must be specified.

Manganese sulphate (IFN 6-03-050, Manganous sulfate tetrahydrate) is the manganese salt of sulphuric acid generally expressed as $MnSO_4$ and its hydrated forms. Minimum manganese (Mn) content must be specified.

Manganous oxide (IFN 6-03-054 Manganous oxide) is an oxide form of manganese generally expressed as MnO . Minimum manganese (Mn) content must be specified.

Metal amino acid complex (IFN 6-32-053 Copper, amino acid complex; IFN 6-32-054 Zinc, amino acid complex; IFN 6-32-055 Magnesium, amino acid complex; IFN 6-32-056 Iron, amino acid complex; IFN 6-32-057 Cobalt, amino acid complex; IFN 6-32-058 Calcium, amino acid complex; IFN 6-32-059 Potassium, amino acid complex; IFN 6-32-060 Manganese, amino acid complex) is the product resulting from complexing of a soluble metal salt (such as potassium or manganese) with an amino acid(s). Minimum metal content must be declared. When used as a commercial feed ingredient, it must be declared as a specific metal amino acid complex, i.e. Potassium Amino Acid Complex; Copper, Amino Acid Complex; Zinc, Amino Acid Complex; Magnesium, Amino Acid Complex; Iron, Amino Acid Complex; Cobalt, Amino Acid Complex; Calcium, Amino Acid Complex; Manganese, Amino Acid Complex.

Metal (specific amino acid) complex (IFN Copper lysine complex; IFN Zinc lysine complex; IFN 6-16-294 Ferric methionine complex; IFN 6-19-2 12 Manganese methionine complex; IFN 6-16-293 Zinc methionine complex) is the product resulting from complexing a soluble metal salt with a specific amino acid. Minimum metal content must be declared. When used as a commercial feed ingredient, it must be declared as a specific metal, specific amino acid, i.e. Copper Lysine Complex, Zinc Lysine Complex, Ferric Methionine Complex, Manganese Methionine Complex and Zinc Methionine Complex.

Metal amino acid chelate (IFN 6-20-981 Calcium amino acid chelate; IFN 6-20-982 Cobalt amino acid chelate; IFN 6-20-983 Copper amino acid chelate; IFN 6-20-984 Iron amino acid chelate; IFN 6-20-985 Magnesium amino acid chelate; IFN 6-20-986 Manganese amino acid chelate; IFN 6-20-987 Zinc amino acid chelate) is the product resulting from the reaction of a metal ion from a soluble metal salt with amino acids with a mole ratio of one mole of metal to one to three (preferably two) moles of amino acids to form coordinate covalent bonds. The average weight of the hydrolysed amino acids must be approximately 150 and the resulting molecular weight of the chelate must not exceed 800. The minimum metal content must be declared. When used as a commercial feed ingredient it must be declared as a specific metal amino acid chelate, i.e. Calcium Amino Acid Chelate, Cobalt Amino Acid Chelate, Copper Amino Acid Chelate, Iron Amino Acid Chelate, Magnesium Amino Acid Chelate, Manganese Amino Acid Chelate or Zinc Amino Acid Chelate.

Metal polysaccharide complex (IFN 8-09-822, Copper polysaccharide complex; IFN 8-09-898 Iron polysaccharide complex; IFN 8-09-899 Zinc polysaccharide complex; IFN 8-19-206 Magnesium polysaccharide complex) is the product resulting from complexing of a soluble salt with a polysaccharide solution, declared as an ingredient as the specific metal complex, i.e. Copper Polysaccharide Complex, Zinc Polysaccharide Complex, Iron Polysaccharide Complex, Cobalt Polysaccharide Complex, Magnesium Polysaccharide Complex and Manganese Polysaccharide Complex.

Metal propionate is the product resulting from reaction of a metal salt with propionic acid. The metal propionates are prepared with an excess of propionic acid at an appropriate stoichiometric ratio. It must be declared as an ingredient of the specific metal propionate, i.e. Zinc Propionate, Chromium Propionate. Chromium propionate is to be used in swine diets not exceeding 200 ppb chromium in the diet. Minimum metal content must be declared.

Metal proteinate (IFN 6-09-896 Copper proteinate; IFN 6-09-897 Zinc proteinate; IFN 6-26-149 Magnesium proteinate; IFN 6-26-150 Iron proteinate; IFN 6-26-151 Cobalt proteinate; IFN 6-16-834 Manganese proteinate; IFN 6-16-833 Calcium proteinate) is the product resulting from the chelation of a soluble salt with amino acids and/or partially hydrolysed protein. It must be declared as an ingredient as the specific metal proteinate, i.e. Copper Proteinate, Zinc Proteinate, Magnesium Proteinate, Iron Proteinate, Cobalt Proteinate, Manganese Proteinate or Calcium Proteinate.

Monocalcium phosphate (IFN 6-01-082 Calcium phosphate, monobasic, from defluorinated phosphoric Acid; IFN 6-26-334 Calcium phosphate, monobasic, from furnace phosphoric acid) is a calcium salt of phosphoric acid generally expressed as $\text{CaH}_4(\text{PO}_4)_2$ and its hydrated forms. Minimum phosphorus (P), minimum calcium (Ca) and maximum fluorine (F) content must be specified. It must contain not more than 1 part fluorine (F) to 100 parts phosphorus (P).

Monosodium phosphate (IFN 6-04-288 Sodium phosphate monobasic monohydrate) is a sodium salt of phosphoric acid generally expressed as NaH_2PO_4 and its hydrated forms. Minimum phosphorus (P), minimum sodium (Na) and maximum fluorine (F) content must be specified. It must contain not more than 1 part fluorine (F) to 100 parts phosphorus (P).

Oyster shell flour (IFN 6-03-481 Oyster shell flour) is an acceptable source of calcium carbonate. It must be true to name and contain not less than 33 percent calcium (Ca).

Phosphate, defluorinated (IFN 6-01-780 Phosphate defluorinated; IFN 6-12-330 Phosphate defluorinated 18.5% phosphorus; IFN 6-12-324 Phosphate defluorinated 18% phosphorus; IFN 6-12-331 Phosphate defluorinated 21% phosphorus) includes either calcined, fused, precipitated or reacted calcium phosphate. It must contain not more than one part of fluorine (F) to 100 parts of phosphorus (P). The minimum percent of calcium (Ca) and phosphorus (P) and the maximum percent of fluorine (F) must be stated on the label. The term “defluorinated” must not be used as a part of the name of any product containing more than one part of fluorine (F) to 100 parts of phosphorus (P). The term “Defluorinated Phosphate” must be used, where appropriate, in labelling ingredient listings.

Rock phosphate, soft (IFN 6-03-947 Rock phosphate soft) is the very finely divided by-product (washings) obtained from mining Florida rock phosphate by the hydraulic process. It must contain a minimum of 9 percent phosphorus (P) and 15 percent calcium (Ca), and not more than 30 percent clay and 1.5 percent fluorine (F). The term soft rock phosphate must be used in all labelling.

Rock phosphate, ground (IFN 6-03-945 Rock phosphate ground) is ground phosphate rock. It must be labelled with guarantees for calcium (Ca) and phosphorus (P) and a maximum guarantee for fluorine (F). “Ground Rock Phosphate” must be used in all labelling.

Rock phosphate, ground, low fluorine (IFN 6-03-946 Rock phosphate ground low fluorine) is ground phosphate rock that contains not more than 0.5 percent fluorine (F). “Low Fluorine Ground Rock Phosphate” must be used in all labelling. It must be labelled with guarantees for minimum percentages of calcium (Ca) and phosphorus (P) and for a maximum percentage of fluorine (F).

Sodium hexametaphosphate (IFN 6-12-315 Sodium hexametaphosphate) is the sodium salt of phosphoric acid generally expressed as $(\text{NaPO}_3)_x \cdot \text{H}_2\text{O}$ ($x=6-20$). Minimum sodium and maximum fluorine must be specified. It must not contain more than one part fluorine (F) to 100 parts phosphorus (P), 75 parts per million of arsenic (As) and 30 parts per million of heavy metals reported as lead.

Tribasic sodium phosphate (IFN 6-20-871 Sodium phosphate tribasic) is the sodium salt of phosphoric acid generally expressed as Na_3PO_4 and its hydrated forms. Minimum phosphorus (P), minimum sodium (Na) and maximum fluorine (F) must be specified. It must contain not more than 1 part fluorine (F) to 100 parts of phosphorus (P).

Tricalcium phosphate (IFN 6-01-084 Calcium phosphate tribasic) is a calcium salt of phosphoric acid generally expressed as $\text{Ca}_3(\text{PO}_4)_2$. Minimum phosphorus (P), minimum calcium (Ca) and maximum fluorine (F) must be specified. It must contain not more than 1 part fluorine (F) to 100 parts phosphorus (P).

Potassium chloride (IFN 6-03-755 Potassium chloride) is the potassium salt of hydrochloric acid generally expressed as KCl. Minimum potassium (K) content must be specified.

Potassium iodate (IFN 6-08-072 Potassium iodate) is the potassium salt of iodic acid generally expressed as KIO_3 . Minimum potassium (K) and minimum iodine (I) content must be specified.

Potassium iodide (IFN 6-03-759 Potassium iodide) is the potassium salt of hydriodic acid generally expressed as KI. Minimum potassium (K) and iodine (I) content must be specified.

Potassium sulfate (IFN 6-08-098 Potassium sulphate) is the potassium salt of sulphuric acid generally expressed as K_2SO_4 . Minimum potassium (K) and sulphur (S) content must be specified.

Salt (IFN 6-04-152 Salt) is an acceptable source of sodium chloride. It must be true to name and contain not less than 95 percent sodium chloride.

Shell flour (IFN 6-05-688 Molluscs shells fine ground) is an acceptable source of calcium carbonate. It must be true to name and contain not less than 33 percent calcium (Ca).

Sodium iodate (IFN 6-04-277 Sodium iodate) is the sodium salt of iodic acid generally expressed as NaIO_3 . Minimum iodine (I) content must be specified.

Sodium iodide (IFN 6-04-279 Sodium iodide) is the sodium salt of hydriodic acid generally expressed as NaI. Minimum sodium (Na) and minimum iodine (I) content must be specified.

Sodium molybdate (IFN 6-19-30 Sodium molybdate) is the sodium salt of molybdenum, generally expressed as Na_2MoO_4 and its hydrated forms. Minimum molybdenum must be specified.

Sodium selenate (IFN 6-26-014 Sodium selenate) is a sodium salt of selenic acid generally expressed as Na_2SeO_4 and its hydrated forms. Minimum selenium (Se) must be specified. All premixes shall bear adequate directions and cautions for use including this statement “Caution. Follow label directions. The addition to feed of higher levels of this premix containing selenium is not permitted.”

Sodium selenite (IFN 6-26-013 Sodium selenite) is a sodium salt of selenious acid generally expressed as Na_2SeO_3 and its hydrated forms. Minimum selenium (Se) must be specified. All premixes shall bear adequate directions and cautions for use including this statement “Caution. Follow label directions. The addition to feed of higher levels of this premix containing selenium is not permitted.”

Zinc carbonate (IFN 6-05-549 Zinc carbonate) is the zinc salt of carbonic acid generally expressed as ZnCO_3 and its hydrated forms. Minimum zinc (Zn) content must be specified.

Zinc chloride (IFN 6-05-551 Zinc chloride) is the zinc salt of hydrochloric acid generally expressed as ZnCl_2 and its hydrated forms. Minimum zinc (Zn) content must be specified.

Zinc oxide (IFN 6-05-553 Zinc oxide) is the oxide form of zinc generally expressed as ZnO . Minimum zinc (Zn) content must be specified.

Zinc sulphate (IFN 6-05-555 Zinc sulphate monohydrate, IFN 6-20-729 Zinc sulphate heptahydrate) is the zinc salt of sulphuric acid generally expressed as ZnSO_4 and its hydrated forms. Minimum zinc (Zn) content must be specified.

Table 55 shows the names, chemical formula and percent composition of elements within mineral salts commonly used in compound aquafeeds.

TABLE 55
Composition of mineral salts commonly used in compound aquafeeds

Mineral	Formula	Elements in salt (percent)
Calcium sources		
Calcium carbonate	CaCO_3	40.05% Ca, 59.95% CO_3
Monocalcium phosphate, monohydrate	$\text{Ca}(\text{H}_2\text{PO}_4)_2 \cdot \text{H}_2\text{O}$	15.9% Ca, 24.6% P
Dicalcium phosphate, anhydrous	CaHPO_4	29.46% Ca, 22.77% P
Dicalcium phosphate, dihydrate	$\text{CaHPO}_4 \cdot 2\text{H}_2\text{O}$	23.29% Ca, 18.01% P
Tricalcium phosphate	$\text{Ca}_3(\text{PO}_4)_2$	38.76% Ca, 19.97% P
Calcium sulphate	CaSO_4	29.43% Ca, 70.57% SO_4
Bonemeal		30.00% Ca, 15.00% P
Oystershell grit		38.00% Ca
Ground limestone	CaCO_3	38.00% Ca
Chloride sources		
Sodium chloride	NaCl	60.65% Cl, 39.35% Na
Potassium chloride	KCl	47.56% Cl, 52.44% K
Chromium sources		
Chromium (III) chloride	CrCl_3	32.8% Cr
Chromium (III) chloride, hexahydrate	$\text{CrCl}_3 \cdot 6\text{H}_2\text{O}$	19.6% Cr
Chromium picolinate	$\text{Cr}(\text{C}_6\text{H}_4\text{NO}_2)_3$	12.4% Cr
Cobalt sources		
Cobalt chloride, pentahydrate	$\text{CoCl}_2 \cdot 5\text{H}_2\text{O}$	26.80% Co, 32.28% Cl
Cobalt chloride, hexahydrate	$\text{CoCl}_2 \cdot 6\text{H}_2\text{O}$	24.77% Co, 29.84% Cl
Cobalt sulphate, monohydrate	$\text{CoSO}_4 \cdot \text{H}_2\text{O}$	20.6-20.7% Co

TABLE 55 – CONTINUED

Mineral	Formula	Elements in salt (percent)
Copper sources		
Copper sulphate	CuSO ₄	39.81% Cu, 60.19% SO ₄
Copper sulphate, pentahydrate	CuSO ₄ ·5H ₂ O	25.46% Cu, 38.49% SO ₄
Copper chloride	CuCl ₂	47.27% Cu, 52.73% Cl
Copper (II) oxide	CuO	78-79% Cu
Copper (II) hydroxide	Cu(OH) ₂	65.0% Cu
Iodine sources		
Potassium iodide	KI	76.45% I, 23.55% K
Potassium iodate	KIO ₃	59.31% I, 18.27% K
Calcium iodate	Ca(IO ₃) ₂	65.09% I, 10.28% Ca
Sodium iodide	NaI	84.68% I, 15.32% Na
Ethylenediamine dihydriodide	C ₂ H ₈ N ₂ ·2HI	78.73% I
Iron sources		
Ferrous sulphate, heptahydrate	FeSO ₄ ·7H ₂ O	19.2% Fe, 34.59% SO ₄
Ferrous (II) carbonate	FeCO ₃	48.2% Fe
Ferrous oxide	FeO	77.7% Fe
Magnesium sources		
Magnesium chloride	MgCl ₂ ·6H ₂ O	12.0% Mg
Magnesium oxide	MgO	60.3% Mg
Magnesium carbonate	MgCO ₃	28.84% Mg, 71.16% CO ₃
Dimagnesium phosphate, trihydrate	MgHPO ₄ ·3H ₂ O	14.0% Mg, 17.8% P
Magnesium sulphate	MgSO ₄	20.19% Mg, 79.81% SO ₄
Magnesium sulphate, heptahydrate	MgSO ₄ ·7H ₂ O	9.87% Mg, 39.01% SO ₄
Manganese sources		
Manganese oxide	MnO	60-63% Mn
Manganese dioxide	MnO ₂	63.19% Mn
Manganese carbonate	MnCO ₃	47.79% Mn, 52.21% CO ₃
Manganese chloride, tetrahydrate	MnCl ₂ ·4H ₂ O	27.76% Mn, 35.86% Cl
Manganese sulphate	MnSO ₄	36.36% Mn, 63.64% SO ₄
Manganese sulphate, hydrate	MnSO ₄ ·H ₂ O	32.49% Mn, 56.86% SO ₄
Manganese sulphate, tetrahydrate	MnSO ₄ ·4H ₂ O	24.63% Mn, 43.10% SO ₄
Molybdenum sources		
Sodium molybdate, dehydrate	Na ₂ MoO ₄ ·2H ₂ O	39.66% Mo, 19.01% Na
Sodium molybdate, pentahydrate	NaMoO ₄ ·5H ₂ O	35.15% Mo, 8.43% Na
Phosphorus sources		
Monocalcium phosphate, monohydrate	Ca(H ₂ PO ₄) ₂ ·H ₂ O	24.6% P, 15.9% Ca
Dicalcium phosphate, anhydrous	CaHPO ₄	22.77% P, 29.46% Ca
Dicalcium phosphate, dehydrate	CaHPO ₄ ·2H ₂ O	18.01% P, 23.29% Ca
Tricalcium phosphate	Ca ₃ (PO ₄) ₂	19.97% P, 38.76% Ca
Potassium orthophosphate	K ₂ HPO ₄	17.79% P, 44.90% K
Potassium dihydrogen orthophosphate	KH ₂ PO ₄	22.76% P, 28.73% K
Sodium hydrogen orthophosphate	Na ₂ HPO ₄	21.82% P, 32.40% Na
Sodium dihydrogen orthophosphate, hydrate	NaH ₂ PO ₄ ·H ₂ O	22.45% P, 16.67% Na
Sodium dihydrogen orthophosphate, dihydr.	NaH ₂ PO ₄ ·2H ₂ O	19.86% P, 14.74% Na
Dimagnesium phosphate, trihydrate	MgHPO ₄ ·3H ₂ O	17.8% P, 14.0% Mg
Rock phosphate	(Ca ₃ (PO ₄) ₂) ₃ CaF ₂	13.00% P, 35.00% Ca
Potassium sources		
Potassium chloride	KCl	52.44% K, 47.56% Cl
Potassium carbonate	K ₂ CO ₃	56.58% K, 43.42% CO ₃
Potassium bicarbonate	KHCO ₃	39.05% K, 60.95% HCO
Potassium acetate	KC ₂ H ₃ O ₂	39.84% K, 60.16% Acetate
Potassium orthophosphate	K ₃ PO ₄	55.25% K, 14.59% P
Potassium sulphate	K ₂ SO ₄	44.87% K, 55.13% SO ₄
Selenium sources		
Sodium selenite	Na ₂ SeO ₃	45.65% Se, 26.60% Na
Sodium selenate	NaSeO ₄	41.79% Se, 24.34% Na

TABLE 55 – CONTINUED

Mineral	Formula	Elements in salt (percent)
Sodium sources		
Sodium chloride	NaCl	39.35% Na, 60.65% Cl
Sodium bicarbonate	NaHCO ₃	27.38% Na, 72.62% HCO ₃
Sodium sulphate	Na ₂ SO ₄	32.39% Na, 67.61% SO ₄
Zinc sources		
Zinc carbonate	ZnCO ₃	52.14% Zn, 47.86% CO ₃
Zinc chloride	ZnCl ₂	47.97% Zn, 52.03% Cl
Zinc oxide	ZnO	80.35% Zn
Zinc sulphate	ZnSO ₄	40.47% Zn, 59.33% SO ₄
Zinc sulphate, hydrate	ZnSO ₄ .H ₂ O	36.42% Zn, 53.55% SO ₄
Zinc sulphate, heptahydrate	ZnSO ₄ .7H ₂ O	22.70% Zn

Source: modified from Hertrampf and Pascual (2000) and Tacon (1987).

4.6.3 Vitamins

Official definitions (AAFCO, 2008b)

Cholecalciferol (D-activated animal sterol) (IFN 7-00-408 Animal sterol irradiated) is obtained by activation of a sterol fraction of animal origin with ultraviolet light or other means. For label identification, it may be followed with the parenthetical phrase “(Source of Vitamin D₃)”.

Ergocalciferol (D-activated plant sterol) (IFN 7-03-728 Plant sterol irradiated) is obtained by activation of a sterol fraction of plant origin with ultraviolet light or other means. For label identification, it may be followed with the parenthetical phrase “(Source of Vitamin D₂)”.

Vitamin B₁₂ supplement (IFN 7-05-146 Vitamin B₁₂ supplement) is a feeding material used for its vitamin B₁₂ activity. It must contain a minimum vitamin B₁₂ activity of 1.5 milligrams per pound. The term must not be applied to products for which there are accepted names and definitions.

Vitamin E supplement (IFN 7-05-150 Vitamin E supplement) is a feeding material used for its vitamin E activity. It must contain a minimum vitamin E activity equal to 10 000 International Units of vitamin E per pound.

Riboflavin supplement (IFN 7-03-921 Riboflavin supplement) is a feeding material used chiefly for its riboflavin content. It must contain not less than 1 000 milligrams of riboflavin per pound. The label must bear a parenthetical statement of origin immediately following this declaration.

Vitamin A supplement (IFN 7-05-144 Vitamin A supplement) is a feeding material used for its vitamin A content. It must contain a minimum of two million International Units of vitamin A per pound. The label must bear a statement of the source of vitamin A and a minimum guarantee of International Units of vitamin A per pound with additional permissive International Units of vitamin A per gram.

Vitamin D₃ supplement (IFN 7-05-699 Vitamin D₃ supplement) is a feeding material used for its vitamin D₃ activity. It must contain a minimum of 100 000 International Units of vitamin D₃ per pound.

Niacin supplement (IFN 7-26-003 Niacin supplement) is a term that may be used in the ingredient list on a feed label of a mixed feed to indicate the addition of either Niacin or Niacinamide. Sources containing only Niacin or Niacinamide must state the source of Niacin on their label.

Betaine (hydrochloride or anhydrous) (IFN 7-00-722 Betaine hydrochloride) is the crystalline chloride of betaine or anhydrous betaine; a partial replacement for choline.

4.6.4 Chemical preservatives and antioxidants

Official listing of approved chemical preservatives, including antioxidants (AAFCO, 2008b)

Ascorbic acid (IFN 7-00-433), FDA Reg. 582.3013,

Limitations or restrictions: none**

Ascorbyl palmitate (IFN 8-26-245), FDA Reg. 582.3149,

Limitations or restrictions: none**

Benzoic acid (IFN 8-26-244), FDA Reg. 582.3021,

Limitations or restrictions: not to exceed 0.1 percent

Butylated hydroxyl anisole (BHA)* (IFN 8-01-044), FDA Reg. 582.3169,

Limitations or restrictions: total content of preservatives not more than 0.02 percent of fat or oil content including essential (volatile) oil content of food

Butylated hydroxyl toluene (BHT)* (IFN 8-01-045), FDA Reg. 582.3173,

Limitations or restrictions: total content of preservatives not more than 0.02 percent of fat or oil content including essential (volatile) oil content of food

Calcium ascorbate (IFN 8-26-246), FDA Reg. 582.3189,

Limitations or restrictions: none**

Calcium propionate (IFN 8-01-085), FDA Reg. 582.3221,

Limitations or restrictions: none**

Calcium sorbate (IFN 8-01-086), FDA Reg. 582.3225,

Limitations or restrictions: none**

Citric acid (IFN 8-01-233), FDA Reg. 582.6033,

Limitations or restrictions: none**

Dilauryl thiodi-propionate (IFN 8-01-789), FDA Reg. 582.3280,

Limitations or restrictions: total content of preservatives not more than 0.02 percent of fat or oil content including essential (volatile) oil content of food

Distearyl thiodi-propionate (IFN 8-01-792), FDA Reg. 582.3280,

Limitations or restrictions: total content of preservatives not more than 0.02 percent of fat or oil content including essential (volatile) oil content of food

Erythroic acid (IFN 8-09-823), FDA Reg. 582.3041,

Limitations or restrictions: none**

Ethoxyquin (IFN 8-01-841), FDA Reg. 573.380,

Limitations or restrictions: 0.015 percent in or on feed

Formic acid (IFN 8-20-739), FDA Reg. 573.480,

Limitations or restrictions: not to exceed 2.25 percent of the silage (dry weight) or 0.45 percent (direct cut)

Methylparaben (IFN 8-03-088), FDA Reg. 582.3490,

Limitations or restrictions: 0.1 percent

Potassium bisulphite (IFN 8-26-302), FDA Reg. 582.3616,

Limitations or restrictions: not for use in meats or vitamin B₁ sources

Potassium meta-bisulphite (IFN 8-26-203), FDA Reg. 582.3637,

Limitations or restrictions: not for use in meats or vitamin B₁ sources

Potassium sorbate (IFN 8-03-761), FDA Reg. 582.3640,

Limitations or restrictions: none**

Propionic acid (IFN 8-02-807), FDA Reg. 582.3081,

Limitations or restrictions: none**

Propyl gallate (IFN 8-03-308), FDA Reg. 582.3660,

Limitations or restrictions: total content of preservatives not more than 0.02 percent of fat or oil content including essential (volatile) oil content of food

Propylparaben (IFN 8-03-810), FDA Reg. 582.3670,

Limitations or restrictions: 0.1 percent

Sodium ascorbate (IFN 8-26-304), FDA Reg. 582.3731,

Limitations or restrictions: none**

Sodium benzoate (FN 8-04-271), FDA Reg. 582.3733,

Limitations or restrictions: 0.1 percent

Sodium bisulphate (IFN 8-26-305), FDA Reg. 582.3739,

Limitations or restrictions: not for use in meats or vitamin B₁ sources

Sodium metabisulphite (IFN 8-26-306), FDA Reg. 582.3766,

Limitations or restrictions: not for use in meats or vitamin B₁ sources

Sodium nitrite (IFN 8-04-283), FDA Reg. 573.700,

Preservative and colour fixative in canned pet food containing fish, meat, and fish and meat by-products.

Limitations or restrictions: 20 ppm (0.002 percent)

Sodium propionate (IFN 8-04-289), FDA Reg. 582.3784,

Limitations or restrictions: none**

Sodium sorbate (IFN 8-04-290), FDA Reg. 582.3795,

Limitations or restrictions: none**

Sodium sulphite (IFN 8-26-307), FDA Reg. 582.3798,

Limitations or restrictions: not for use in meats or vitamin B₁ sources

Sorbic acid (IFN 8-04-297), FDA Reg. 582.3089,

Limitations or restrictions: none**

Stannous chloride (IFN 8-26-308), FDA Reg. 582.3845,

Limitations or restrictions: not to exceed 0.0015 percent as tin

Sulfur dioxide (IFN 8-26-309), FDA Reg. 582.3862,
Limitations or restrictions: not for use in meats or vitamin B₁ sources

Tertiary butyl hydroquinone (TBHQ), Informal review process,
Limitations or restrictions: total content of preservatives not more than 0.02 percent of fat or oil content including essential (volatile) oil content of food

Thiodipropionic acid (IFN 8-04-830), FDA Reg. 582.3109,
Limitations or restrictions: total contents of preservatives not more than 0.02 percent of fat or oil content including essential (volatile) oil content of food

Tocopherols (IFN 7-05-038), FDA Reg. 582.3890,
Limitations or restrictions: none**

Notes: *For BHA and BHT, either the name or the abbreviation may be used.

**None. No quantitative restrictions although use must conform to good manufacturing practices.

When using any of the above materials, a statement of the fact that a chemical preservative has been added must be shown. Examples: BHA (a preservative), or preserved with BHT, or sorbic acid added to retard mold growth, etc.

For additional information on the use of chemical preservatives and antioxidants in aquaculture feeds, see Balamurali and Aravindan (1997); Bautista-Teruel and Subosa (1999); Barrows and Hardy (2000); Benzie (2003); Berdikova Bohne *et al.* (2007); Bustos *et al.* (2003); Hardy and Roley (2000); Holler (2005); Hossain *et al.* (2007b); Hwang *et al.* (1995); Kestemont *et al.* (2001); Lückstädt (2008); Pandey and Satoh (2008); Petri *et al.* (2008); Verleyen and Adams (2005); Vielma and Lall (1997); Vielma *et al.* (1999); Woolford (2004); and Yamashita (2009).

4.6.5 Others

Other feed additives used within compound aquafeeds vary depending on the manufacturing process used to produce the feed, the country of production and the target species for which the feed is being produced. These additives may include the use of:

- Binders and binding agents (including starches, wood processing by-products, celluloses, pectins, alginates, carrageenans, gelatin, collagen, mineral clays, and synthetic polymers: Abad *et al.*, 2002; Adebayo *et al.*, 2003; Akiyama *et al.*, 1997; Barrows and Hardy, 2000; Brinker, 2005, 2007; deSeixas *et al.*, 1997a, 1997b; Dominy *et al.*, 2004; Durazo Beltran and Viana, 2001; Fagbenro and Jauncey, 1995b; Gabrielsen and Austreng, 1998; Genodepa *et al.*, 2007; Hansen and Storebakken, 2007; Jasmine, 2000; Johnston and Johnston, 2007; Liu *et al.*, 2008; Medina-Reyna *et al.*, 2000; Palma *et al.*, 2008; Partridge and Southgate, 1999; Pearce *et al.*, 2002; Penafiorida and Golez, 1996; Rosas *et al.*, 2008; Rout and Bandyopadhyay, 1999; Ruscoe *et al.*, 2005; Sanchez *et al.*, 2005; Suppadit *et al.*, 2006; Yamamoto and Akiyama, 1995).
- Enzyme supplements (including phytases: Barrows and Hardy, 2000; Baruah *et al.*, 2005, 2007; Biswas *et al.*, 2007; Buchanan *et al.*, 1997; Cheng and Hardy, 2004b; Cheng *et al.*, 2004b; Debnath *et al.*, 2005a, 2005b, 2005c; Denstadli *et al.*, 2007; Eya and Lovell, 1997; Forster *et al.*, 1999; Gabriel *et al.*, 2007; Huang *et al.*, 2009; Hughes and Soares, 1998; Jackson *et al.*, 1996; Ji *et al.*, 2008; Obradovic *et al.*, 2007; Ogunkoya *et al.*, 2006; Kureshy *et al.*, 2000; Ng and Chong, 2002b; Ng *et al.*, 2002; Rao *et al.*, 2009; Riche *et al.*, 2001; Silva *et al.*, 2005; Singh *et al.*, 2008; Skrede *et al.*, 2002; Storebakken *et al.*, 1998b; Sugiura *et al.*, 2001; Van Weerd *et al.*, 1999; Vielma *et al.*, 1998, 2002, 2004; Yan *et al.*, 2002).

- Microbial supplements and health promoting compounds (including prebiotics, probiotics, nucleotides, immunostimulants: Abdel-Tawwab *et al.*, 2008, 2009; Amar *et al.*, 2001; Bagni *et al.*, 2000; Burr *et al.*, 2008; Burrells *et al.*, 2001; Campa-Cordova *et al.*, 2005; Cruz-Suarez *et al.*, 2008; Hidalgo *et al.*, 2006; Jin and Xiao-Ling, 2004; Kim and Lee, 2008; Lara-Flores *et al.*, 2003; Li and Gatlin, 2003, 2004, 2005, 2006; Li *et al.*, 2005, 2006, 2007; Lin *et al.*, 2004b; Mustafa and Nakagawa, 1995; Mustafa *et al.*, 1995; Nakagawa *et al.*, 1997; Nayak *et al.*, 2007; Ochoa-Solano and Olmos-Soto, 2006; Reyes-Becerril *et al.*, 2008a, 2008b; Sealey *et al.*, 2007; Scholz *et al.*, 1999; Singh *et al.*, 2008; Supamattaya *et al.*, 2005; Tovar *et al.*, 2002; Vadstein, 1997; Wache *et al.*, 2006).
- Pigments and colouring agents (including astaxanthin, other carotenoid pigments, and food dyes: Buttle *et al.*, 2001b; Chien *et al.*, 2003; Choubert *et al.*, 2006; Chou and Chien, 2006; Christiansen and Torrissen (1995, 1996); Dall *et al.*, 2005; Fujii *et al.*, 2007; Hertrampf and Pascual, 2000; Hynes *et al.*, 2009; Jensen *et al.*, 1998; Nakano *et al.*, 1995, 1999; Nickell and Bromage, 1998; Page *et al.*, 2005; Pan and Chien, 2009; Park *et al.*, 1997; Plank *et al.*, 2002; Sinha and Asimi, 2007; Storebakken *et al.*, 2004b; Tejera *et al.*, 2007; Yanar *et al.*, 2008; Wang *et al.*, 2006b; Wathne *et al.*, 1998; White *et al.*, 2003).
- Growth promoters (including specific animal and plant hormones, antibiotics, saponins: Ali *et al.*, 2007; Barrows and Hardy, 2000; Francis *et al.*, 2005; Gilchrist *et al.*, 2007; Ölmez and Tiryaklıođlu, 2006; Peterson *et al.*, 2004; Sambhu and Jayaprakas, 2003; Singh *et al.*, 2008).

4.7 FERTILIZERS AND MANURES

Official definitions (AAFCO, 2008b)

Dried poultry waste (DPW) (IFN 4-07-255 Poultry manure non-protein nitrogen extracted dehydrated) means a processed animal waste product composed primarily of faeces from commercial poultry, which has been thermally dehydrated to a moisture content not in excess of 15.0 percent. It shall contain not less than 18.0 percent crude protein and not more than 15.0 percent crude fibre, 30.0 percent ash and 1.0 percent feathers.

Dried poultry waste non-protein nitrogen (NPN) extracted (IFN 4-07-255 Poultry manure non-protein nitrogen extracted dehydrated) means a processed animal waste product composed primarily of faeces from commercial poultry which has been processed to remove part or all of the equivalent crude protein, NPN as urea and/or uric acid and which has been thermally dehydrated to a moisture content not in excess of 15.0 percent. It shall contain not less than 11.0 percent crude protein and not more than 15.0 percent crude fibre, 30.0 percent ash and 1.0 percent feathers.

Dried poultry litter (DPL) (IFN 5-05-587 Poultry manure and litter dehydrated) means a processed animal waste product composed of a processed combination of faeces from commercial poultry together with litter that was present in the floor production of poultry, which has been artificially dehydrated to a moisture content not in excess of 15.0 percent. It shall contain not less than 18.0 percent crude protein and not more than 25.0 percent crude fibre, 20.0 percent ash and 4.0 percent feathers.

Dried ruminant waste (DRW) (IFN 1-07-526 Animal manure dehydrated) means a processed animal waste product composed primarily of processed ruminant excreta which has been artificially dehydrated to a moisture content not in excess of 15.0 percent. It shall contain not less than 12.0 percent crude protein and not more than 40.0 percent crude fibre, including straw, woodshavings, etc., and not more than 30.0 percent ash.

Dried swine waste (DSW) (IFN 5-02-790 Swine manure dehydrated) means a processed animal waste product composed primarily of swine excreta which has been artificially dehydrated to a moisture content not in excess of 15.0 percent. It shall contain not less than 20.0 percent crude protein, not more than 35.0 percent crude fibre, including other material such as straw, woodshavings, or acceptable other bedding materials, and not more than 20.0 percent ash.

Undried processed animal waste products (IFN 2-07-258 Animal-poultry manure and litter processed wet) means a processed animal waste product composed of excreta, with or without litter, from poultry, ruminants or any other animal except humans, which may or may not include other feed ingredients, and which contains in excess of 15.0 percent feed ingredients and in excess of 15.0 percent moisture. It shall contain no more than 30 percent combined wood, woodshavings, litter, dirt, sand, rocks and similar extraneous materials. The specific name of each component material in the product must be declared on the label.

Processed animal waste derivative (IFN 1-07-307 Animal waste processed derivative) means a product resulting from the chemical, physical or microbiological alteration of an animal waste. Examples of processed animal waste derivatives are composts, yeasts, algae or other organisms produced from non-human animal wastes, or wastes treated with ammonia, formaldehyde or other chemicals. The specific name of each such animal waste derivative product must be descriptive, and efficacy and safety data must be submitted and approved before the product is registered or offered for sale.

4.7.1 Chemical fertilizers

Table 56 summarizes the elemental composition of the major chemical fertilizers commonly used for increasing the natural productivity of water bodies.

4.7.2 Organic manures

Organic manures include all plant and animal materials which in their fresh, decomposed or dried form can be used as fertilizers to enhance the production of natural live food organisms within an enclosed water body containing fish or shrimp. The most commonly used organic manures include fresh or dried livestock manure (i.e. farm animal faeces, with or without urine), fresh or dried plant residues (i.e. straw, husks, leaves, vegetable waste, grass cuttings, tree by-products, seaweed), farmyard manure (i.e. mixture of animal faeces and urine with crop residues, usually straw or sawdust, and compost (i.e. partially decomposed mixture of animal and/or vegetable materials).

The fertilizer value of an organic manure will depend primarily on its carbon (C), nitrogen (N), phosphorus (P) and potassium (K) content, and its consequent susceptibility to bacterial degradation within the water body. For example, the C:N ratio of the applied manure will determine its rate of bacterial decomposition and hence the time lag between application and increased pond productivity; manures with a low C:N ratio (<50; animal faeces/urine/green weeds/grass) are more rapidly decomposed by bacteria than manures with a high C:N ratio (>100; straw, sugar cane bagasse, sawdust).

Table 57 summarizes the average composition of some organic manures with potential for use within aquaculture systems. However, it should be pointed out that the nutrient analyses reported should only serve as a rough guide, as composition will vary widely depending on the feed and the age of the animal livestock species and/or treatment of the manure before use.

For example, Bangladesh Barman and Karim (2007) report the moisture, nitrogen, phosphorus, and potassium content of fresh cow dung, decomposed cow dung, poultry manure, and compost as 60.0 percent, 0.5 percent, 0.15 percent, 0.5 percent; 35.0 percent,

1.2 percent, 1.0 percent, 1.6 percent; 55.0 percent, 1.9 percent, 0.56 percent, 0.75 percent; and 40.0 percent, 0.75 percent, 0.60 percent, 1.0 percent; respectively. However, in the same report (Hasan *et al.* 2007), Hung and Huy (2007) report the moisture, nitrogen, P₂O₅ and K₂O content of pig, cattle, horse, chicken and duck manure as 82.0 percent, 0.8 percent, 0.4 percent, 0.3 percent; 83.1 percent, 0.3 percent, 0.2 percent, 1.0 percent; 75.7 percent, 0.4 percent, 0.4 percent, 0.4 percent; 56.0 percent, 1.6 percent, 0.5 percent, 0.9 percent; and 56.0 percent, 1.0 percent, 1.4 percent, 0.6 percent; respectively. Clearly, each manure is unique and as such its composition and potential fertilized value should be determined on an individual, farm and country-specific basis.

4.7.3 Use of fertilizers and manures

For general reviews on the use of chemical fertilizers and manures in aquaculture, see Boyd and Tucker (1998), Bowman (1998), Coche *et al.* (1996), Egna and Boyd (1997), El-Sayed (2006), Green and Boyd (1995), Hasan *et al.* (2007), Knud-Hansen (1998) and Pillay and Kutty (2005).

For more specific examples of fertilizer use within specific countries and cultured species see Afzal *et al.* (2007), Azim (2005), Barman and Karim (2007), Bhakta *et al.* (2004, 2006), Burford and Pearson (1998), Chakrabarty *et al.* (2009), Diana and Lin (1998), El-Sayed (2007), Garg and Bhatnagar (2000), Ghaffar *et al.* (2002), Hasan *et al.* (2007), Hung and Huy (2007), Khan *et al.* (2002), Kumar *et al.* (2005), Mahboob and Sheri (1997), Sahu *et al.* (2007), Samocha *et al.* (2007), Sughra *et al.* (2003), Yang *et al.* (1998), and Zoccarato *et al.* (1995).

TABLE 56
Elemental composition of the major chemical fertilizers used in aquaculture

Fertilizer	Formula	Elemental composition (% pure salt ¹)			
		Ca	N	P	K
Calcareous²					
Calcium carbonate (limestone)	CaCO ₃	40.0	-	-	-
Marl	CaMg (CO ₃) ₂	21.7	-	-	-
Calcium hydroxide (slaked/caustic lime)	Ca (OH) ₂	54.1	-	-	-
Calcium oxide (quicklime)	CaO	71.5	-	-	-
Nitrogen fertilizers					
Sodium nitrate	NaNO ₃	-	16.5	-	-
Ammonium sulphate	(NH ₄) ₂ SO ₄	-	21.2	-	-
Ammonium nitrate	NH ₄ NO ₃	-	35.0	-	-
Urea	CO(NH ₂) ₂	-	46.7	-	-
Ammonium phosphate, dibasic	(NH ₄) ₂ HPO ₄	-	21.2	23.5	-
Ammonium phosphate, monobasic	(NH ₄)H ₂ PO ₄	-	12.2	27.0	-
Potassium (potash) fertilizers					
Potassium chloride (muriate of potash)	KCL	-	-	-	52.4
Potassium nitrate	KNO ₃	-	13.8	-	38.7
Potassium sulphate	K ₂ SO ₄	-	-	-	44.9
Sulphate of potash-magnesia	K ₂ SO ₄ .2MgSO ₄	-	-	-	18.8
Phosphate fertilizers					
Di-calcium phosphate, anhydrous	CaHPO ₄	29.5	-	22.8	-
Bone meal		30.0	-	15.0	-
Rock phosphate (fluoroapatite)	(Ca ₃ (PO ₄) ₃ CaF ₂)	35.0	-	13.0	-
Single superphosphate ³	Ca(H ₂ PO ₄) ₂ + CaSO ₄	-	-	7–8.7	-
Triple superphosphate ⁴	Ca(H ₂ PO ₄) ₂	-	-	19.2–23.6	-

Source: after Tacon (1987).

¹ Values expressed as a percent of the pure salt.

² Liming materials differ in their ability to neutralize acid; the neutralizing value of the pure salts of CaCO₃, CaMg(CO₃)₂ and CaO being 100%, 109%, 136% and 179% respectively (Boyd, 1979).

³ Super phosphate is a mixture of Ca(H₂PO₄)₂ and CaSO₄ (gypsum) and has a P₂O₅ equivalence of 16–20%, 85% of which is water soluble (Boyd, 1979).

⁴ Triple superphosphate is a more concentrated form of Ca(H₂PO₄)₂ and has a P₂O₅ equivalence of 44–54%, 85% of which is water soluble (Boyd, 1979).

TABLE 57
Average elemental composition of organic manures – values are expressed as % by weight

Manure	C:N ratio	% moisture-free basis		
		N	P	K
Animal manures				
Faeces/dung				
Buffalo	19	1.23	0.55	0.69
Cattle	19	1.91	0.56	1.40
Sheep	29	1.87	0.79	0.92
Goat and sheep (mixed)	-	1.50	0.72	1.38
Horse	24	2.33	0.83	1.31
Pig	13	2.80	1.36	1.18
Camel	-	1.51	0.15	1.50
Elephant	43	1.29	0.33	0.14
Tiger	10	2.82	3.19	0.03
Lion	9	3.60	3.21	0.04
Human	8	7.24	1.72	2.41
Poultry	9	3.77	1.89	1.76
Duck	10	2.15	1.13	1.15
Rabbit	-	1.72	1.30	1.08
Urine				
Buffalo	-	2.05	0.01	3.78
Cattle	-	9.74	0.05	7.78
Sheep	-	9.90	0.10	12.31
Goat and sheep (mixed)	-	9.64	0.14	-
Pig	-	10.88	1.25	17.86
Horse	-	13.20	0.02	10.90
Human	0.8	17.14	1.57	4.86
Meals				
Blood meal	3.5	11.12	0.66	-
Horn and hoof meal	-	12.37	1.60	-
Bone meal	8	3.36	10.81	-
Fish manure	4.5	7.5	2.82	0.8
Plant manures				
Crop residues				
Wheat straw	105	0.49	0.11	1.06
Barley straw	110	0.47	0.13	1.01
Rice straw	105	0.58	0.10	1.38
Oats straw	-	0.46	0.11	0.97
Maize straw	55	0.59	0.31	1.31
Soybean straw	32	1.30	-	-
Cotton stalks and leaves	-	0.88	0.15	1.45
Cottonseed meal	-	7.05	0.90	1.16
Groundnut straw	19	0.59	-	-
Groundnut hulls	-	1.75	0.20	1.24
Groundnut shells	-	1.00	0.06	0.90
Bean straw	-	1.57	0.32	1.34
Cowpea stems	-	1.07	1.14	2.54
Cowpea roots	-	1.06	0.12	1.50
Coffee pulp	-	1.79	0.12	1.80
Sugarcane trash	116	0.35	0.04	0.50
Grass ⁴	20	0.41	0.03	0.26
Green weeds	13	2.45	-	-
Oil palm bunch ash	-	-	1.71	32.50
Oil palm pressed fibre	-	1.24	0.10	0.36
Oil palm sludge cake	-	4.30	1.19	1.15
Molasses	-	2.09	5.30	1.99
Cowpea leaves	-	1.99	0.19	2.20
Jute leaves	-	1.75	0.58	4.12
Groundnut leaves	-	2.56	0.17	2.11
Tree leaves (general)	60	1.00	0.30	0.57

TABLE 57 – CONTINUED

Manure	C:N ratio	% moisture-free basis		
		N	P	K
Aquatic plants and algae				
Water hyacinth	18	2.04	0.37	3.40
<i>Azolla</i> sp.	-	3.68	0.20	0.15
<i>Lemna</i> sp.	-	3.31	0.20	0.69
<i>Chara vulgaris</i>	-	1.27	0.19	0.84
<i>Ceratophyllum</i> sp.	-	3.30	0.47	5.90
<i>Elodia Canadensis</i>	-	3.29	0.51	3.26
<i>Hydrilla</i> sp.	-	2.70	0.28	2.90
<i>Myriophyllum</i> sp.	-	2.81	0.17	1.20
<i>Pistia stratiotes</i>	-	2.10	0.30	3.50
<i>Potamogeton</i> sp.	-	2.51	0.33	2.28
<i>Typha</i> sp.	-	1.37	0.21	2.38
Marine seaweeds (air-dried)	-	0.66	0.32	1.20
Oilseed cakes				
Castor	-	4.89	0.80	1.04
Coconut	-	3.07	1.23	1.57
Cotton-decorticated	-	6.36	1.26	1.82
Cotton-undecorticated	-	3.95	0.81	1.35
Linseed	-	5.48	0.60	0.99
Neem	4.5	5.21	0.46	1.19
Rape	-	5.08	0.88	0.95
Safflower-decorticated	-	7.88	0.97	1.59
Safflower-undecorticated	-	4.03	0.63	1.02
Mustard	-	4.93	0.53	0.65
Sesame	-	6.12	0.92	1.04
Soybean	-	6.95	2.88	1.02
Miscellaneous				
Peat	80	1.08	0.02	0.08
Animal/plant (mixed) manures				
Farmyard manure (general)	-	0.80	0.21	0.68
Rice straw bedding	-	1.06	0.27	2.00
Wheat straw bedding	-	1.09	0.17	1.40
Litter bedding	-	1.13	0.20	2.03
Straw	-	0.62	0.21	0.49
Peat moss	-	0.88	0.16	0.85
Earth bedding	-	0.48	0.14	0.40
Rural composts (general)	-	1.10	0.29	1.37
Raw material				
Straw	-	1.31	0.19	7.81
Cow manure	-	0.37	0.10	0.08
Buffalo manure	-	0.44	0.14	0.11
Pig manure	-	0.68	0.13	0.05
Water hyacinth	-	1.40	0.46	0.54
Water hyacinth	13	2.05	0.48	2.10
Cotton stalks	-	1.61	0.21	2.80
Mixed crop residues	-	0.91	0.20	1.62
Mulberry leaves	-	1.00	0.45	1.49
Rice straw	-	1.04	0.26	0.85
Azolla	-	3.88	1.10	1.60
Pine needles	-	1.00	1.43	3.53
Pine leaves	-	0.99	0.63	2.93
Urban refuse compost	-	1.29	0.50	0.94
Sewage sludge (general)	9	4.00	1.40	0.30
Raw sludge	-	3.10	1.10	0.20
Anaerobically digested sludge	10	3.30	1.60	0.67
Aerobic activated sludge	-	6.00	1.40	0.80
Raw sawdust	511	0.11	-	-
Rotted sawdust	208	0.25	-	-

Source: Adapted from Tacon (1987).

5. Contaminants

In the context of responsible and sustainable aquaculture, the nutritional and economic role of feed ingredients and feed inputs within finfish and crustacean aquaculture production systems is of paramount importance. It follows therefore that the aquaculture feed compounder and/or farmer must ensure that the aquaculture feeds used on the farm are not only nutritionally sound and economically viable, but are also safe and free from unwanted contaminants (FAO/WHO, 2003, 2004).

Contaminants may be derived from within the individual feed ingredients themselves or may result from the poor handling and storage of finished feeds. Moreover, these contaminants may not only negatively impact the health of the cultured species but they may also negatively effect the health of the end consumer of aquaculture products produced from contaminated feeds (Berntssen and Lundebye, 2008; FAO, 1998; FAO/NACA/WHO, 1999; Lie, 2008; Subasinghe *et al.*, 2000; Tacon and Metian, 2008b).

For the purposes of this sourcebook, a contaminant is defined as any biological or chemical agent, foreign matter or other substances that may compromise food safety or suitability (ANZFA, 2001). The major feed contaminants may include:

Metals and mineral salts: including mercury, lead, cadmium, copper, selenium, fluorine, chromium, and arsenic (Amlund *et al.*, 2007; Baker *et al.*, 1997; Berntssen *et al.*, 2003, 2004; Hertrampf and Pascual, 2000; Lacerda *et al.*, 2006; Mai *et al.*, 2006a ; Maule *et al.*, 2007; Moreau *et al.*, 2007; Sloth *et al.*, 2005).

Mycotoxins: including aflatoxins, fumonisin, zearalenones, tricothecenes – vomitoxins, T2, ochratoxins, cyclopiazonic acid, patulin, slaframine, and citrinin (Abdelhamid *et al.*, 1998; Bhat and Vasanthi, 1999; Binder *et al.*, 2007; Bintvihok *et al.*, 2004; Boonyaratpalin *et al.*, 2001; Burgos-Hernandez *et al.*, 2005; Chavez-Sanches *et al.*, 1994; Ellis *et al.*, 2000; El-Banna *et al.*, 1992; El-Sayed *et al.*, 2009; Jouany, 2007; Li *et al.*, 1994; Lovell, 2000; Lumlertdacha and Lovell, 1995; Lumlertdacha *et al.*, 1995; Manning, 2001; Manning *et al.*, 2003a, 2003b, 2005a, 2005b; Meronuck and Xie, 2000; Ostrowski-Meissner *et al.*, 1995; Pepeljnjak *et al.*, 2002; Petrinc *et al.*, 2004; Sahoo and Mukherjee, 2001; Santacroce *et al.*, 2008; Smith, 2008; Trigo-Stockli *et al.*, 2000; Tuan *et al.*, 2002, 2003; Voss *et al.*, 2007; Yldirim *et al.*, 2000;

Persistent organic pollutants: including halogenated hydrocarbons (pesticides and dioxins) and other hydrocarbons (Berntssen *et al.*, 2005; 2007, 2008; Coimbra *et al.*, 2007; Glover *et al.*, 2007; Hites *et al.*, 2004; Little *et al.*, 2008; Maule *et al.*, 2007; Minh *et al.*, 2006; Moreau *et al.*, 2007; Petri *et al.*, 2006).

Salmonellae and other pathogenic microbes: including Salmonella (Dalsgaard *et al.*, 1995; EFSA, 2008; Lunestad *et al.*, 2007; Nesse *et al.*, 2003).

Veterinary drug residues: including antibiotics and hormones (FAO/WHO, 2005, 2006; Lunestad and Samuelsen, 2008; Stolker *et al.*, 2007).

Other agricultural chemicals and solvent residues: (FAO/NACA/WHO, 1999; Subasinghe *et al.*, 2000).

Transmissible spongiform encephalopathies (TSEs): (EFSA, 2007; FAO, 1998; FAO/NACA/WHO., 1999).

6. Ingredient profiles and dietary inclusion levels

6.1 INGREDIENT ESSENTIAL AMINO ACID PROFILES: COMPARATIVE ANALYSIS

Table 58 presents a comparative view of the calculated essential amino acid (EAA) score of the different major protein ingredients in this sourcebook compared with the estimated EAA requirement profile of fish and shrimp, respectively. However, it is important to mention at the outset that the EAA scores are based on total amino acid levels within ingredients and as such do not take into account the digestibility and availability of the individual amino acids present, which in turn will vary depending on the processing and/or cooking method employed prior to usage. It follows, therefore, that such profiles should be based on digestible EAA scores in order to be truly useful. Despite the above limitations, the following general observations can be made. For the purpose of this sourcebook, the classical EAA score is the level of the most limiting EAA compared with the ideal fish or shrimp requirement. Thus, the observed chemical score of anchovy fishmeal was 70 and 59 for fish and shrimp, respectively (Table 58).

Observations on calculated EAA scores based on dietary fish EAA requirements:

- In general, the best EAA scores (65 to 80) were observed for fishery products, with the highest being for squid meal and white fishmeal (80), followed by krill meal (76), herring fishmeal (74), squid liver meal (71), anchovy fishmeal (70), shrimp meal (68) and menhaden fishmeal (67).
- The second best EAA scores (60 to 70) were observed for terrestrial livestock and invertebrate products, with the highest being for poultry by-product meal (72), followed by liver meal (68), meat and bone meal and earthworm meal (65) and meat meal (63).
- Of the different single cell proteins and plant proteins, candida yeast had the highest EAA score (76), followed by rapeseed meal (solvent extracted: 75), canola meal (solvent extracted: 74), canola protein concentrate (71), malt sprouts (culms: 69), wheat germ meal (68), extracted yeast (67), brewers yeast, rapeseed meal (mechanically extracted) and bambarra groundnut (65), potato protein concentrate (62), and activated bacterial SCP (brewery) and leaf protein concentrate (59).
- Examples of proteins with very low EAA scores included soldier fly larvae (16), corn gluten meal (41 percent and 60 percent protein: 21 and 19), urd (20), pigeon pea and Egyptian bean (22), blood meal (spray dried: 25), feather meal (hydrolysed) and wheat gluten meal (26), lentil (28), lupin and pea protein concentrate (30).
- From the Table 58 it can be clearly seen that the first two limiting EAAs are usually the sulphur amino acids methionine and cystine (within animal protein ingredients, pulse/grain legume seed products, soybean products and single cell proteins) and lysine (within protein-rich cereal products and most oilseed products: Table 58).

Observations on calculated EAA scores based on dietary shrimp EAA requirements:

- In contrast to fish, there was no single grouping of ingredients that had the best EAA scores, with the highest values ranging from wheat germ meal (80), followed by shrimp meal (79), linseed meal (mechanically extracted: 73), safflower meal (undecorticated, mechanically extracted) and white fishmeal (72), canola protein

concentrate, earthworm meal, linseed/flax, and meat and bone meal (69), linseed meal (solvent extracted), mixed bacterial SCP, soybean protein concentrate (68), oil palm seed (kernel: 67), bambarra groundnut, canola meal (solvent extracted), coconut kernel (endosperm), ground bean, rapeseed meal (mechanically extracted), soybean meal (unhulled, mechanically extracted), soybean meal (dehulled, solvent extracted), and tuna fishmeal (66), safflower oilmeal (decorticated, solvent extracted), squid meal (65), cottonseed (kernel), soybean seed (heat processed), sunflower seed (decorticated, mechanically extracted), sunflower seed (decorticated, solvent extracted: 64).

- Examples of proteins with very low EAA scores included soldier fly larvae (21), blood meal (spray dried: 23), urd (26), pigeon pea, Egyptian bean (28), corn gluten meal (60 percent protein: 30), corn gluten meal (41 percent crude protein), feather meal (hydrolysed: 33), lentil (35) and lupin pea protein concentrate (38).
- In contrast to fish, the first two limiting EAAs for shrimp were arginine and to a lesser extent tyrosine in the case of fishery products, tyrosine and arginine/methionine in the case of terrestrial livestock products, lysine/tyrosine and arginine/methionine in the case of protein-rich cereal proteins, methionine and arginine in the case of pulse/grain legume products, and arginine and cystine/methionine in the case of single cell proteins (Table 58).

6.2 DIETARY INGREDIENT INCLUSION LEVELS AND MAJOR ATTRIBUTES AND LIMITATIONS

Table 59 presents some guidelines concerning the recommended use of some commonly used protein-rich ingredients used in compound aquafeeds, including major attributes and possible limitations. However, as mentioned previously, the dietary inclusion levels and use will depend on the feeding habits of the fish or crustacean species in question, the stocking density and farming system employed, and on the market availability, price and nutritional quality of the ingredient used – which in turn will vary from factory to factory and/or from country to country, depending on the quality of the raw material used and ingredient processing method employed; for general review, see Hertrampf and Pascual (2000) and Galano *et al.* (2007).

TABLE 58

Calculated essential amino acid (EAA) score¹ of different animal and plant feed ingredients compared with the estimated EAA requirement profile of fish and crustaceans² – Arginine-Arg; Cystine-Cys; Methionine-Met; Threonine-Thr; Isoleucine-Iso; Leucine-Leu; Lysine-Lys; Valine-Val; Tyrosine-Tyr; Tryptophan-Try; Phenylalanine-Phe; Histidine-His

Product/EAA	Arg	Cys	Met	Thr	Iso	Leu	Lys	Val	Tyr	Try	Phe	His	Diff ³
Ingredient EAA profile compared with estimated dietary EAA requirements of fish³													
Fishery products													
Anchovy fishmeal	98	70	109	80	123	112	91	112	103	135	86	100	65
Menhaden fishmeal	104	67	107	76	125	112	93	113	98	129	84	98	62
Herring fishmeal	107	74	109	78	117	110	91	122	95	129	81	98	55
Tuna fishmeal	109	63	100	81	120	104	91	108	97	123	84	135	72
White fishmeal	120	81	107	81	117	109	92	106	95	123	80	94	43
Fish solubles, condensed	108	74	105	66	105	112	87	106	51	135	81	244	193
Fish soluble, dehydrated	110	104	91	79	115	100	92	98	61	276	73	177	215
Shrimp meal (process residue)	144	93	80	80	121	106	68	107	100	106	103	100	76
Shrimp head meal	104	63	163	73	101	92	70	103	123	123	142	90	100
Krill meal	106	93	107	76	128	108	86	102	118	129	94	85	53
Squat lobster/langostilla meal	61	74	70	78	112	96	78	117	148	159	91	169	108
Squid meal	109	104	83	80	105	103	80	98	126	188	88	154	108
Squid liver meal	105	89	87	73	132	95	71	95	95	259	89	206	188

TABLE 58 – CONTINUED

Product/EAA	Arg	Cys	Met	Thr	Iso	Leu	Lys	Val	Tyr	Try	Phe	His	Diff ²
Terrestrial livestock products													
Blood meal, spray dried	62	63	30	71	25	167	86	160	69	135	127	187	152
Feather meal, hydrolysed	131	322	26	90	128	129	31	159	91	88	88	42	296
Meat and bone meal, rendered	141	93	65	78	103	115	79	122	88	100	90	106	76
Meat meal, rendered	144	111	63	73	109	112	87	123	68	106	88	96	81
Poultry by-product meal, rendered	134	130	78	78	120	120	72	117	80	106	87	98	62
Liver meal	104	104	68	71	124	118	93	132	78	123	93	92	56
Terrestrial invertebrate products													
Soldier fly larvae	83	16	73	21	117	113	89	157	169	51	102	173	157
Earthworm meal	141	93	65	78	103	115	79	122	88	100	90	106	76
Marine polychaete meal	140	78	48	94	119	120	75	110	112	94	82	87	92
Protein-rich cereal products													
Brewers grains (5-02-141)	82	96	63	67	157	144	40	127	143	165	117	83	125
Malt sprouts (culms)	95	89	59	89	136	113	69	143	89	229	90	102	170
Maize gluten feed	81	189	91	80	100	163	37	120	123	105	91	142	152
Maize gluten meal (41% protein)	54	118	87	62	132	238	21	103	83	59	136	90	217
Maize gluten meal (60% protein)	53	126	94	61	103	232	19	96	155	65	127	83	213
Maize DDS	70	141	83	77	139	136	46	133	108	106	126	112	95
Maize DDG	83	100	78	37	124	202	48	121	125	118	76	123	165
Maize DDGS	75	118	78	76	145	124	34	134	103	71	129	112	111
Maize germ meal	106	189	109	102	93	115	51	125	85	129	85	146	138
Wheat germ meal	142	144	68	81	101	91	81	112	101	153	89	115	85
Wheat gluten meal	80	215	78	64	127	138	26	108	141	141	146	115	189
Rice protein concentrate	130	152	91	71	103	118	36	114	161	153	108	90	117
Oilseed protein products													
Canola meal, solvent extracted	110	148	78	87	112	108	74	111	88	153	93	133	79
Canola protein concentrate	118	167	81	83	109	117	71	108	88	159	88	110	96
Rapeseed meal, mech. extracted	110	78	81	93	120	115	65	122	85	170	96	123	105
Rapeseed meal, solv. extracted	111	85	80	92	113	115	76	118	75	159	93	127	84
Coconut kernel (endosperm), dry	230	85	72	63	107	100	42	115	83	123	96	87	188
Copra meal, mech. extracted	219	104	65	67	117	108	38	116	85	123	95	79	181
Copra meal, solv. extracted	217	96	61	65	116	112	37	115	92	123	95	83	180
Cottonseed (kernel), whole	202	118	50	65	92	92	55	102	94	153	115	119	152
Cottonseed meal, mech. extr.	189	141	55	66	101	92	50	110	85	165	119	112	139
Cottonseed meal, solv. extr.	197	133	55	64	97	86	56	104	77	159	126	114	142
Cottonseed meal (dehul. solv. extr.)	196	181	67	74	93	80	48	107	58	171	130	119	148
Linseed/flax (kernel)	171	148	76	74	120	94	47	118	88	188	105	90	141
Linseed meal, mech. extr.	163	137	68	73	148	95	46	115	92	200	99	87	154
Linseed meal, solv. extr.	159	141	61	74	147	95	43	115	108	188	99	92	145
Oil palm seed (kernel)	239	133	89	61	53	92	43	118	85	112	80	90	196
Oil palm (kernel), solv. extracted	238	122	72	67	100	103	37	101	85	135	97	77	201
Peanut meal, mech. extracted	204	130	43	55	105	104	42	102	120	129	115	104	162
Peanut meal, solvent extracted	201	115	37	59	111	103	48	96	125	129	109	106	164
Safflower seed (kernel)	179	126	43	69	132	110	45	123	88	135	90	119	136
Safflower oilcake decort. mech. extr.	139	152	85	74	124	105	36	131	85	235	107	110	199
Safflower oilmeal decort. solv. extr.	170	141	68	67	116	98	41	132	88	188	102	117	147
Sesame seed (kernel)	212	137	105	68	97	101	33	98	98	159	95	102	179
Sesame oilcake, mech. extr.	194	133	107	68	108	102	31	101	117	159	96	100	163
Soybean seed, heat processed	123	93	50	79	139	104	74	112	97	159	109	104	109
Soybean meal, undehull. mech. extr.	117	93	52	71	156	118	72	104	105	159	100	102	107
Soybean meal, undehull. solv. extr.	131	122	48	74	127	112	76	101	100	171	102	108	123
Soybean meal, dehulled, solv. extr.	128	111	52	73	124	110	75	107	108	159	105	102	107
Soybean protein concentrate	131	100	54	74	128	110	74	104	106	141	104	110	87
Sunflower seed (kernel) with hulls	155	122	78	78	129	107	49	119	65	176	105	110	127
Sunflower seed, decort. solv. extr.	153	118	91	74	127	107	48	120	81	153	105	102	105

TABLE 58 – CONTINUED

Product/EAA	Arg	Cys	Met	Thr	Iso	Leu	Lys	Val	Tyr	Try	Phe	His	Diff ²
Pulse/grain legume seed products													
Pigeon pea	93	78	22	61	93	105	103	84	69	76	196	175	174
Jack bean	89	96	54	91	117	118	72	106	118	153	119	123	99
Chickpea	159	85	37	70	116	110	80	94	89	100	118	108	122
Egyptian bean	116	74	22	67	117	126	90	106	105	88	108	133	111
Lentil	147	67	28	74	113	112	84	104	98	112	108	112	119
Lupin	174	107	30	74	124	113	67	90	115	123	82	115	144
African locust bean	119	96	39	65	116	112	84	109	121	118	109	123	84
Lima bean	99	74	46	76	128	117	86	104	97	118	123	127	82
Kidney bean	103	74	43	80	120	120	92	103	83	129	117	127	86
Pea/field pea	123	67	41	77	127	113	78	109	106	106	109	112	86
Pea protein concentrate	162	89	30	68	112	30	87	97	95	112	105	106	132
Urd	98	55	20	65	217	108	99	89	80	94	106	125	197
Broad bean	160	52	35	74	115	108	80	106	112	118	94	108	125
Cowpea	119	85	46	73	109	112	87	102	86	135	117	146	100
Bambara groundnut	109	74	65	66	117	116	77	113	108	129	119	125	64
Ground beans	110	70	52	72	119	112	78	130	106	88	120	115	78
Miscellaneous plant protein products													
Leaf protein concentrate	100	59	59	84	119	126	70	122	112	159	118	85	100
Potato protein concentrate	69	111	83	86	135	121	77	102	158	118	114	62	96
Cassava leaf meal	83	81	48	81	100	136	112	119	111	118	75	94	88
Alfalfa leaf meal (22% protein)	81	107	61	90	139	118	56	133	97	282	117	90	226
Single cell proteins													
<i>Pseudomonas/Methylophilus</i> spp.	92	44	94	90	129	117	74	127	120	135	94	92	91
Mixed bacterial SCP	121	52	102	85	119	115	67	122	109	159	87	92	107
Brewers yeast (<i>S. cerevisiae</i>)	89	92	65	95	133	107	87	118	108	153	88	108	98
Extracted yeast (<i>S. cerevisiae</i>)	80	93	67	89	125	129	79	125	111	141	95	98	74
Torula yeast (<i>T. utilis</i>)	85	85	54	93	144	98	84	117	117	112	115	106	90
Candida spp. (alkane substrate)	73	85	76	103	136	118	80	120	118	165	89	85	89
Aspergillus oryzae (waste starch)	97	74	54	88	121	112	68	117	195	171	75	102	141
Rhodotorula pilimanae	129	18	93	101	113	104	104	113	83	35	72	110	111
Spirulina maxima	113	41	65	87	159	121	55	129	131	165	92	69	124
Activated bacterial SCP (brewery)	92	59	78	88	135	112	77	110	129	171	103	90	112
Ingredient EAA profile compared with estimated dietary EAA requirements of shrimp⁴													
Fishery products													
Anchovy fishmeal	59	95	140	106	112	106	143	116	82	128	83	112	84
Menhaden fishmeal	63	90	138	101	115	106	146	118	78	122	81	109	83
Herring fishmeal	64	100	140	104	107	104	143	127	76	122	78	109	77
Tuna fishmeal	66	85	129	107	110	99	143	113	77	117	81	151	85
White fishmeal	72	110	138	107	107	103	145	111	76	117	77	105	67
Fish solubles, condensed	65	100	136	87	96	106	136	111	40	128	78	272	232
Fish soluble, dehydrated	66	140	117	105	105	95	145	102	49	261	70	198	212
Shrimp meal (process residue)	86	125	102	106	111	101	107	112	79	100	99	112	46*
Shrimp head meal	63	85	209	96	93	87	110	108	98	117	136	100	146
Krill meal	64	122	137	102	117	103	135	107	94	121	90	95	73
Squat lobster/langostilla meal	58	100	90	104	102	91	122	122	117	150	87	188	130
Squid meal	65	140	107	106	96	98	125	102	100	178	85	172	113
Squid liver meal	63	120	112	96	121	91	112	99	76	244	86	230	181
Terrestrial livestock products													
Blood meal, spray dried	37	83	38	94	23	158	135	167	55	127	122	209	186
Feather meal, hydrolysed	79	424	33	119	117	122	49	166	72	83	85	46	391
Meat and bone meal, rendered	85	122	82	104	93	110	125	127	69	94	87	119	58
Meat meal, rendered	86	146	80	97	100	106	138	129	53	100	85	107	93
Poultry by-product meal, rendered	80	171	99	104	109	114	114	122	63	99	84	109	108
Liver meal	63	137	87	94	113	113	147	137	62	116	89	102	84
Terrestrial invertebrate products													
Soldier fly larvae	50	21	93	27	107	108	140	164	134	48	97	194	173
Earthworm meal	85	122	82	104	93	110	125	127	69	94	87	119	58

TABLE 58 – CONTINUED

Product/EAA	Arg	Cys	Met	Thr	Iso	Leu	Lys	Val	Tyr	Try	Phe	His	Diff ²
Marine polychaete meal	84	102	61	125	108	114	118	115	89	88	79	98	64
Protein-rich cereal products													
Brewers grains (5-02-141)	49	127	80	89	143	137	64	133	113	155	112	93	106
Malt sprouts (culms)	57	117	75	118	124	108	109	149	70	215	87	114	158
Maize gluten feed	49	249	116	107	91	155	59	125	97	99	87	158	200
Maize gluten meal (41% protein)	33	156	111	83	120	227	34	108	66	56	130	100	194
Maize gluten meal (60% protein)	32	166	120	82	93	221	30	100	123	61	122	93	191
Maize DDS	42	185	106	103	126	130	72	138	85	99	121	126	143
Maize DDG	50	132	99	49	113	192	76	126	98	110	73	137	143
Maize DDGS	45	156	99	102	132	196	53	140	81	66	124	126	151
Maize germ meal	64	249	139	135	85	110	80	131	67	121	82	163	185
Wheat germ meal	85	190	87	108	92	87	128	116	80	144	86	128	110
Wheat gluten meal	48	283	99	85	115	131	41	113	112	133	140	128	242
Rice protein concentrate	78	200	116	94	94	113	57	119	128	144	104	100	143
Oilseed protein products													
Canola meal, solvent extracted	66	195	199	115	102	103	116	115	69	144	89	149	129
Canola protein concentrate	71	219	104	110	100	111	113	113	69	149	85	123	150
Rapeseed meal, mech. extracted	66	102	104	124	109	110	102	127	67	160	92	137	94
Rapeseed meal, solv. extracted	67	112	101	123	103	110	119	123	60	149	89	142	89
Coconut kernel (endosperm) dry	138	112	92	84	97	95	66	120	66	116	92	98	72
Copra meal, mech. extracted	131	136	82	89	107	103	60	121	67	116	91	88	76
Copra meal, solv. extracted	130	127	78	87	106	106	59	120	73	116	91	93	71
Cottonseed (kernel), whole	122	156	64	87	84	87	86	106	74	144	110	132	92
Cottonseed meal, mech. extr.	113	185	71	88	92	88	79	115	67	155	114	126	118
Cottonseed meal, solv. extr.	118	176	71	85	89	82	89	109	61	149	121	128	115
Cottonseed meal (dehul. solv. extr.)	118	239	85	98	88	76	75	112	46	160	125	132	193
Linseed/flax (kernel)	103	195	97	99	109	89	74	123	69	177	101	100	126
Linseed meal, mech. extracted	98	180	87	97	135	91	73	120	73	188	95	98	115
Linseed meal, solv. extracted	96	185	78	98	134	91	68	120	85	177	95	102	117
Oil palm seed (kernel)	143	176	113	81	87	87	67	123	67	105	77	100	109
Oil palm (kernel), solv. extracted	143	161	92	89	91	98	59	105	67	127	93	86	102
Peanut meal, mech. extracted	123	171	54	73	96	99	66	106	95	121	110	116	117
Peanut meal, solvent extracted	121	151	47	79	101	98	75	100	98	121	105	119	104
Safflower seed (kernel)	108	166	54	92	120	105	70	129	69	127	87	132	112
Safflower oilcake, decort. mech. extr.	83	200	108	99	113	100	57	137	67	221	103	123	164
Safflower oilmeal decort. solv. extr.	102	185	87	89	106	94	65	137	69	177	98	130	120
Sesame seed (kernel)	127	180	134	90	89	96	52	102	78	149	91	114	128
Sesame oilcake, mech. extracted	116	176	137	90	98	97	49	105	92	149	92	112	127
Soybean seed, heat processed	74	122	64	105	126	99	116	116	76	149	105	116	85
Soybean meal, undehull. mech. extr.	70	122	66	94	142	113	113	109	83	149	96	114	83
Soybean meal, undehull. solv. extr.	79	161	61	98	115	106	119	105	79	160	98	121	100
Soybean meal, dehulled, solv. extr.	77	146	66	97	113	105	118	112	85	149	101	114	80
Soybean protein concentrate	79	132	68	99	117	104	117	109	84	133	100	123	65
Sunflower seed (kernel) with hulls	93	161	99	104	118	101	77	124	51	166	101	123	115
Sunflower seed, undec. solv. extr.	102	200	99	110	104	96	82	138	-	177	98	144	118
Sunflower seed, decor. mech. extr.	97	180	130	93	120	91	80	119	64	149	101	116	116
Sunflower seed, decor. solv. extr.	92	156	115	98	115	102	75	125	64	144	101	114	92
Pulse/grain legume seed products													
Pigeon pea	56	102	28	81	85	100	162	88	55	72	188	195	166
Jack bean	53	127	68	122	107	112	113	111	93	144	114	137	91
Chickpea	96	112	47	93	106	104	127	98	70	94	113	121	80
Egyptian bean	70	97	28	89	107	120	142	111	83	83	104	149	121
Lentil	88	88	35	98	103	106	133	109	78	105	104	126	98
Lupin	104	141	38	98	113	108	105	94	91	116	98	128	103
African locust bean	71	127	49	87	106	106	133	114	96	110	105	137	88
Lima bean	59	97	59	102	117	111	136	109	76	110	118	142	83
Kidney bean	62	97	54	107	109	114	144	108	66	121	112	142	90
Pea/field pea	74	88	52	103	115	107	123	114	84	99	105	126	74

TABLE 58 – CONTINUED

Product/EAA	Arg	Cys	Met	Thr	Iso	Leu	Lys	Val	Tyr	Try	Phe	His	Diff ²
Pea protein concentrate	97	117	38	90	102	38	137	101	75	105	101	119	99
Urd	59	73	26	87	198	103	157	93	63	88	102	139	172
Broad bean	96	68	45	99	104	103	127	111	89	110	90	121	82
Cowpea	71	112	59	97	100	106	138	107	68	127	112	163	104
Bambarra groundnut	66	97	82	88	107	111	122	117	85	121	114	139	73
Ground bean	66	93	66	95	108	106	123	136	84	83	115	128	62
Miscellaneous plant protein products													
Leaf protein concentrate	60	78	75	112	108	120	111	127	89	149	113	95	89
Potato protein concentrate	41	146	106	114	123	115	121	107	125	110	109	70	105
Cassava leaf meal	50	107	61	108	91	129	176	124	87	110	72	105	126
Alfalfa leaf meal (22% protein)	49	141	78	119	126	112	89	138	76	265	112	100	216
Single cell proteins													
<i>Pseudomonas/Methylophilus</i> spp.	55	58	120	120	118	111	117	133	95	127	90	102	78
Mixed bacterial SCP	73	68	130	113	108	110	106	127	86	149	84	102	81
Brewers yeast (<i>S. cerevisiae</i>)	53	122	82	127	121	102	137	123	85	144	85	121	91
Extracted yeast (<i>S. cerevisiae</i>)	48	122	85	118	114	123	124	131	87	133	91	109	85
Torula yeast (<i>T. utilis</i>)	51	112	68	124	131	94	133	122	92	105	110	119	82
<i>Candida</i> spp. (alkane substrate)	44	112	97	137	124	113	126	125	93	155	86	95	111
<i>Aspergillus oryzae</i> (waste starch)	58	98	58	117	111	106	108	122	154	160	72	114	102
<i>Rhodotorula pilimanae</i>	78	24	118	134	103	99	163	118	66	33	69	123	139
<i>Rhodotorula pilimanae</i>	68	54	82	115	145	115	86	135	103	155	88	77	101
Activated bacterial SCP (brewery)	55	78	99	117	123	106	121	115	102	160	99	100	105

¹ Calculated essential amino acid (EAA) score calculated by comparing the level of the different EAA with the EAA requirements of farmed finfish and shrimp, respectively.

² Difference between the highest and lowest calculated EAA score.

³ EAA requirement profile of farmed fish (Arg 11.6%, Cys 2.7%, Met 5.4%, Thr 10.6%, Iso 7.5%, Leu 13.5%, Val 9.5%, Tyr 6.5%, Try 1.7%, Phe 9.5% and His 4.8%; Ogino, 1980).

⁴ EAA requirement profile of farmed shrimp (Arg 19.3%, Cys 2.0%, Met 4.2%, Thr 8.0%, Iso 8.2%, Leu 14.2%, Val 9.1%, Tyr 8.2%, Try 1.8%, Phe 9.9% and His 4.3%; Tacon *et al.*, 2002).

TABLE 59

Recommended use of some common protein-rich ingredients used in compound aquafeeds

Feed ingredient	Species group: Finfish ¹		Species group: Crustaceans ²	
	Range of use	Mean use	Range of use	Mean use
Fishery products				
Fishmeal (general) ³	5–75	25–35	10–45	20–25
Fish solubles, condensed	1–5	2–3	1–5	2–3
Shrimp meal (process residue)	1–10	3–5	1–10	2–6
Shrimp head meal ⁴	1–10	2–3	1–10	3–5
Krill meal ⁵	1–10	2–5	1–10	2–5
Squid meal ⁶	1–10	2–5	1–10	2–5
Squid liver meal	1–5	1–3	1–10	2–6
Terrestrial livestock products				
Blood meal (spray dried) ⁷	1–8	2–4	1–5	1–2
Feather meal (hydrolysed) ⁸	1–12	3–6	1–5	2–3
Meat and bone meal ⁹	2–10	3–5	2–10	3–5
Meat meal	2–10	3–5	1–5	2–3
Poultry by-product meal	5–25	5–10	3–20	4–8
Liver meal	1–5	2–3	1–3	1–2
Protein-rich cereal products				
Brewers grains (5-02-141)	10–35	10–15	5–20	5–10
Maize gluten meal (60% protein) ¹⁰	4–12	4–6	3–9	3–5
Maize DDGS	3–20	5–10	2–18	3–5
Wheat gluten meal ¹¹	4–12	6–9	2–12	3–5
Oilseed protein products				
Canola meal, solvent extracted	2–25	6–18	2–20	4–12
Rapeseed meal, mech/solv. extr.	2–25	5–15	2–20	5–15
Copra meal, mech/solv. extr.	2–15	3–10	1–12	3–6
Cottonseed meal, mech/solv. extr.	5–25	10–15	3–20	10–15
Oil palm (kernel), solv. extracted	5–25	10–15	3–20	10–15
Peanut meal, mech/solv. extr.	5–25	10–15	3–20	10–15
Soybean seed, heat processed	2–15	3–9	2–10	3–6
Soybean, undehull. mech/solv. extr.	5–30	10–20	5–25	10–15
Soybean meal, dehulled, solv. extr.	5–30	10–20	5–35	10–15
Soybean protein concentrate	2–10	3–5	2–10	3–5
Sunflower seed, decor. solv. extr.	2–25	10–15	2–20	6–12
Pulse/grain legume seed products				
Lupin	3–25	9–15	2–20	6–12
Pea/field pea	3–15	5–10	2–12	4–8
Single cell proteins				
Bacterial SCP	1–3	1–2	1–3	1–2
Brewers yeast (malt)	1–6	2–4	1–6	2–4
Alcohol yeast (sugarcane)	1–6	2–4	1–6	2–4

¹ Finfish: requirements range from herbivorous/omnivorous finfish species (i.e. carps, tilapia, catfishes, milkfish, mullets, etc.) to carnivorous finfish species (i.e. salmonids, groupers, croakers, flounders, seabass, seabreams, turbot, snappers, drums, mandarin fish, snakeheads, etc.).

² Crustaceans: requirements range from freshwater crustaceans (i.e. freshwater prawns and crabs, crayfish) to marine crustaceans (ie. penaeid shrimp, crabs, lobsters, etc.).

³ Fishmeal inclusion levels vary depending upon feeding habit of the cultured species in question (carnivore, omnivore or herbivore) and the dietary requirement of the target species for the marine n-3 essential fatty acids found in fishmeal and/or fish oil.

⁴ Shrimp head meal is generally produced from farmed shrimp processing wastes and its use as a feed ingredient for farmed shrimp is not recommended due to potential biosecurity hazards from intra-species recycling and the potential of disease transmission from inadequately processed meals.

⁵ Krill meal, depending on source and processing method, may contain high levels of fluorine (2,000 – 2,700 mg/kg krill meal) which may be subject to limitations in some countries. For example, according to German feedstuff legislation the flourine content may not exceed 500 mg/kg for a single feedstuff of animal origin, and 150 mg/kg for compound feed (Hertrampf and Pascual, 2000).

⁶ Squid meal and squid products, depending upon source, may contain high levels of cadmium which may be subject to limitations in some countries (Mai et al., 2006a).

⁷ Blood meal is a rich source of leucine, valine and histidine, but very deficient in isoleucine and methionine (Table 58). Moreover, due to the antagonistic effect of excess dietary leucine on isoleucine metabolism, animals fed high dietary levels of blood meal may suffer from isoleucine deficiency.

⁸ Feather meal is a rich source of cystine but very deficient in methionine, lysine and histidine (Table 58). Moreover, due to the antagonistic effect of excess dietary cystine on methionine metabolism, animals fed high dietary levels of feather meal may suffer from methionine deficiency.

- ⁹ Meat and bone meal has a high ash content which may limit its use at high dietary inclusion levels due to the antagonistic effect of excess dietary calcium on trace element metabolism.
- ¹⁰ Maize gluten meal is a rich source of leucine but is very deficient in lysine and to a lesser extent arginine (Table 58). Its use in animal feeds may be limited due to the presence of carotenoids (xanthophylls) which may impart an unwanted yellow pigmentation to the flesh of the cultured species.
- ¹¹ Wheat gluten meal is a good natural protein binder, is a rich source of cystine, but is very deficient in lysine (Table 58).
- ¹² Canola meal has a well-balanced essential amino acid (EAA) profile (Table 58), but may contain a variety of anti-nutritional factors including protease inhibitors, glucosinolates, phytic acid, tannins and non-starch polysaccharides – oligosaccharides.
- ¹³ Rapessed meal has a well-balanced essential amino acid (EAA) profile (Table 59), but may contain a variety of anti-nutritional factors including protease inhibitors, glucosinolates, phytic acid, tannins, non-starch polysaccharides – oligosaccharides, and erucic acid.
- ¹⁴ Copra meal is a rich source of arginine, but is very deficient in lysine and to a lesser extent methionine (Table 58). Moreover, due to the antagonistic effect of excess dietary arginine on lysine metabolism, animals fed high dietary levels of copra meal may suffer from lysine deficiency. In addition, copra meal may contain anti-nutritional factors, including phytic acid, tannins, and non-starch polysaccharides – oligosaccharides.
- ¹⁵ Cottonseed meal is a rich source of arginine (and to a lesser extent tryptophan and cystine), but is deficient in methionine and lysine (Table 58). In addition, cottonseed meal may contain anti-nutritional factors, including phytic acid, estrogenic factors, gossypol, anti-vitamin E factor and cyclopropenoic acids.
- ¹⁶ Oil palm meal is a rich source of arginine, but is very deficient in lysine (Table 58). Moreover, due to the antagonistic effect of excess dietary arginine on lysine metabolism, animals fed high dietary levels of oil palm meal may suffer from lysine deficiency. In addition, oil palm meal may contain high levels of anti-nutritional factors and in particular of non-starch polysaccharides – oligosaccharides.
- ¹⁷ Peanut meal is a rich source of arginine, but is very deficient in methionine and lysine (Table 58). Moreover, due to the antagonistic effect of excess dietary arginine on lysine metabolism, animals fed high dietary levels of peanut meal may suffer from lysine deficiency. In addition, peanut meal may contain anti-nutritional factors, including protease inhibitors, phyto-haemagglutinins, phytic acid, saponins and oestrogenic factors.
- ¹⁸ Soybean meal is a rich source of tryptophan, but is deficient in methionine and to a lesser extent lysine (Table 58). It may contain a variety of anti-nutritional factors (depending upon processing), including protease inhibitors, phyto-haemagglutinins, glucosinolates, phytic acid, saponins, estrogenic factors, flatulence factor, anti-vitamin E factor, anti-vitamin A factor, anti-vitamin D factor, anti-vitamin B₁₂ factor, allergens, and non-starch polysaccharides – oligosaccharides.
- ¹⁹ Sunflower seed meal is a rich source of tryptophan and to a lesser extent arginine, but is deficient in lysine and to a lesser extent tyrosine (Table 58). In addition, sunflower seed meal may contain anti-nutritional factors, including protease inhibitors, tannins and arginase inhibitor.
- ²⁰ Lupin seed meal is a rich source of arginine, but is very deficient in methionine and to a lesser extent lysine (Table 58). In addition, lupin seed meal may contain anti-nutritional factors, including protease inhibitors, phyto-haemagglutinins, cyanogens, phytic acid tannins and allergens.
- ²¹ Pea seed meal is deficient in methionine (Table 58) and may contain anti-nutritional factors, including protease inhibitors, phyto-haemagglutinins, cyanogens, phytic acid, saponins and anti-vitamin E factor.

7. Conclusion

There is no doubt that the long-term sustainability of the aquaculture sector will be governed by the long-term sustainability and market availability and cost of feed ingredient supplies. It follows therefore that for net importing countries (including most developing countries), effort should be focused on trying to reduce reliance on imported feed ingredient sources and maximizing the use of locally available agricultural and fishery by-products and waste streams.

As in humans and livestock, farmed fish and shrimp do not have a specific dietary requirement for a particular feed ingredient such as fishmeal or fish oil, but rather have a specific requirement for 40 or so essential dietary nutrients. It follows that in the short term, effort should be focused on further improvements in feed formulation techniques and on formulating rations on the basis of individual digestible nutrient levels rather than on crude gross nutrient levels.

Finally, in a world of increasing transparency and accountability in the food production process, it is clear that feed safety, traceability and sustainability of ingredient supplies will become ever more important and will dictate future ingredient selection. Moreover, in a world with over 1.4 billion people in the developing world (one in four) still living below the poverty line of US\$1.25 a day (<http://web.worldbank.org>), clearly effort must also be focused on identifying and using feed-grade ingredient sources within compound aquafeeds if the aquaculture sector is to be truly sustainable (from an economic, ecological, environmental and socio-economic viewpoint) in the long term.

One positive prospect on the horizon is the recent development of microbial floc-based aquaculture production systems (Tacon *et al.*, 2002) and the real possibility of changing the nutrition of the target species from essentially a monogastric animal to that more akin to an aerobic ruminant by providing an additional, bacterial-based external culture medium (equivalent to a rumen). By so doing, herbivorous/omnivorous filter feeding species, such as tilapia and shrimp, produced within such floc-based culture systems would be able to use increasing levels of feed grade nutrient sources within lower cost compound aquafeeds, with the nutrient deficiencies inherent in feed-grade ingredients being compensated by the continuous supply and availability of a second nutrient source – nutrient-rich bacterial-based microbial floc endogenously produced within the culture system.

8. References

- AAFCO (Association of American Feed Control Officials). 2008a. Official feed terms. *Official Publication of the Association of American Feed Control Officials*. Inc, Oxford, IN USA, pp. 239–252.
- AAFCO (Association of American Feed Control Officials). 2008b. Official feed definitions, *Official Publication of the Association of American Feed Control Officials*. Inc, Oxford, IN, USA. pp. 256–361.
- Aas, T.S., Grisdale-Helland, B., Terjesen, B.F. & Helland, S.J. 2006a. Improved growth and nutrient utilisation in Atlantic salmon (*Salmo salar*) fed diets containing a bacterial protein meal. *Aquaculture*, 259 (1-4): 365–376.
- Aas, T.S., Hatlen, B., Grisdale-Helland, B., Terjesen, B.F., Bakke-McKellep, A.M. & Helland, S.J. 2006b. Effects of diets containing a bacterial protein meal on growth and feed utilisation in rainbow trout (*Oncorhynchus mykiss*). *Aquaculture*, 261 (1): 357–368.
- Aas, T.S., Hatlen, B., Grisdale-Helland, B., Terjesen, B.F., Penn, M., Bakke-McKellep, A.M. & Helland, S.J. 2007. Feed intake, growth and nutrient utilization in Atlantic halibut (*Hippoglossus hippoglossus*) fed diets containing a bacterial protein meal. *Aquaculture Research*, 38: 351–360.
- Abad, E., Llerena, J.J., Saulo, J., Caixach, J. & Rivera, J. 2002. Comprehensive study on dioxin contents in binder and anti-caking agent feed additives. *Chemosphere*, 46 (9): 1417–1421.
- Abbas, K., Ahmed, I. & Rehman, H. 2005. Growth performance as influenced by partial replacement of fish meal with plant proteins in the diet of major carps. *Indus Journal of Biological Science*, 2 (2): 219–226.
- Abbas, S., Ahmed, I., Hafeez-Ur-Rehman, M. & Mateen, A. 2008. Replacement of fish meal by canola meal in diets for major carps in fertilized ponds. *Pakistan Veterinary Journal*, 28 (3): 111–114.
- Abdelghany, A.E., Sayed, S.H., Abdul-Aziz, G.M. & Shalaby, A.S. 1997. Partial replacement of soybean meal with poultry manure meal in diets for blue tilapia (*Oreochromis aureus*). *Journal of Aquaculture in the Tropics*, 12 (4): 275–288.
- Abdelhamid, A.M., Khalil, F.F. & Ragab, M.A. 1998. Problem of mycotoxins in fish production. *Egyptian Journal of Nutrition and Feeds*, 1 (1): 63–71.
- Abdel-Tawwab, M., Abdel-Rahman, A.M. & Ismael, N.E.M. 2008. Evaluation of commercial live bakers' yeast, *Saccharomyces cerevisiae*, as a growth and immunity promoter for fry Nile tilapia, *Oreochromis niloticus* (L.), challenged in situ with *Aeromonas hydrophila*. *Aquaculture*, 280 (1): 185–189.
- Abdel-Tawwab, M. & Ahmad, M.H. 2009. Live *Spirulina* (*Arthrospira platensis*) as a growth and immunity promoter for Nile tilapia, *Oreochromis niloticus* (L.), challenged with pathogenic *Aeromonas hydrophila*. *Aquaculture Research*, 40: 1037–1046.
- Abdel-Warith, A. A., Russell, P.M. & Davies, S.J. 2001. Inclusion of a commercial poultry by-product meal as a protein replacement of fish meal in practical diets for African catfish *Clarias gariepinus* (Burchell 1822). *Aquaculture Research*, 32: 296–305.
- Abdul-Aziz, G.M., El-Nady, M.A., Shalaby, A.S. & Mohmoud, S.H. 1999. Partial substitution of soybean meal protein by different plant protein sources in diets for Nile tilapia fingerlings. *Bull. Fac. Agric. Cairo Univ.*, 50: 189–202.
- Abe, M.P., Froes, C.N., Prentice-Hernandez, C., Junior, W.W. & Cavalli, R.O. 2008. Fishmeal replacement by soybean meal in practical diets for shrimp *Farfantepenaeus paulensis*. *Ciencia Rural*, 38 (1): 219–224.
- Abery, N.W., Gunasekera, R.M. & De Silva, S.S. 2002. Growth and nutrient utilization of Murray cod *Maccullochella peelii peelii* (Mitchell) fingerlings fed diets with varying levels of soybean meal and blood meal. *Aquaculture Research*, 33 (4): 279–289.
- Abimorad, E.G., Squassoni, G.H. & Carneiro, D.J. 2008. Apparent digestibility of protein, energy and amino acids in some selected feed ingredients for pacu *Piaractus mesopotamicus*. *Aquaculture Nutrition*, 14 (4): 374–380.
- Adamidou, S., Nengas, I., Alexis, M., Foundoulaki, E., Nikolopoulou, D., Campbell, P., Karacostas, I., Rigos, G., Bell, G.J. & Jauncey, K. 2009. Apparent nutrient digestibility and gastrointestinal evacuation time in European seabass (*Dicentrarchus labrax*) fed diets containing different levels of legumes. *Aquaculture*, 289 (1-2): 106–112.
- Adebayo, O.T., Balogun, A.M. & Falayi, B.A. 2003. Evaluation of some carbohydrates derivatives as binder in practical diets for African catfish, *Heterobranchus bidorsalis*. *Applied fisheries and aquaculture*, 3 (1-2): 37–41.
- Adebayo, O.T., Fagbenro, O.A. & Jegede, T. 2004. Evaluation of *Cassia fistula* meal as a replacement for soybean meal in practical diets of *Oreochromis niloticus* fingerlings. *Aquaculture Nutrition*, 10 (2): 99–104.
- Adelizi, P.D., Rosati, R.R., Warner, K., Wu, Y.V., Muench, T.R., White, M.R. & Brown, P.B. 1998. Evaluation of fishmeal free diets for rainbow trout, *Oncorhynchus mykiss*. *Aquaculture Nutrition*, 4 (4): 255–262.
- Afzal, M., Rab, A., Akhtar, N., Farhan Khan, M., Barlas, A. & Qayyum, M. 2007. Effect of organic and inorganic fertilizers on the growth performance of bighead carp (*Aristichthys nobilis*) in polyculture system. *International Journal of Agriculture and Biology*, 9 (6): 931–933.

- Aguiar, A.C., Morais, D.R., Santos, L.P., Stevanato, F.B., Visentainer, J.E.L., de Souza, N.E. & Visentainer, J.V. 2007. Effect of flaxseed oil in diet on fatty acid composition in the liver of Nile Tilapia (*Oreochromis niloticus*). *Archivos Latinoamericanos de Nutricion*, 57 (3): 273–277.
- Aguila, J., Cuzon, G., Pascual, C., Domingues, P.M., Gaxiola, G., Sanchez, A., Maldonado, T. & Rosas, C. 2007. The effects of fish hydrolysate (CPSP) level on Octopus maya (Voss and Solis) diet: Digestive enzyme activity, blood metabolites, and energy balance. *Aquaculture*, 273 (4): 641–655.
- Ai, Q. & Xie, X. 2002a. The nutrition of *Silurus meridionalis*: effects of different levels of dietary soybean protein on growth. *Acta hydrobiologica sinica/Shuisheng Shengwu Xuebao*, 26 (1): 57–65.
- Ai, Q. & Xie, X. 2002b. The nutrition of *Silurus meridionalis*: effects of different levels of dietary soybean protein on digestibility and feeding rate. *Acta hydrobiologica sinica/Shuisheng Shengwu Xuebao*, 26 (3): 215–220.
- Ai, Q. & Xie, X. 2005a. Effects of dietary soybean protein levels on energy budget of the southern catfish, *Silurus meridionalis*. *Comparative Biochemistry and Physiology, Part A: Molecular and Integrative Physiology*, 141 (4): 461–469.
- Ai, Q.H. & Xie, X.J. 2005b. Effects of replacement of fish meal by soybean meal and supplementation of methionine in fish meal/soybean meal-based diets on growth performance of the southern catfish *Silurus meridionalis*. *Journal of the World Aquaculture Society*, 36 (4): 498–507.
- Ai, Q.H. & Xie, X.J. 2006. Effects of dietary soybean protein levels on metabolic response of the southern catfish, *Silurus meridionalis*. *Comparative Biochemistry and Physiology a-Molecular and Integrative Physiology*, 144 (1): 41–47.
- Ai, Q. H., Mai, K.S. Tan, B.P., Xu, W., Duan, Q. Y., Ma, H.M. & Zhang, L. 2006. Replacement of fish meal by meat and bone meal in diets for large yellow croaker, *Pseudosciaena crocea*. *Aquaculture*, 260 (1-4): 255–263.
- Ajani, E.K., Nwanna, L.C. & Musa, B.O. 2004. Replacement of fishmeal with maggot meal in the diets of Nile tilapia, *Oreochromis niloticus*. *World Aquaculture*, 35 (1): 52–54.
- Akegbejo-Samsons, Y. & Fasakin, A.E. 2008. Use of rendered animal protein meals as fish meal replacer in the diets of the African catfish, *Clarias gariepinus* (Burchell, 1822) juveniles. *Tropicultura*, 26 (2): 89–92.
- Akinwande, A.A., Ugwumba, A.A. & Ugwumba, A.O. 2002. Effects of replacement of fish meal with maggot meal in the diet of *Clarias gariepinus* (Burchell, 1822) fingerlings. *The Zoologist*, 1 (2): 41–46.
- Akinwande, A.A., Alatise, P.S., Ayanlode, F.V., Enin, U.I., Chukwu, E.L., Ajah, P.O., Ama-Abasi, D.A. & Nwosu, F.M. 2007. Evaluation of pawpaw leaf-based diets (*Carica papaya*) on growth and survival of African catfish (*Clarias gariepinus*) fingerlings reared in plastic bowls. *Proceedings of the annual conference of Fisheries Society of Nigeria*, pp. 320–324.
- Akiyama, T., Shiraishi, M., Yamamoto, T. & Unuma, T. 1996. Effect of dietary tryptophan on maturation of ayu *Plecoglossus altivelis*. *Fisheries Science*, 62 (5): 776–782.
- Akiyama, T., Unuma, T., Yamamoto, T., Marcouli, P. & Kishi, S. 1995. Combinational use of malt protein flour and soybean meal as alternative protein sources of fishmeal in fingerling rainbow trout diets. *Fisheries Science*, 61 (5): 828–832.
- Akiyama, T., Unuma, T., Yamamoto, T., Furuita, H. & Konishi, K. 1997. An evaluation of amino acid sources and binders in semipurified diet for red sea urchin *Pseudocentrotus depressus*. *Fisheries Science*, 63 (6): 881–886.
- Aksnes, A., Hope, B., Hostmark, O. & Albrektsen, S. 2006a. Inclusion of size fractionated fish hydrolysate in high plant protein diets for Atlantic cod, *Gadus morhua*. *Aquaculture*, 261 (3): 1102–1110.
- Aksnes, A., Hope, B., Jonsson, E., Bjornsson, B.T. & Albrektsen, S. 2006b. Size-fractionated fish hydrolysate as feed ingredient for rainbow trout (*Oncorhynchus mykiss*) fed high plant protein diets. I: Growth, growth regulation and feed utilization. *Aquaculture*, 261(1): 305–317.
- Aksnes, A., Hope, B. & Albrektsen, S. 2006c. Size-fractionated fish hydrolysate as feed ingredient for rainbow trout (*Oncorhynchus mykiss*) fed high plant protein diets. II: Flesh quality, absorption, retention and fillet levels of taurine and anserine. *Aquaculture*, 261(1): 318–326.
- Aksnes, A., Hope, B. & Albrektsen, S. 2006d. Size-fractionated fish hydrolysate as feed ingredient for rainbow trout (*Oncorhynchus mykiss*) fed high plant protein diets. II: Flesh quality, absorption, retention and fillet levels of taurine and anserine. *Aquaculture*, 261(1): 318–326.
- Aksnes, A., Izquierdo, M.S., Robaina, L., Vergara, J.M. & Montero, D. 1997. Influence of fish meal quality and feed pellet on growth, feed efficiency and muscle composition in gilthead seabream (*Sparus aurata*). *Aquaculture*, 153(3–4): 251–261.
- Aksnes, A. & Mundheim, H. 1997. The impact of raw material freshness and processing temperature for fish meal on growth, feed efficiency and chemical composition of Atlantic halibut (*Hippoglossus hippoglossus*). *Aquaculture*, 149 (1-2): 87–106.
- Alam, M.S., Teshima, S., Koshio, M. & Ishikawa, M. 2004. Effects of supplementation of coated crystalline amino acids on growth performance and body composition of juvenile kuruma shrimp *Marsupenaeus japonicus*. *Aquaculture Nutrition*, 10 (5): 309–316.
- Alam, M., Teshima, S., Koshio, S., Ishikawa, M., Uyan, O., Hernandez, L.H.H. & Michael, F.R. 2005. Supplemental effects of coated methionine and/or lysine to soy protein isolate diet for juvenile kuruma shrimp, *Marsupenaeus japonicus*. *Aquaculture*, 248 (1–4): 13–19.
- Alam Sarker, S., Satoh, S. & Kiron, V. 2005. Supplementation of citric acid and amino acid-chelated trace element to develop environment-friendly feed for red sea bream, *Pagrus major*. *Aquaculture*, 248 (1–4): 3–11.
- Alasgah, N.A. & Ali, A. 1996. Effect of feeding different levels of wheat bran on the growth performance and body composition of *Oreochromis niloticus*. *Agribiological Research-Zeitschrift für Agrarbiologie Agrikulturchemie Ökologie*, 49 (2–3): 193–202.

- Alava, V.R. 1998. Effect of salinity, dietary lipid source and level on growth of milkfish (*Chanos chanos*) fry. *Aquaculture*, 167: 229–236.
- Albrecht-Ruiz, M., Clark-Leza, D. & Aleman-Polo, M. 1999. Rapid method for biogenic amines evaluation in fish meal. *Journal of Aquatic Food Product Technology*, 8 (4): 71–83.
- Albrektsen, S., Mundheim, H. & Aksnes, A. 2006. Growth, feed efficiency, digestibility and nutrient distribution in Atlantic cod (*Gadus morhua*) fed two different fish meal qualities at three dietary levels of vegetable protein sources. *Aquaculture*, 261 (2): 626–640.
- Alexis, M.N. 1997. Fish meal and fish oil replacers in Mediterranean marine fish diets. Feeding tomorrow's fish. Proceedings of the Workshop of the CIHEAM Network on Technology of Aquaculture in the Mediterranean (TECAM), jointly organized by CIHEAM, FAO and IEO, Mazarron (Spain), 24–26 June 1996. pp. 183–204. *Cab. Options Mediterr.* Vol. 22, 1997.
- Al-Hafedh, Y.S. & Siddiqui, A.Q. 1998. Evaluation of guar seed as a protein source in Nile tilapia, *Oreochromis niloticus* (L.), practical diets. *Aquaculture Research*, 29 (10): 703–708.
- Ali, A.J. & Dumont, H.J. 2002. Rice bran as a diet for culturing *Streptocephalus proboscideus* (Crustacea: Anostraca). *Hydrobiologia*, 486 (1): 249–254.
- Ali, M.S., Chaudhari, A. & Sahu, N.P. 2000. Changes in proteolytic and amylolytic activities in *Macrobrachium rosenbergii* post larvae fed on fish silage based diet. *Journal of Aquaculture in the Tropics*, 15 (3): 243–252.
- Ali, S.A., Gopal, C. & Ramana, J.V. 2007. Attractant and growth promoting properties of some feed materials and chemicals incorporated in the diets for *Penaeus monodon* (Fabricius). *Indian Journal of Fisheries*, 54 (1): 67–73.
- Allameh, S.K., Soofiani, N.M. & Pourreza, J. 2007. Determination of digestible and metabolizable energy of fishmeal and soybean meal in rainbow trout with two different sizes (*Oncorhynchus mykiss*). *Pakistan Journal of Biological Sciences*, 10 (20): 3722–3725.
- Allan, G.L. & Booth, M.A. 2004. Effects of extrusion processing on digestibility of peas, lupins, canola meal and soybean meal in silver perch *Bidyanus bidyanus* (Mitchell) diets. *Aquaculture Research*, 35 (10): 981–991.
- Allan, G.L., Parkinson, S., Booth, M.A., Stone, D.A.J., Rowland, S.J., Frances, J., Warner-Smith, R. (2000). Replacement of fish meal in diets for Australian silver perch, *Bidyanus bidyanus*: I. Digestibility of alternative ingredients. *Aquaculture*, 186 (3–4): 293–310.
- Allan, G.L. & Rowland, S.J. 2005. Performance and sensory evaluation of silver perch (*Bidyanus bidyanus* Mitchell) fed soybean or meat meal-based diets in earthen ponds. *Aquaculture Research*, 36 (13): 1322–1332.
- Allen, V.J., Marsden, I.D. & Ragg, N.L.C. 2000. The use of stimulants as an aid to wean fishery-caught blackfoot abalone (*Haliotis iris*) to artificial food. 4. International Abalone Symposium, Cape Town, South Africa, February 2000, 19 (1): 501.
- Allen, V.J., Marsden, I.D. & Ragg, N.L.C. 2001. The use of stimulants as an aid to wean fishery caught blackfoot abalone (*Haliotis iris*) to artificial food. 4. International Symposium on Abalone Biology, Fisheries, and Culture, Cape Town, South Africa, 6–11 Feb 2000, 20 (2): 647–651.
- Almaida-Pagan, R., Hernandez, M.D., Garcia, B.G., Madrid, J.A., De Costa, J. & Mendiola, P. 2007. Effects of total replacement of fish oil by vegetable oils on n-3 and n-6 polyunsaturated fatty acid desaturation and elongation in sharpnose seabream (*Diplodus puntazzo*) hepatocytes and enterocytes. *Aquaculture*, 272 (1–4): 589–598.
- Al-Ogaily, S.M., Al-Asgah, N.A. & Ali, A. 1996. Effect of feeding different grain sources on the growth performance and body composition of tilapia, *Oreochromis niloticus* (L.). *Aquaculture Research*, 27 (7): 523–529.
- Alvarez, J. S., Hernandez-Llamas, A., Galindo, J., Fraga, I., Garcia, T. & Villarreal, H. 2007. Substitution of fishmeal with soybean meal in practical diets for juvenile white shrimp *Litopenaeus schmitti* (Perez-Farfante & Kensley 1997). *Aquaculture Research*, 38 (7): 689–695.
- Alvarez, M. J., Lopez-Bote, C.J., Diez, A., Corraze, G., Arzel, J., Dias, J., Kaushik, S.J. & Bautista, J.M. 1998. Dietary fish oil and digestible protein modify susceptibility to lipid peroxidation in the muscle of rainbow trout (*Oncorhynchus mykiss*) and sea bass (*Dicentrarchus labrax*). *British Journal of Nutrition*, 80 (3): 281–289.
- Amar, B., Philip, R. & Singh, I.S.B. 2006. Efficacy of fermented prawn shell waste as a feed ingredient for Indian white prawn, *Fenneropenaeus indicus*. *Aquaculture Nutrition*, 12 (6): 433–442.
- Amar, E. C., Kiron, V., Satoh, S. & Watanabe, T. 2001. Influence of various dietary synthetic carotenoids on bio-defence mechanisms in rainbow trout, *Oncorhynchus mykiss* (Walbaum). *Aquaculture Research*, 32 (s1): 162–173.
- Amaya, E., Davis, D.A. & Rouse, D.B. 2007a. Alternative diets for the Pacific white shrimp *Litopenaeus vannamei*. *Aquaculture*, 262: 419–425.
- Amaya, E.A., Davis, D.A. & Rouse, D.B. 2007b. Replacement of fish meal in practical diets for the Pacific white shrimp (*Litopenaeus vannamei*) reared under pond conditions. *Aquaculture*, 262 (2–4): 393–401.
- Ambardekar, A. A. & Reigh, R.C. 2007. Sources and utilization of amino acids in Channel catfish diets: A review. *North American Journal of Aquaculture*, 69 (2): 174–179.
- Ambardekar, A.A., Reigh, R.C. & Williams, M.B. 2009. Absorption of amino acids from intact dietary proteins and purified amino acid supplements follows different time-courses in channel catfish (*Ictalurus punctatus*). *Aquaculture*, 291 (3–4): 179–187.

- Amerio, M., Vignali, C., Castelli, L., Fiorentini, L. & Tibaldi, E. 1998. Vegetable protein sources, protein evaluation indices and 'ideal protein' of sea bream (*Sparus aurata*). *Rivista Italiana di Acquacoltura*, 33 (3):135–145.
- Amlund, H., Lundebye, A.K., & Berntssen, M.H.G. 2007. Accumulation and elimination of methyl mercury in Atlantic cod (*Gadus morhua* L.) following dietary exposure. *Aquatic Toxicology*, 83(4): 323–330.
- 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 sea water. *Aquaculture*, 108 (1–2): 111–124.
- Anderson, J.S., Lall, S.P., Anderson, D.M. & McNiven, M.A. 1993. Evaluation of protein quality in fish meals by chemical and biological assays. *Aquaculture*, 115: 305–325.
- Anderson, J.S., Lall, S.P., Anderson, D. & McNiven, M.A. 1995. Availability of amino acids from various fish meals fed to Atlantic salmon (*Salmo salar*). *Aquaculture*, 138: 291–301.
- Anderson, J.S., Higgs, D.A., Beames, R.M. & Rowshandeli, M. 1997. Fish meal quality assessment for Atlantic salmon (*Salmo salar* L.) reared in sea water. *Aquaculture Nutrition*, 3 (1): 25–38.
- Anderson, J.S., Richardson, N.L., Higgs, D.A., Dosanjh, B.S. & Department of Fisheries & Oceans, West Vancouver, BC, Canada, Sci. Branch. 1997b. The evaluation of air-dried krill meal as a dietary protein supplement for juvenile chinook salmon (*Oncorhynchus tshawytscha*). *Can. Tech. Rep. Fish. Aquat. Sci.*, 17 pp.
- Anh, N.T.N., Hien, T.T.T., Mathieu, W., Hoa, N.V. & Sorgeloos, P. 2009. Effect of fishmeal replacement with Artemia biomass as a protein source in practical diets for the giant freshwater prawn *Macrobrachium rosenbergii*. *Aquaculture Research*, 40: 669–680.
- Anon. 2001. Fast-grown worms enhance broodstocks. *Fish Farmer*, 24 (1): 12–14.
- Anon. 2009. A buyer's guide to rendered fats. *Render*, 38 (1): 14–19.
- ANZFA (Australia New Zealand Food Standards), now called Food Standards Australia New Zealand (FSANZ). 2001. Food Standards Code, Standard 1.4.1. Australia New Zealand Food Authority (available from www.nzfsa.govt.nz/).
- AOAC (Association of Official Analytical Chemists) International. 2005. *Official Methods of Analysis of AOAC International, 18th Edition*. Gaithersburg, Maryland, USA, AOAC International.
- Aoki, H., Akimoto, A. & Watanabe, T. 2001. Periodical changes of plasma free amino acid levels and feed digesta in yellowtail after feeding non-fishmeal diets with or without supplemental crystalline amino acids. *Fisheries Science*, 67: 614–618.
- Aoki, H., Shimazu, H., Fukushige, T., Akano, H., Yamagata, Y & Watanabe, T. 1996. Flesh quality in red sea bream fed with diet containing a combination of different protein sources as total substitution for fish meal. *Bull. Fish. Res. Inst. Mie.*, no. 6, pp. 47–54.
- Aoki, H., S. Tanaka, Y. Shimizu, Y. Yamagata, Maita, M. & Watanabe, T. 1999. Potential of scrap fish meal as partial or total replacement of fish meal in extruded pellets for young yellowtail. *Bull. Fish. Res. Inst. Mie.*, 8 (8): 7–14.
- Apines, M., Satoh, S., Kiron, V., Watanabe, T., Nasu, N. & Fujita, S. 2001. Bioavailability of amino acids chelated and glass embedded zinc to rainbow trout, *Oncorhynchus mykiss*, fingerlings. *Aquaculture Nutrition*, 7 (4):221–228.
- Apines, M. J. S., Satoh, S., Kiron, V., Watanabe, T. & Aoki, T. 2003a. Availability of supplemental amino acid-chelated trace elements in diets containing tricalcium phosphate and phytate to rainbow trout, *Oncorhynchus mykiss*. *Aquaculture*, 225 (1–4): 431–444.
- Apines, M. J. S., Satoh, S., Kiron, V., Watanabe, T. & Fujita, S. 2003b. Bioavailability and tissue distribution of amino acid-chelated trace elements in rainbow trout *Oncorhynchus mykiss*. *Fisheries Science*, 69(4): 722–730.
- Apines, M.J.S., Satoh, S., Caipang, C.M.A., Kiron, V. Watanabe, T. & Aoki, T. 2004. Amino acid-chelate: a better source of Zn, Mn and Cu for rainbow trout, *Oncorhynchus mykiss*. *Aquaculture*, 240(1–4): 345–358.
- Appelbaum, S. & Raj, A.J.A. 2008. Utilization of canola oil and beef fat coated commercial diets by African catfish (*Clarias gariepinus*) juveniles. *Animal Nutrition and Feed Technology*, 8 (1): 73–79.
- Appleford, P. & Anderson, T.A. 1997a. Effect of inclusion level and time on apparent digestibility of solvent-extracted soybean meal for common carp (*Cyprinus carpio*, Cyprinidae). *Asian Fisheries Science*, 10 (1): 65–74.
- Appleford, P. & Anderson, T.A. 1997b. Apparent digestibility of tuna oil for common carp, *Cyprinus carpio* - Effect of inclusion level and adaptation time. *Aquaculture*, 148 (2–3): 143–151.
- Aragao, C., Conceicao, L.C., Dias, J., Marques, A.C., Gomes, E., & Dinis, M.T. 2003. Soy protein concentrate as a protein source for Senegalese sole (*Solea senegalensis* Kaup 1858) diets: effects on growth and amino acid metabolism of postlarvae. *Aquaculture Research*, 34 (15): 1443–1452.
- Arndt, R. E., Hardy, R.W., Sugiura, S.H. & Dong, F.M. 1999. Effects of heat treatment and substitution level on palatability and nutritional value of soy defatted flour in feeds for Coho Salmon, *Oncorhynchus kisutch*. *Aquaculture*, 180 (1–2): 129–145.
- Arnesen, P. & Krogdahl, A. 1995. Nutrient digestibilities, weight gain and plasma and liver levels of carbohydrate in rainbow trout, *Oncorhynchus mykiss* (Walbaum), fed diets with oats. *Aquaculture Nutrition*, 1 (4): 201–211.
- Arnesen, P., Krogdahl, A. & Sundby, A. 1995. Nutrient digestibilities, weight gain and plasma and liver levels of carbohydrate in Atlantic salmon (*Salmo salar*, L.) fed diets containing oats and maize. *Aquaculture Nutrition*, 1 (3): 151–158.

- Arslan, M., Rinchard, J., Dabrowski, K. & Portella, M.C. 2008. Effects of different dietary lipid sources on the survival, growth, and fatty acid composition of South American catfish, *Pseudoplatystoma fasciatum*, Surubim, juveniles. *Journal of the World Aquaculture Society*, 39 (1): 51–61.
- Arzel, J., Regost, C. & Kauskik, S.J. 1999. Incorporation of plant protein sources in fish diet. (INRA-Ifremer Workshop on Fish Nutrition, Brest, 9–10 March 1999. Collected papers). Journées nutrition des poissons INRA-Ifremer, Brest, 9–10 March 1999. Recueil des communications. 5 pp. 1999.
- Asturiano, J.F., Sorbera, L. A., Carrillo, M., Zanuy, S., Ramos, J., Navarro, J.C. & Bromage, N. 2001. Reproductive performance in male European sea bass (*Dicentrarchus labrax*, L.) fed two PUFA-enriched experimental diets: a comparison with males fed a wet diet. *Aquaculture*, 194 (1–2): 173–190.
- Atalah, E., Cruz, C.M.H., Izquierdo, M.S., Rosenlund, G., Caballero, M.J. Valencia, A. & Robaina, L. 2007. Two microalgae *Cryptocodinium cohnii* and *Phaeodactylum tricornutum* as alternative source of essential fatty acids in starter feeds for seabream (*Sparus aurata*). *Aquaculture*, 270 (1–4): 178–185.
- Ayinla, O.A. 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in Nigeria, pp. 453–470. In: M.R. Hasan, T. Hecht, S.S. De Silva and A.G.J Tacon (eds). Study and analysis of feeds and fertilizers for sustainable aquaculture development. *FAO Fisheries Technical Paper No. 497*. Rome. 510 pp.
- Ayyappan, S. & Ahamad Ali, S. 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in India, pp. 191–219. In: M.R. Hasan, T. Hecht, S.S. De Silva and A.G.J Tacon (eds). Study and analysis of feeds and fertilizers for sustainable aquaculture development. *FAO Fisheries Technical Paper No. 497*. Rome. 510 pp.
- Azaza, M.S., Mensi, F., Imorou Toko, I., Dhraief, M.N., Abdelmouleh, A., Brini, B. & Kraiem, M.M. 2006. Effects of incorporation of dietary tomato feedstuff on nutrition of Nile tilapia (*Oreochromis niloticus*, L., 1758) reared in geothermal waters in southern Tunisia. *Bulletin de l'Institut National des Sciences et Technologies de la Mer*, 33: 47–58.
- Azaza, M.S., Wassim, K., Mensi, F., Abdelmouleh, A., Brini, B. & Kraiem, M.M. 2009a. Evaluation of faba beans (*Vicia faba* L. var. minuta) as a replacement for soybean meal in practical diets of juvenile Nile tilapia *Oreochromis niloticus*. *Aquaculture*, 287 (1–2): 174–179.
- Azaza, M.S., Wassim, K., Mensi, F., Abdelmouleh, A., Brini, B. & Kraiem, M.M. 2009b. Nutritional evaluation of waste date fruit as partial substitute for soybean meal in practical diets of juvenile Nile tilapia *Oreochromis niloticus* L. *Aquaculture Nutrition*, 15: 262–272.
- Azim, M.E. 2005. Periphyton: ecology, exploitation and management. CABI Publishing Series, 319 p.
- Babalola, T.O.O., Adebayo, M.A., Apata, D.F. & Omotosho, J.S. 2009. Effect of dietary alternative lipid sources on haematological parameters and serum constituents of *Heterobranchius longifilis* fingerlings. *Tropical Animal Health and Production*, 41 (3): 371–377.
- Bagni, M., Archetti, L., Amadori, M. & Marino, G. 2000. Effect of long-term oral administration of an immunostimulant diet on innate immunity in sea bass (*Dicentrarchus labrax*). *Journal of Veterinary Medicine Series B-Infectious Diseases and Veterinary Public Health*, 47 (10): 745–751.
- Bahuaud, D., Ostbye, T. K., Torstensen, B.E., Rora, M.B., Ofstad, R., Veiseth, E., Thomassen, M.S. & Ruyter, B. 2009. Atlantic salmon (*Salmo salar*) muscle structure integrity and lysosomal cathepsins B and L influenced by dietary n-6 and n-3 fatty acids. *Food Chemistry*, 114 (4): 1421–1432.
- Bahurmiz, O.M. & Ng, W.K. 2007. Effects of dietary palm oil source on growth, tissue fatty acid composition and nutrient digestibility of red hybrid tilapia, *Oreochromis* sp., raised from stocking to marketable size. *Aquaculture*, 262: 382–392.
- Bai, S., Jang, H.K. & Cho, E.S. 1998. Possible use of the animal by-product mixture as a dietary fish meal replacer in growing common carp (*Cyprinus carpio*). *Journal of the Korean Fisheries Society*, 31 (3): 380–385.
- Bai, S.C., Wang, X.J. & Shin, I.S. 2005. Dietary dehulled soybean meal as a replacement for fishmeal in fingerling and larger Olive Flounder, *Paralichthys olivaceus*. *World Aquaculture*, 36 (1): 14–16.
- Bai, S.C., Choi, S., Kim, K. & Wang, X.J. 2001. Apparent protein and phosphorus digestibilities of five different dietary protein sources in Korean rockfish, *Sebastes schlegeli* (Hilgendorf). *Aquaculture Research*, 32 (s1): 99–105.
- Baillet, C., Cuzon, G., Cousin, M., & Kerleguer, C. 1997. Effect of dietary protein levels on growth of *Penaeus stylirostris* juveniles. *Aquaculture Nutrition*, 3: 49–53.
- Bairagi, A., Ghosh, K. S., Sen, S.K. & Ray, A.K. 2002. Duckweed (*Lemna polyrhiza*) leaf meal as a source of feedstuff in formulated diets for rohu (*Labeo rohita* Ham.) fingerlings after fermentation with a fish intestinal bacterium. *Bioresource Technology*, 85 (1):17–24.
- Bairagi, A., Ghosh, K.S., Sen, S.K. & Ray, A.K. 2004. Evaluation of the nutritive value of *Leucaena leucocephala* leaf meal, inoculated with fish intestinal bacteria *Bacillus subtilis* and *Bacillus circulans* in formulated diets for rohu, *Labeo rohita* (Hamilton) fingerlings. *Aquaculture Research* 35 (5): 436–446.
- Baker, R.T.M., Martin, P. & Davies, S.J. 1997. Ingestion of sub-lethal levels of iron sulphate by African catfish affects growth and tissue lipid peroxidation. *Aquatic Toxicology*, 40 (1): 51–61.
- Bakke-McKellep, A.M., Press, C.M., Baeverfjord, G., Krogdahl, A. & Landsverk, T. 2000. Changes in immune and enzyme histochemical phenotypes of cells in the intestinal mucosa of Atlantic salmon, *Salmo salar* L., with soybean meal-induced enteritis. *Journal of Fish Diseases*, 23 (2):115–127.
- Bakke-McKellep, A.M., Refstie, S., Stefanou, S.O., Vanthanoovong, V., Roomans, G., Hemre, G.I. & Krogdahl, A. 2006. Effects of dietary soybean meal and photoperiod cycle on osmoregulation following seawater exposure in Atlantic salmon smolts. *Journal of Fish Biology*, 69 (5): 1396–1426.
- Balamurali, R.S. & Aravindan, C.M. 1997. Citric acid as a feed stimulant. *Soc.Fish. Technol.* 34 (1): 9–12.

- Ballestrazzi, R. & Lanari, D. 1996. Growth, body composition and nutrient retention efficiency of growing sea bass (*Dicentrarchus labrax* L.) fed fish oil or fatty acid Ca salts. *Aquaculture*, 139 (1–2): 101–108.
- Ballestrazzi, R., Rainis, S., Tulli, F. & Bracelli, A. 2003. The effect of dietary coconut oil on reproductive traits and egg fatty acid composition in rainbow trout (*Oncorhynchus mykiss*). *Aquaculture International*, 11 (3): 289–299.
- Ballestrazzi, R., Rainis, S. & Maxia, M. 2006. The replacement of fish oil with refined coconut oil in the diet of large rainbow trout (*Oncorhynchus mykiss*). *Italian Journal of Animal Science*, 5 (2): 155–164.
- Balogun, A.M. & Fagbenro, O.A. 1995. Use of macadamia presscake as a protein feedstuff in practical diets for tilapia, *Oreochromis niloticus* (L.). *Aquaculture Research*, 26 (6): 371–377.
- Balogun, A.M., Fasakin, E.A. & Owolanke, D. 1997. Evaluation of fish silage soybean meal blends as protein feedstuff for *Clarias gariepinus* (Burchell, 1822) fingerlings. *Journal of Applied Animal Research*, 11 (2): 129–136.
- Barbarito, J. 2007. Micro algae, pp. 194–203. In: T.G. Galano, H. Villarreal-Colmenares and J.L. Fenucci (eds), *Manual de ingredientes proteicos y aditivos empleados en la formulacion de alimentos balanceados para camarones peneidos*. Subprograma II “Acuicultura” Red Tematica II.C, Proyecto II-8 Ciencia y Tecnologia El Desarrollo (CYTED). Universidad Nacional de Mar del Plata, Argentina, 264 pp.
- Barman, B.K. & Karim, M. 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in Bangladesh, pp. 113–140. In: M.R. Hasan, T. Hecht, S.S. De Silva and A.G.J Tacon (eds). Study and analysis of feeds and fertilizers for sustainable aquaculture development. *FAO Fisheries Technical Paper* No. 497. Rome. 510 pp.
- Barnes, M.E., Durben, D.J., Reeves, S.G. & Sanders, R. 2006. Dietary yeast culture supplementation improves initial rearing of McConaughy strain rainbow trout. *Aquaculture Nutrition*, 12 (5): 388–394.
- Barrias, C. & Oliva-Teles, A. 2000. The use of locally produced fish meal and other dietary manipulations in practical diets for rainbow trout *Oncorhynchus mykiss* (Walbaum). *Aquaculture Research* 31 (2): 213–218.
- Barros, M.M., Lim, C., Evans, J. J. & Klesius, P.H. 2000. Effect of iron supplementation to cottonseed meal diets on the growth performance of Channel Catfish, *Ictalurus punctatus*. *Journal of Applied Aquaculture*, 10 (1): 65–86.
- Barros, M.M., Lim, C. & Klesius, P.H. 2002. Effect of soybean meal replacement by cottonseed meal and iron supplementation on growth, immune response and resistance of Channel Catfish (*Ictalurus punctatus*) to *Edwardsiella ictaluri* challenge. *Aquaculture*, 207 (3–4): 263–279.
- Barros, M.M., Pezzato, L.E., Miranda, E.C., Carmo e Sa, M.V. & Sampaio, F.G. 2004. Zinc-amino acid complex in practical diets for Nile tilapia (*Oreochromis niloticus*). *Acta Scientiarum*, 26 (4): 437–441.
- Barrows, F.T. & Hardy, R.W. 2000. Feed additives, pp. 335–340. In: R.R. Stickney (ed.). *The Encyclopedia of Aquaculture*. New York, John Wiley & Sons Inc. 1063 pp.
- Barrows, F.T., Stone, D.A.J. & Hardy, R.W. 2007. The effects of extrusion conditions on the nutritional value of soybean meal for rainbow trout (*Oncorhynchus mykiss*). *Aquaculture*, 265 (1–4): 244–252.
- Barrows, F.T., Gaylord, T.G., Sealey, W.M., Haas, M.J. & Stroup, R.L. 2008. Processing soybean meal for biodiesel production; effect of a new processing method on growth performance of rainbow trout, *Oncorhynchus mykiss*. *Aquaculture*, 283 (1–4): 141–147.
- Baruah, K., Pal, A.K., Sahu, N. P., Jain, K.K., Mukherjee, S.C. & Debnath, D. 2005. Dietary protein level, microbial phytase, citric acid and their interactions on bone mineralization of *Labeo rohita* (Hamilton) juveniles. *Aquaculture Research*, 36 (8): 803–812.
- Baruah, K., Sahu, N.P., Pal, A.K., Jain, K.K., Debnath, D. & Mukherjee, S.C. 2007. Dietary microbial phytase and citric acid synergistically enhances nutrient digestibility and growth performance of *Labeo rohita* (Hamilton) juveniles at sub-optimal protein level. *Aquaculture Research*, 38 (2): 109–120.
- Basudham, C. & Vishwanath, W. 1997. Formulated feed based on aquatic weed Azolla and fish meal for rearing medium carp *Osteobrama belangeri* (Valenciennes). *Journal of Aquaculture in the Tropics*, 12 (3): 155–164.
- Basuyaux, O. & Blin, J.L. 1998. Use of maize as a food source for sea urchins in a recirculating rearing system. *Aquaculture International*, 6 (3): 233–247.
- Bates, L.S., Akiyama, D.M. & Shing, L.R. 1995. *Aquaculture Feed Microscopy Manual*. Singapore, American Soybean Association. 49 pp.
- Bautista, E.O., Useche, M., Pérez, P.F.M. & Linares, F. 1999. Utilización de la pulpa de café ensilada y deshidratada en la alimentación de cachaway (*Colossoma x Piaractus*). In: J.R. Ramirez Martinez (ed.), *Pulpa de café ensilada. Producción, caracterización y utilización en alimentación animal*. San Cristóbal, Estado Táchira, Venezuela, Universidad Nacional Experimental del Táchira (UNET). pp. 109–135.
- Bautista-Teruel, M.N. & Subosa, P.F. 1999. Butylated hydroxytoluene: its effect on the quality of shrimp diet stored at various temperatures and on growth and survival of *Penaeus monodon* juveniles. *Aquaculture*, 179 (1–4): 403–414.
- Bautista-Teruel, M.N., Eusebio, P.S. & Welsh, T.P. 2003a. Utilization of feed pea, *Pisum sativum*, meal as a protein source in practical diets for juvenile tiger shrimp, *Penaeus monodon*. *Aquaculture*, 255: 121–131.
- Bautista-Teruel, M.N., Fermin, A.C. & Koshio, S.S. 2003b. Diet development and evaluation for juvenile abalone, *Haliotis asinina*: animal and plant protein sources. *Aquaculture*, 219 (1–4): 645–653.
- Bautista, E.O., Pernia, J., Barrueta, D. & Useche, M. 2005. Use of ecological coffee pulp silage in feeding for cachamay fingerlings (*Colossoma macropomus x Piaractus brachypomus*). *Revista Científica – Facultad De Ciencias Veterinarias*, 15 (1): 33–40.
- Belal, I. 2004. Replacement of corn with mangrove seeds in bluespot mullet *Valamugil seheli* diets. *Aquaculture Nutrition*, 10 (1): 25–30.

- Belal, I.E.H. 2008. Evaluating fungi-degraded date pits as a feed ingredient for Nile tilapia *Oreochromis niloticus* L. *Aquaculture Nutrition*, 14 (5): 445–452.
- Belal, I.E.H. & Assem, H. 1995. Substitution of soybean meal and oil for fish meal in practical diets fed to channel catfish, *Ictalurus punctatus* (Rafinesque): Effects on body composition. *Aquaculture Research*, 26 (2): 141–145.
- Belal, I.E.H. & Al Jasser, M.S. 1997. Replacing dietary starch with pitted date fruit in Nile tilapia *Oreochromis niloticus* (L) feed. *Aquaculture Research*, 28 (6): 385–389.
- Belal, I.E.H. & Al-Dosari, M. 1999. Replacement of fish meal with Salicornia meal in feeds for Nile tilapia *Oreochromis niloticus*. *Journal of the World Aquaculture Society*, 30 (2): 285–289.
- Belal, I.E.H., Al-Owaifeir, A. & Al-Dosari, M. 1995. Replacing fish meal with chicken offal silage in commercial *Oreochromis niloticus* (L.) feed. *Aquaculture Research* 26 (11): 855–858.
- Belay, A., Kato, T. & Ota, Y. 1996. Spirulina (Arthrospira): Potential application as an animal feed supplement. *J. Appl. Phycol.*, 8: 303–311.
- Bell, J.G., Farndale, B.M., Dick, J.R. & Sargent, J.R. 1996. Modification of membrane fatty acid composition, eicosanoid production, and phospholipase A activity in Atlantic salmon (*Salmo salar*) gill and kidney by dietary lipid. *Lipids*, 31 (11): 1163–1171.
- Bell, J.G., Farndale, B.M., Bruce, M.P., Navas, J.M. & Carillo, M. 1997. Effects of broodstock dietary lipid on fatty acid compositions of eggs from sea bass (*Dicentrarchus labrax*). *Aquaculture*, 149 (1–2): 107–119.
- Bell, J.G., McEvoy, J., Tocher, D.R., McGhee, F., Campbell, P.J. & Sargent, J.R. 2001. Replacement of fish oil with rape seed oil in diets of Atlantic salmon (*Salmo salar*) affects tissue lipid compositions and hepatocyte fatty acid metabolism. *The Journal of Nutrition*, 131: 1535–1543.
- Bell, J.G., Henderson, R.J., Tocher, D.R., McGhee, F., Dick, J.R. & Porter, A. 2002. Substituting fish oil with crude palm oil in the diet of Atlantic salmon (*Salmo salar*) affects muscle fatty acid composition and hepatic fatty acid metabolism. *The Journal of Nutrition*, 132: 222–230.
- Bell, J.G., McGhee, F., Campbell, P.J. & Sargent, J.R. 2003a. Rapeseed oil as an alternative to marine fish oil in diets of post-smolt Atlantic salmon (*Salmo salar*): changes in flesh fatty acid composition and effectiveness of subsequent fish oil “wash out”. *Aquaculture*, 218: 515–528.
- Bell, J.G., Tocher, D.R., Henderson, R.J., Dick, J.R. & Crampton, V.O. 2003b. Altered fatty acid compositions in Atlantic salmon (*Salmo salar*) fed diets containing linseed and rapeseed oils can be partially restored by a subsequent fish oil finishing diet. *The Journal of Nutrition*, 133: 2793–2801.
- Bell, J.G., Henderson, R.J., Tocher, D.R., Sargent, J.R. 2004. Replacement of dietary fish oil with increasing levels of linseed oil: modification of flesh fatty acid composition in Atlantic salmon (*Salmo salar*) using a fish oil finishing diet. *Lipids*, 39: 223–232.
- Bell, J.G., Strachan, F., Good, J.E., Tocher, D.R. 2006. Effect of dietary echium oil on growth, fatty acid composition and metabolism, gill prostaglandin production and macrophage activity in Atlantic cod (*Gadus morhua* L.). *Aquaculture Research*, 37: 606–617.
- Bendiksen, E.A., Berg, O.K., Jobling, M., Arnesen, A.M. & Masoval, K. 2003. Digestibility, growth and nutrient utilisation of Atlantic salmon parr (*Salmo salar* L.) in relation to temperature, feed fat content and oil source. *Aquaculture*, 224 (1–4): 283–299.
- Benedito-Palos, L., Saera-Vila, A., Calduch-Giner, J.A., Kaushik, S. & Perez-Sanchez, J. 2007. Combined replacement of fish meal and oil in practical diets for fast growing juveniles of gilthead sea bream (*Sparus aurata* L.): Networking of systemic and local components of GH/IGF axis. *Aquaculture*, 267 (1–4): 199–212.
- Benedito-Palos, L., Navarro, J.C., Sitja-Bobadilla, A., Bell, J.G., Kaushik, S. & Perez-Sanchez, J. 2008. High levels of vegetable oils in plant protein-rich diets fed to gilthead sea bream (*Sparus aurata* L.): growth performance, muscle fatty acid profiles and histological alterations of target tissues. *British Journal of Nutrition*, 100 (5): 992–1003.
- Benzie, I.F.F. 2003. Evolution of dietary antioxidants. *Comparative Biochemistry and Physiology – Part A: Molecular and Integrative Physiology*, 136 (1): 113–126.
- Berdikova Bohne, V.J., Hamre, K. & Arukwe, A. 2007. Hepatic metabolism, phase I and II biotransformation enzymes in Atlantic salmon (*Salmo salar*, L) during a 12 week feeding period with graded levels of the synthetic antioxidant, ethoxyquin. *Food and Chemical Toxicology*, 45 (5): 733–746.
- Berge, G.M., Grisdale-Helland, B., & Helland, S.J. 1999. Soy protein concentrate in diets for Atlantic halibut (*Hippoglossus hippoglossus*). *Aquaculture*, 178 (1–2): 139–148.
- Berge, G.M., Baeverfjord, G., Skrede, A. & Storebakken, T. 2005. Bacterial protein grown on natural gas as protein source in diets for Atlantic salmon, *Salmo salar*, in saltwater. *Aquaculture*, 244(1–4): 233–240.
- Bergheim, A. 2001. Recycling and utilization of aquaculture by-products. *Fish Farmer*, 24 (1): 35
- Bergheim, A. & Sveier, H. 1995. Replacement of fish meal in salmonid diets by soya meal reduces phosphorus excretion. *Aquaculture International*, 3 (3): 265–268.
- Bergmeyer, H.U. 1965. *Methods of enzymatic analysis*. New York, NY, USA, Academic Press, 555 pp.
- Berntssen, M.H.G. & Lundebye, A.K. 2008. Environmental contaminants in farmed fish and potential consequences for seafood safety, pp. 39–70. In: Ø Lie (ed.), *Improving farmed fish quality and safety*. Cambridge, UK, Woodhead Publishing Limited. 500 pp.
- Berntssen, M.H.G., Aatland, A. & Handy, R.D. 2003. Chronic dietary mercury exposure causes oxidative stress, brain lesions, and altered behaviour in Atlantic salmon (*Salmo salar*) parr. *Aquatic Toxicology*, 65 (1): 55–72.
- Berntssen, M.H.G., Hylland, K., Julshamn, K., Lundebye, A.K. & Waagbo, R. 2004. Maximum limits of organic and inorganic mercury in fish feed. *Aquaculture Nutrition*, 10 (2): 83–97.

- Berntssen, M.H.G., Lundebye, A.K. & Torstensen, B.E. 2005. Reducing the levels of dioxins and dioxin-like PCBs in farmed Atlantic salmon by substitution of fish oil with vegetable oil in the feed. *Aquaculture Nutrition*, 11 (3): 219–231.
- Berntssen, M.H., Giskegjerde, T.A., Rosenlund, G., Torstensen, B.E. & Lundebye, A.K. 2007. Predicting World Health Organization toxic equivalency factor dioxin and dioxin-like polychlorinated biphenyl levels in farmed Atlantic salmon (*Salmo salar*) based on known levels in feed. *Environ. Toxicol. Chem.*, 26 (1): 13–23.
- Berntssen, M.H.G., Glover, C.N., Robb, D.H.F., Jakobsen, J.-V. & Petri, D. 2008. Accumulation and elimination kinetics of dietary endosulfan in Atlantic salmon (*Salmo salar*). *Aquatic Toxicology*, 86 (1): 104–111.
- Bhakta, J.N., Sarkar, D., Jana, S. & Jana, B.B. 2004. Optimizing fertilizer dose for rearing stage production of carps under polyculture. *Aquaculture*, 239: 125–39
- Bhakta, J.N., Bandyopadhyay, P.K. & Jana, B.B. 2006. Effect of different doses of mixed fertilizer on some biogeochemical cycling bacterial population in carp culture pond. *Turkish Journal of Fisheries and Aquatic Sciences*, 6:16
- Bharadwaj, A.S., Brignon, W.R., Gould, N.L., Brown, P.B. & Wu, Y.V. 2002. Evaluation of meat and bone meal in practical diets fed to juvenile hybrid striped bass *Morone chrysops* x *M. saxatilis*. *Journal of the World Aquaculture Society*, 33 (4): 448–457.
- Bhat, R.V. & Vasanthi, S. 1999. *Mycotoxin contamination of foods and feeds*. MYC-CONF/99/4a. Third Joint FAO/WHO/UNEP International Conference on Mycotoxins, 3–6 March 1999, Tunis, Tunisia. FAO, World Health Organization (WHO) and United Nations Environment Programme (UNEP).
- Bilgin, O., Turker, A. & Tekinay, A.A. 2007. The use of hazelnut meal as a substitute for soybean meal in the diets of rainbow trout (*Oncorhynchus mykiss*). *Turkish Journal of Veterinary and Animal Sciences*, 31 (3): 145–151.
- Bimbo, A.P. 2009. *Alaska seafood by-products: potential products, markets and competing products (revised 2008)*. Report prepared for the Alaska Fisheries Development Foundation, Anchorage, Alaska, January 8, 2009 (www.afdf.org/past_research/2008_by_product_mkt_study.pdf).
- Binder, E.M., Tan, L.M., Chin, L.J., Handl, J. & Richard, J. 2007. Worldwide occurrence of mycotoxins in commodities, feeds and feed ingredients. *Journal of Feed Science and Technology*, 137: 265–282.
- Bindu, M.S. & Sobha, V. 2004. Conversion efficiency and nutrient digestibility of certain seaweed diets by laboratory reared *Labeo rohita* (Hamilton). *Indian Journal of Experimental Biology*, 42 (12): 1239–1244.
- Bintvihok, A., Ponpornpisit, A., Tangtrongpiros, J., Panichkriangkrai, W., Rattanapanee, R., Doi K. & Kumagai, S. 2003. Aflatoxin contamination in shrimp feed and effects of aflatoxin addition to feed on shrimp production. *J. Food Prot.* 66, 882–885.
- Bishop, C.D., Angus, R.A. & Watts, S.A. 1995. The use of feather meal as a replacement for fish meal in the diet of *Oreochromis niloticus* fry. *Bioresource Technology*, 54 (3): 291–295.
- Biswas, A.K., Kaku, H., Ji, S.C., Seoka, M. & Takii, K. 2007. Use of soybean meal and phytase for partial replacement of fish meal in the diet of red sea bream, *Pagrus major*. *Aquaculture*, 267 (1–4): 284–291.
- Biswas, P., Pal, A.K., Sahu, N.P., Reddy, A.K., Prusty, A.K. & Misra, S. 2007b. Lysine and/or phytase supplementation in the diet of *Penaeus monodon* (Fabricius) juveniles: Effect on growth, body composition and lipid profile. *Aquaculture*, 265 (1–4): 253–260.
- Bjerkeng, B., Refstie, S., Fjalestad, K.T., Storebakken, T., Roedbotten, M. & Roem, A.J. 1997. Quality parameters of the flesh of Atlantic salmon (*Salmo salar*) as affected by dietary fat content and full-fat soybean meal as a partial substitute for fish meal in the diet. *Aquaculture*, 157 (3–4): 295–307.
- Bligh, E.G. & Dyer, W.J. 1959. A rapid method of total lipid extraction and purification. *Canadian Journal of Biochemistry and Physiology*, 37: 911–917.
- Blom, J.H., Lee, K.J., Rinchar, J., Dabrowski, K. & Ottobre, J. 2001. Reproductive efficiency and maternal-offspring transfer of gossypol in rainbow trout (*Oncorhynchus mykiss*) fed diets containing cottonseed meal. *Journal of Animal Science*, 79 (6): 1533–1539.
- Bolasina, S.N. & Fenucci, J.L. 2005. Apparent digestibility of crude protein and lipids in Brazilian codling, *Urophycis brasiliensis* (Kamp, 1858) (Pisces: Gadiformes), fed with partial replacements of soybean meal and meat meal diets. *Revista de Biologia Marina y Oceanografía*, 40 (2): 127–131.
- Bombeo-Tuburan, I., Fukumoto, S. & Rodriguez, E.M. 1995. Use of the golden apple snail, cassava and maize as feeds for the tiger shrimp, *Penaeus monodon*, in ponds. *Aquaculture*, 131 (1–2): 91–100.
- Bonaldo, A., Roem, A.J., Pecchini, A., Grilli, E. & Gatta, P.P. 2006. Influence of dietary soybean meal levels on growth, feed utilization and gut histology of Egyptian sole (*Solea aegyptiaca*) juveniles. *Aquaculture*, 261 (2): 580–586.
- Bonaldo, A., Roem, A.J., Fagioli, P., Pecchini, A., Cipollini, I. & Gatta, P.P. 2008. Influence of dietary levels of soybean meal on the performance and gut histology of gilthead sea bream (*Sparus aurata* L.) and European sea bass (*Dicentrarchus labrax* L.). *Aquaculture Research*, 39 (9): 970–978.
- Boonyaratpalin, M., Suraneiranat, P. & Tumpibal, T. 1998. Replacement of fish meal with various types of soybean products in diets for the Asian seabass, *Lates calcarifer*. *Aquaculture*, 161: 67–78.
- Boonyaratpalin, M., Supamattaya, K., Verakunpiriya, V. & Suprasert, D. 2001. Effects of aflatoxin B1 on growth performance, blood components, immune function and histopathological changes in black tiger shrimp (*Penaeus monodon* Fabricius). *Aquaculture Research*, 32 (suppl. 1): 388–398.
- Booth, M.A., Allan, G.L., Frances, J. & Parkinson, S. 2001. Replacement of fish meal in diets for Australian silver perch, *Bidyanus bidyanus* IV. Effects of dehulling and protein concentration on digestibility of grain legumes. *Aquaculture*, 196 (1–2): 67–85.

- Borgeson, T.L., Racz, V.J., Wilkie, D.C., White, L.J. & Drew, M.D. 2006. Effect of replacing fishmeal and oil with simple or complex mixtures of vegetable ingredients in diets fed to Nile tilapia (*Oreochromis niloticus*). *Aquaculture Nutrition*, 12 (2): 141–149.
- Borghesi, R., Portz, L., Oetterer, M & Cyrino, J.E.P. 2008. Apparent digestibility coefficient of protein and amino acids of acid, biological and enzymatic silage for Nile tilapia (*Oreochromis niloticus*). *Aquaculture Nutrition*, 14 (3): 242–248.
- Borlongan, I.G., Eusebio, P.S. & Welsh, T. 2003. Potential of feed pea (*Pisum sativum*) meal as a protein source in practical diets for milkfish (*Chanos chanos* Forsskal). *Aquaculture*, 225: 89–98.
- Borquez, A. & Cerqueira, V.R. 1998. Feeding behavior in juvenile snook, *Centropomus undecimalis* - I. Individual effect of some chemical substances. *Aquaculture*, 169 (1–2): 25–35.
- Boscolo, W.R., Hayashi, C., Meurer, F., Feiden, A. & Bombardelli, R.A. 2004. Apparent digestibility of energy and protein of tilapia (*Oreochromis niloticus*) and corvina (*Plagioscion squamosissimus*) by-product meal, and canela crayfish (*Macrobrachium amazonicum*) meal for Nile tilapia. *Revista Brasileira De Zootecnia – Brazilian Journal of Animal Science*, 33 (1): 8–13.
- Boscolo, W.R., Hayashi, C., Meurer, F., Feiden, A., Bombardelli, R.A. & Reidel, A. 2005a. Effects of feeding tilapia filleting by-product meal for Nile tilapia (*Oreochromis niloticus* L.) during the sexual reversion phase. *Revista Brasileira De Zootecnia – Brazilian Journal of Animal Science*, 34 (6): 1807–1812.
- Boscolo, W.R., Meurer, F., Feiden, A., Hayashi, C., Reidel, A. & Genteline, A.L. 2005b. Poultry meal by-products in diets for Nile tilapia (*Oreochromis niloticus* L.) in the reversion phase. *Revista Brasileira De Zootecnia – Brazilian Journal of Animal Science*, 34 (2): 373–377.
- Bouda, S. & Chien, Y.H. 2005. Effects of blood meal inclusion levels in rice bran based diets on the palatability, growth, and feed utilization of juvenile tilapia (*Oreochromis mossambicus*). *Journal of the Fisheries Society of Taiwan*, 32 (3): 207–215.
- Bowman, J.R. 1998. A review of lime requirement determination methods for aquaculture ponds, p. 195. In: L. Coetzee, J. Gon and C. Kulongowski (eds), *African Fishes and Fisheries Diversity and Utilisation. Poissons et Peches Africains Diversite et Utilisation*. International Conference for the Paradi Association and The Fisheries Society of Africa, Grahamstown, South Africa, 13–18 Sept 1998. Grahamstown, South Africa, FISA/PARADI.
- Boyd, C.E. 1979. *Water quality in warmwater fish ponds*. Opelika, AL, USA. Auburn University, Craftmaster Printers Inc. 359 pp.
- Boyd, C.E. & Tucker, C.S. 1998. *Pond aquaculture water quality management*. Chapman & Hall Aquaculture Series, 700 pp.
- Braga, L.G.T., Borghesi, R. & Cyrino, J.E.P. 2008. Apparent digestibility of ingredients in diets for *Salminus brasiliensis*. *Pesquisa Agropecuaria Brasileira*, 43 (2): 271–274.
- Bransden, M.P. & Carter, C.G. 1999. Effect of processing soybean meal on the apparent digestibility of practical diets for the greenback flounder *Rhombosolea tapirina* (Gunther). *Aquaculture Research*, 30 (9): 719–723.
- Bransden, M.P., Carter, C.G. & Nichols, P.D. 2003. Replacement of fish oil with sunflower oil in feeds for Atlantic salmon (*Salmo salar* L.): effect on growth performance, tissue fatty acid composition and disease resistance. *Comparative Biochemistry and Physiology*, Part B 135: 611–625.
- Breck, O., Bjerkas, E., Campbell, P., Arnesen, P., Haldorsen, P. & Waagbo, R. 2003. Cataract preventative role of mammalian blood meal, histidine, iron and zinc in diets for Atlantic salmon (*Salmo salar* L.) of different strains. *Aquaculture Nutrition*, 9 (5): 341–350.
- Brinker, A., Koppe, W. & Bosch, R. 2005. Optimised effluent treatment by stabilised trout faeces. *Aquaculture*, 249 (1–4): 125–144.
- Brinker, A. 2007. Guar gum in rainbow trout (*Oncorhynchus mykiss*) feed: the influence of quality and dose on stabilisation of faecal solids. *Aquaculture*, 267: 315–327.
- Britz, P.J. 1996. The suitability of selected protein sources for inclusion in formulated diets for the South African abalone, *Haliotis midae*. *Aquaculture*, 140 (1–2): 63–73.
- Broughton, W.J. 1970. Determination of total nucleic acids in plant tissue. *Analytical Biochemistry*, 38 (1): 291–295.
- Browdy, C., Seaborn, G., Atwood, H., Davis, D.A., Bullis, R.A. & Wirth, E. 2006. Comparison of pond production efficiency, fatty acid profiles, and contaminants in *Litopenaus vannamei* fed organic plant-based and fish-meal based diets. *Journal of the World Aquaculture Society*, 37: 437–447.
- Brown, P.B., Strange, R.J. & Robbins, K.R. 1985. Protein digestibility coefficients for yearling channel catfish fed high protein feedstuffs. *Progressive Fish-Culturist*, 47 (2): 94–97.
- Brown, P.B., Wilson, K.A., Hodgins, Y. & Stanley, J.D. 1997. Use of soy protein concentrates and lecithin products in diets fed to coho and Atlantic salmon. *Journal of the American Oil Chemists Society*, 74 (3): 187–193.
- Brown, P.B., Twibell, R., Jonker, Y. & Wilson, K.A. 1997b. Evaluation of three soybean products in diets fed to juvenile hybrid striped bass *Morone saxatilis* x *M. chrysops*. *Journal of the World Aquaculture Society*, 28 (3): 215–223.
- Brown, P.B., Wilson, K.A., Jonker, Y. & Nickson, T.E. 2003. Glyphosate tolerant canola meal is equivalent to the parental line in diets fed to rainbow trout. *Journal of Agricultural and Food Chemistry*, 51 (15): 4268–4272.
- Brunson, J.F., Romaine, R.P. & Reigh, R.C. 1997. Apparent digestibility of selected ingredients in diets for white shrimp *Penaeus setiferus* L. *Aquaculture Nutrition*, 3 (1): 9–16.
- Buchanan, J., Sarac, H.Z., Poppi, D. & Cowan, R.T. 1997. Effects of enzyme addition to canola meal in prawn diets. *Aquaculture*, 151 (1–4): 29–35.

- Bureau, D.P. 2006. Rendered products in fish aquaculture feeds, pp. 179–194. In: D.L. Meeker (ed.), *Essential Rendering – All about the animal by-products industry*. Arlington, Virginia, USA, National Renderers Association. Kirby Lithographic Company, Inc.
- Bureau, D., & Gibson, J. 2004. Animal fats as aquaculture feed ingredients: nutritive value, product quality and safety. *Aquafeed International*, 7:32–37.
- Bureau, D.P., De La Noue, J. & Jaruratjamorn, P. 1995. Effect of dietary incorporation of crop residues on growth, mortality and feed conversion ratio of the African catfish, *Clarias gariepinus* (Burchell). *Aquaculture Research*, 26 (5): 351–360.
- Bureau, D.P., Harris, A. M. & Cho, C.Y. 1998. The effects of purified alcohol extracts from soy products on feed intake and growth of chinook salmon (*Oncorhynchus tshawytscha*) and rainbow trout (*Oncorhynchus mykiss*). *Aquaculture*, 161 (1–4):27–43.
- Bureau, D.P., Harris, A.M. & Cho, C.Y. 1999. Apparent digestibility of rendered animal protein ingredients for rainbow trout (*Oncorhynchus mykiss*). *Aquaculture*, 180 (3–4): 345–358.
- Bureau, D.P., Harris, A.M., Bevan, D.J., Simmons, L.A., Azevedo, P.A. & Cho, C.Y. 2000. Feather meals and meat and bone meals from different origins as protein sources in rainbow trout (*Oncorhynchus mykiss*) diets. *Aquaculture*, 181 (3–4): 281–291.
- Bureau, D.P., Gibson, J. & El-Mowafi, A. 2002. Review: use of animal fats in aquaculture feeds. In: L.E. Cruz-Suarez, D. Ricque-Marie, M. Tapia-Salazar, M.G. Gaxiola-Corte's and N. Simoes (eds), *Avances en Nutricion Acuicola VI. Memorias del VI Simposium Internacional de Nutricion Acuicola*, 3–7 Sep 2002, Cancun, Quintana Roo, Mexico.
- Bureau, D.P., Hua, K. & Harris, A.M. 2008. The effect of dietary lipid and long-chain n-3 PUFA levels on growth, energy utilization, carcass quality, and immune function of rainbow trout, *Oncorhynchus mykiss*. *Journal of the World Aquaculture Society*, 39 (1):1–21.
- Burel, C., Boujard, T., Corraze, G., Kaushik, S.J., Boeuf, G., Mol, K.A., Van der Geyten, S. & Kuhn, E.R. 1998. Incorporation of high levels of extruded lupin in diets for rainbow trout (*Oncorhynchus mykiss*): nutritional value and effect on thyroid status. *Aquaculture*, 163 (3–4): 325–345.
- Burel, C., Boujard, T., Tulli, F. & Kaushik, S.J. 2000. Digestibility of extruded peas, extruded lupin, and rapeseed meal in rainbow trout (*Oncorhynchus mykiss*) and turbot (*Psetta maxima*). *Aquaculture*, 188 (3–4): 285–298.
- Burel, C., Boujard, T., Kaushik, S.J., Boeuf, G., Mol, K.A., Van der Geyten, S., Darras, V.M., Kuhn, E.R., Pradet-Balade, B., Querat, B., Quinsac, A., Krouti, M. & Ribailier, D. 2001. Effects of rapeseed meal-glucosinolates on thyroid metabolism and feed utilization in rainbow trout. *General and Comparative Endocrinology*, 124 (3): 343–358.
- Burford, M.A. & Pearson, D.C. 1998. Effect of different nitrogen sources on phytoplankton composition in aquaculture ponds. *Aquatic Microbial Ecology*, 15:277–284.
- Burgos-Hernandez, A., Farias, S.I., Torres-Arreola, W., Ezquerro-Brauer, J.M. 2005. In Vitro studies of the effects of aflatoxin B1 and fumonisin B1 on trypsin-like and collagenase-like activity from the hepatopancreas of white shrimp (*Litopenaeus vannamei*). *Aquaculture*, 250: 399–410.
- Burr, G., Hume, M., Neill, W.H. & Gatlin, D.M. 2008. Effects of prebiotics on nutrient digestibility of a soybean-meal-based diet by red drum *Sciaenops ocellatus* (Linnaeus). *Aquaculture Research*, 39 (15): 1680–1686.
- Burrells, C., Williams, P.D., Southgate, P.J. & Crampton, V.O. 1999. Immunological, physiological and pathological responses of rainbow trout (*Oncorhynchus mykiss*) to increasing dietary concentrations of soybean proteins. *Veterinary Immunology and Immunopathology*, 72 (3–4): 277–288.
- Burrells, C., Williams, P.D. & Forno, P.F. 2001. Dietary nucleotides: a novel supplement in fish feeds: 1. Effects on resistance to disease in salmonids. *Aquaculture*, 199: 159–169.
- Bustos, R., Romo, L., Yanez, K., Diaz, G. & Romo, C. 2003. Oxidative stability of carotenoid pigments and polyunsaturated fatty acids in microparticulate diets containing krill oil for nutrition of marine fish larvae. *Journal of Food Engineering*, 56: 289–293.
- Buttle, L.G., Burrells, A.C., Good, J.E., Williams, P.D., Southgate, P.J. & Burrells, C. 2001. The binding of soybean agglutinin (SBA) to the intestinal epithelium of Atlantic salmon, *Salmo salar* and Rainbow trout, *Oncorhynchus mykiss*, fed high levels of soybean meal. *Veterinary Immunology and Immunopathology*, 80 (3–4): 237–244.
- Buttle, L., Crampton, V., & Williams, P. 2001b. The effect of feed pigment type on flesh pigment deposition and colour in farmed Atlantic salmon, *Salmo salar* L. *Aquaculture Research*, 32 (2): 103–111.
- Caballero, M. J., Lopez-Calero, G., Socorro, J., Roo, F.J., Izquierdo, M.S., & Fernandez, A.J. 1999. Combined effect of lipid level and fish meal quality on liver histology of gilthead seabream (*Sparus aurata*). *Aquaculture*, 179(1–4): 277–290.
- Caballero, M.J., Obach, A., Rosenlund, G., Montero, D., Gisvold, M., Izquierdo, M.S. 2002. Impact of different dietary lipid sources on growth, lipid digestibility, tissue fatty acid composition and histology of rainbow trout, *Oncorhynchus mykiss*. *Aquaculture*, 214(1): 253–271.
- Caballero, M.J., Izquierdo, M.S., Kjorsvik, E., Montero, D., Socorro, J., Fernandez, A.J. & Rosenlund, G. 2003. Morphological aspects of intestinal cells from gilthead seabream (*Sparus aurata*) fed diets containing different lipid sources. *Aquaculture*, 225(1): 325–340.
- Caballero, M.J., Izquierdo, M.S., Kjorsvik, E., Fernández, A. & Rosenlund, G. 2004. Histological alterations in the liver of sea bream, *Sparus aurata* L., caused by short- or long-term feeding with vegetable oils. Recovery of normal morphology after feeding fish oil as the sole lipid. *J. Fish Diseases*, 27: 535–541.

- Caballero, M.J., Torstensen, B., Robaina, L., Montero, D. & Izquierdo, M.S. 2006a. Vegetable oils affect composition of lipoproteins in sea bream (*Sparus aurata*). *British Journal of Nutrition*, 96: 830–839.
- Caballero, M.J., Gallardo, G., Robaina, L., Montero, D., Fernández, A. & Izquierdo, M.S. 2006b. Vegetable lipid sources affect in vitro biosynthesis of triacylglycerols and phospholipids in the intestine of sea bream (*Sparus aurata*). *British Journal of Nutrition*, 95: 448–454.
- Cabanillas-Beltran, H., Ponce-Palafox, J.T., Martinez-Palacios, C.A., Chavez-Sanchez, M.C. & Ross, L.G. 2001. Comparison of the digestibility of diets based on fish meal and soybean meal in *Litopenaeus vannamei* Boone 1931, using different temperatures and salinities for culture. *Ciencias Marinas*, 27(4):577–593.
- Cahu, C., Zambonino-Infante, J., Escaffre, A.M., Bergot, P. & Kaushik, S. 1998. Preliminary results on sea bass (*Dicentrarchus labrax*) larvae rearing with compound diet from first feeding comparison with carp (*Cyprinus carpio*) larvae. *Aquaculture*, 169(1–2):1–7.
- Cahu, C.L., Zambonino-Infante, J.L., Quazuguel, P. & Le Gall, M.M. 1999. Protein hydrolysate vs. fish meal in compound diets for 10-day old sea bass *Dicentrarchus labrax* larvae. *Aquaculture*, 171(1–2): 109–119.
- Cai, X., Luo, L., Xue, M., Wu, X. & Zhan, W. 2005. Growth performance, body composition and phosphorus availability of juvenile grass carp (*Ctenopharyngodon idellus*) as affected by diet processing and replacement of fishmeal by detoxified castor bean meal. *Aquaculture Nutrition*, 11(4): 293–299.
- Cai, Y.J. & Burtle, G.J. 1996. Methionine requirement of channel catfish fed soybean meal-corn-based diets. *Journal of Animal Science*, 74(3):514–521.
- Cain, K.D. & Garling, D.L. 1995. Pretreatment of soybean-meal with phytase for salmonid diets to reduce phosphorus concentrations in hatchery effluents. *Progressive Fish Culturist*, 57(2): 114–119.
- Campa-Cordova, A.I., Hernandez-Saavedra, N.Y., Aguirre-Guzman, G. & Ascencio, F. 2005. Immunomodulatory response of superoxide dismutase in juvenile American white shrimp (*Litopenaeus vannamei*) exposed to immunostimulants. *Ciencias Marinas*, 31(4): 661–669.
- Campos, E.M. (ed). 1994. *Control de calidad de insumos y dietas acuicolas*. FAO Field Document, Project GCP/RLA/102/ITA, Field Document No. 16, Mexico City, Mexico. 251 pp.
- Campos, P., Martino, R.C. & Trugo, L.C. 2006. Amino acid composition of Brazilian surubim fish (*Pseudoplatystoma coruscans*) fed diets with different levels and sources of fat. *Food Chemistry*, 96(1): 126–130.
- Carnevale de Almeida, J., Perassolo, M.S., Camargo, J.L., Bragagnolo, N. & Gross, J.L. 2006. Fatty acid composition and cholesterol content of beef and chicken meat in Southern Brazil. *Brazilian Journal of Pharmaceutical Sciences*, 42(1): 109–117.
- Carrillo, O. 2007. Harina de soya, pp. 108–120. In: T.G. Galano, H. Villarreal-Colmenares and J.L. Fenucci (eds), *Manual de ingredientes proteicos y aditivos empleados en la formulacion de alimentos balanceados para camarones peneidos*. Subprograma II “Acuicultura” Red Tematica II.C, Proyecto II-8 Ciencia y Tecnologia El Desarrollo (CYTED). Argentina, Universidad Nacional de Mar del Plata, 264 pp.
- Carter, C.G. 2000. Fish meal replacement by plant meals in extruded feeds for Atlantic salmon, *Salmo salar* L. *Aquaculture*, 185(3–4): 299–311.
- Carter, C.G. & Hauler, R.C. 2000. Fish meal replacement by plant meals in extruded feeds for Atlantic salmon, *Salmo salar* L. *Aquaculture*, 185: 299–311.
- Carter, C.G., Bransden, M.P., Lewis, T.E. & Nichols, P.D. 2003. Potential of thraustochytrids to partially replace fish oil in Atlantic salmon feeds. *Marine Biotechnology*, 5(5):480–492.
- Carvalho, A.P., Escaffre, A.M., Oliva Teles, A. & Bergot, P. 1997. First feeding of common carp larvae on diets with high levels of protein hydrolysates. *Aquaculture International*, 5(4): 361–367.
- Castell, J.D., Kennedy, E.J., Robinson, S.M.C., Parsons, G.J., Blair, T.J. & Gonzalez-Duran, E. 2004. Effect of dietary lipids on fatty acid composition and metabolism in juvenile green sea urchins (*Strongylocentrotus droebachiensis*). *Aquaculture*, 242(1–4): 417–435.
- Catacutan, M.R. 2002. Formulation of aquafeeds, pp. 99–123. In: O.M. Millamena, R.M. Coloso and F.P. Pascual (eds), *Nutrition in Tropical Aquaculture*. Tigbauan, Iloilo, Philippines, Aquaculture Department, Southeast Asian Fisheries Development Center. 221 pp.
- Catacutan, M.R. & Coloso, R.M. 1997. Growth of juvenile Asian seabass, *Lates calcarifer*, fed varying carbohydrate and lipid levels. *Aquaculture*, 149(1–2): 137–144.
- Catacutan, M.R. & Pagador, G.E. 2004. Partial replacement of fishmeal by defatted soybean meal in formulated diets for the mangrove red snapper, *Lutjanus argentimaculatus* (Forsskal 1775). *Aquaculture Research*, 35(3): 299–306.
- Chainark, P., Satoh, S., Hino, T., Kiron, V., Hirono, I. & Aoki, T. 2006. Availability of genetically modified soybean meal in rainbow trout *Oncorhynchus mykiss* diets. *Fisheries Science*, 72(5): 1072–1078.
- Chaiyapechara, S., Liu, K.K.M., Barrows, F.T., Hardy, R.W. & Dong, F.M. 2003. Proximate composition, lipid oxidation, and sensory characteristics of filets from rainbow trout *Oncorhynchus mykiss* fed diets containing 10 percent to 30 percent lipid. *Journal of the World Aquaculture Society*, 34(3): 266–277.
- Chakrabarty, D., Das, S.K. & Das, M.K. 2009. Relative efficiency of vermicompost as direct application manure in pisciculture. *Paddy and Water Environment*, 7(1): 27–32.
- Chang, Q., Liang, M., Wang, J. & Zhai, Y. 2004. Available amino acid and phosphorus of various feed ingredients for Japanese sea bass (*Lateolabrax* sp.). *Marine Fisheries Research/Haiyang Shuichan Yanjiu*, 25(2): 35–40.
- Chatzifotis, S., Polemitou, I., Divanach, P., Antonopoulou, E. 2008. Effect of dietary taurine supplementation on growth performance and bile salt activated lipase activity of common dentex, *Dentex dentex*, fed a fish meal/soy protein concentrate-based diet. *Aquaculture*, 275(1–4): 201–208.

- Chavez-Sanches, M.C., Martinez, C.A., Moreno, I.O. 1994. Pathological effects of feeding young *Oreochromis niloticus* diets supplemented with different levels of aflatoxin B1. *Aquaculture* 127: 49–60.
- Chen, L., Du, N. & Lai, W. 1994. Evaluation of soybean cake as a substitute for partial fish meal in formulated diets for Chinese mitten-handed crab juvenile. *Journal of Fisheries of China/Shuichan Xuebao Shanghai*, 18(1): 24–31.
- Cheng, Y.X., Du, N.S. & Lai, W. 1998. Lipid composition in hepatopancreas of Chinese mitten crab *Eriocheir sinensis* at different stages. *Acta Zoologica Sinica*, 44 (4), 420–429 (in Chinese, with English abstract).
- Cheng, Z.J. & Hardy, R.W. 2002a. Apparent digestibility coefficients of nutrients and nutritional value of poultry by-product meals for rainbow trout *Oncorhynchus mykiss* measured in vivo using settlement. *Journal of the World Aquaculture Society*, 33(4):458–465.
- Cheng, Z.J. & Hardy, R.W. 2002b. Effect of microbial phytase on apparent nutrient digestibility of barley, canola meal, wheat and wheat middlings, measured in vivo using rainbow trout (*Oncorhynchus mykiss*). *Aquaculture Nutrition* 8(4): 271–277.
- Cheng, Z.J. & Hardy, R.W. 2002c. Apparent digestibility coefficients and nutritional value of cottonseed meal for rainbow trout (*Oncorhynchus mykiss*). *Aquaculture*, 212(1–4): 361–372.
- Cheng, Z.J. & Hardy, R.W. 2003. Effects of extrusion processing of feed ingredients on apparent digestibility coefficients of nutrients for rainbow trout (*Oncorhynchus mykiss*). *Aquaculture Nutrition*, 9(2): 77–83.
- Cheng, Z.J. & Hardy, R.W. 2004. Protein and lipid sources affect cholesterol concentrations of juvenile Pacific white shrimp, *Litopenaeus vannamei* (Boone). *Journal of Animal Science*, 82:1136–1145.
- Cheng, Z.J. & Hardy, R.W. 2004b. Effects of Microbial Phytase Supplementation in Corn Distiller's Dried Grain with Solubles on Nutrient Digestibility and Growth performance of Rainbow Trout, *Oncorhynchus mykiss*. *Journal of Applied Aquaculture*, 15(3–4): 83–100.
- Cheng, Z.J., Behnke, K.C. & Dominy, W.G. 2001. Pulverizing and/or defatting effects on electrical energy consumption and particle size and moisture levels of poultry by-products. *Journal of Applied Aquaculture*, 11(4): 67–73.
- Cheng, Z.J., Behnke, K.C. & Dominy, W.G. 2002a. Effects of poultry by-product meal as a substitute for fish meal in diets on growth and body composition of juvenile Pacific white shrimp *Litopenaeus vannamei*. *Journal of Applied Aquaculture*, 12(1): 71–83.
- Cheng, Z.J., Behnke, K.C. & Dominy, W.G. 2002b. Effect of feather meal on growth and body composition of the juvenile Pacific white shrimp, *Litopenaeus vannamei*. *Journal of Applied Aquaculture*, 12: 57–69.
- Cheng, Z.J., Hardy, R.W. & Blair, M. 2003. Effects of supplementing methionine hydroxy analogue in soybean meal and distiller's dried grain-based diets on the performance and nutrient retention of rainbow trout [*Oncorhynchus mykiss* (Walbaum)]. *Aquaculture Research*, 34(14): 1303–1310.
- Cheng, Z.J., Hardy, R.W. & Usry, J.L. 2003b. Effects of lysine supplementation in plant protein-based diets on the performance of rainbow trout (*Oncorhynchus mykiss*) and apparent digestibility coefficients of nutrients. *Aquaculture*, 215(1–4): 255–265.
- Cheng, Z.J., Hardy, R.W. & Usry, J.L. 2003c. Plant protein ingredients with lysine supplementation reduce dietary protein level in rainbow trout (*Oncorhynchus mykiss*) diets, and reduce ammonia nitrogen and soluble phosphorus excretion. *Aquaculture*, 218(1–4):553–565.
- Cheng, Z.J., Hardy, R.W. & Huige, N.J. 2004. Apparent digestibility coefficients of nutrients in brewer's and rendered animal by-products for rainbow trout (*Oncorhynchus mykiss* (Walbaum)). *Aquaculture Research*, 35(1): 1–9.
- Cheng, Z.J., Hardy, R.W., Verlhac, V. & Gabaudan, J. 2004. Effects of microbial phytase supplementation and dosage on apparent digestibility coefficients of nutrients and dry matter in soybean product-based diets for rainbow trout *Oncorhynchus mykiss*. *Journal of the World Aquaculture Society*, 35(1): 1–15.
- Chevanan, N., Muthukumarappan, K. & Rosentrater, K.A. 2009. Extrusion studies of aquaculture feed using distillers dried grains with solubles and whey. *Food and Bioprocess Technology*, 2(2): 177–185.
- Chien, Y.H., Chen, C.C. & Chen, J.H. 2005. Substitution of defatted soybean meal with condensed molasses fermentation soluble in diets for fingerling Nile tilapia (*Oreochromis niloticus* L.). *Journal of the Fisheries Society of Taiwan*, 32(4): 317–325.
- Chien, Y.H. & Chen, C.C. 2007. Substitution of defatted soybean meal with condensed molasses fermentation soluble in diets for fingerling milkfish (*Chanos chanos* Forsskal). *Journal of the Fisheries Society of Taiwan*, 34(4): 11.
- Chien, Y.H. & Chiu, Y.H. 2003. Replacement of soybean (*Glycine max* (L.) Merrill) meal by lupin (*Lupinus angustifolius*) seed meal in diet for juvenile tilapia (*Oreochromis niloticus* x *O.-aureus*) reared indoors. *Aquaculture Research*, 34(14): 1261–1268.
- Chien, Y.H., Pan, C.H. & Hunter, B. 2003. The resistance to physical stresses by *Penaeus monodon* juveniles fed diets supplemented with astaxanthin. *Aquaculture*, 216(1–4): 177–191.
- Chikafumbwa, F.J.K. 1996. The use of napier grass (*Pennisetum purpureum*) and maize (*Zea mays*) bran as low-cost tilapia aquaculture inputs. *Aquaculture*, 146(1–2): 101–107.
- Cho, C.Y., Slinger, S.J. & Bayley, H.S. 1982. Bioenergetics 532 of salmonid fishes: Energy intake, expenditure and productivity. *Comparative Biochemistry and Physiology*, Part B: 73, 25–41.
- Cho, S.H., Park, J., Kim, C. & Yoo, J.H. 2008. Effect of casein substitution with fishmeal, soybean meal and crustacean meal in the diet of the abalone *Haliotis discus hannai* Ino. *Aquaculture Nutrition*, 14(1): 61–66.
- Choi, S.M., Wang, X., Park, G.J., Lim, S.R., Kim, K.W., Bai, S.C. & Shin, I.S. 2004. Dietary dehulled soybean meal as a replacement for fish meal in fingerling and growing olive flounder *Paralichthys olivaceus* (Temminck et Schlegel). *Aquaculture Research*, 35(4): 410–418.

- Chou, B.S. & Shiau, S.Y. 1996. Optimal dietary lipid level for growth of juvenile hybrid tilapia, *Oreochromis niloticus* x *Oreochromis aureus*. *Aquaculture*, 143(2): 185–195.
- Chou, B.S. & Shiau, S.Y. 1999. Both n-6 and n-3 fatty acids are required for maximal growth of juvenile hybrid tilapia. *North American Journal of Aquaculture*, 61(1): 13–20.
- Chou, R.L., Her, B.Y., Su, M.S., Hwang, G., Wu, Y.H. & Chen, H.Y. 2004. Substituting fish meal with soybean meal in diets of juvenile cobia *Rachycentron canadum*. *Aquaculture*, 229(1–4): 325–333.
- Chou, Y.H. & Chien, Y.H. 2006. Effects of astaxanthin and vitamin E supplement in Japanese sea bass (*Lateolabrax japonicus*) broodstock diet on their spawning performance and egg quality. *Journal of the Fisheries Society of Taiwan*, 33(2): 157–169.
- Choubert, G., Mendes-Pinto, M.M. & Morais, R. 2006. Pigmenting efficacy of astaxanthin fed to rainbow trout *Oncorhynchus mykiss*: Effect of dietary astaxanthin and lipid sources. *Aquaculture*, 257(1–4): 429–436.
- Chrappa, V. & Sabo, V. 1999. Feeding meals of housefly larvae and pupae to the Nile tilapia (*Oreochromis niloticus*). *Czech Journal of Animal Science*, 44(2): 81–85.
- Christiansen, R., Lie, O. & Torrissen, O.J. 1995. Growth and survival of Atlantic salmon, *Salmo salar* L., fed different dietary levels of astaxanthin. First-feeding fry. *Aquaculture Nutrition*, 1(3): 189–198.
- Christiansen, R. & Torrissen, O.J. 1996. Growth and survival of Atlantic salmon, *Salmo salar* L. fed different dietary levels of astaxanthin. Juveniles. *Aquaculture Nutrition*, 2(1): 55–62.
- Christie, W.W. 2003. *Lipid analysis, isolation, separation and structural analysis of lipids*, 3rd Edition. Bridgewater, England, The Oily Press.
- Chu, S.F. 1992. Recent progress on analytical techniques for mycotoxins in feedstuffs. *J. Anim. Sci.* 70: 3950–3963.
- Cisse, A., Luquet, P. & Etchian, A. 1995. Use of chemical or biological fish silage as feed for *Chrysichthys nigrodigitatus* (Bagridae). *Aquatic Living Resources*, 8(4): 373–377.
- Civera R., Viliarreal, H., Vega-Villasante, F., Nolasco, H., Rocha, S., Goytortúa, E., González, M., & Camarillo, T. 1999. La langostilla (*Pleuroncodes planipes*) como fuente de proteína en dietas experimentales para camarón. 325–347 pp. In: L.E. Cruz Suárez, M.D. Ricque, y R. Mendoza (eds), *Avances en Nutrición Acuicola III*. Memorias del tercer Simposium Internacional de Nutrición Acuicola. November 11–13, 1996. Monterrey, N.L., México.
- Clarke, E. & Wiseman, J. 1998. *Nutritional value of soya products for non-ruminant farm animals*. Singapore, American Soybean Association, F99GX17503/0761999/0600, MITA(P)No.219/10/98, 183 pp.
- Clayton, R.D., Morris, J.E. & Summerfelt, R.C. 2008. Comparison of soy and fish oils in practical diets for fingerling walleyes. *North American Journal of Aquaculture*, 70: 171–174.
- Coche, A.G., Muir, J.F. & Laughlin, T.L. 1996. *FAO Training Series: Simple methods for aquaculture. Issue 21 of Management for Freshwater Fish, Culture Ponds and Water Practices*. Rome, FAO. 233 pp.
- Cochasee, T., Jintataporn, O., Tabthipwon, P. & Mahasawasde, S. 2003. Substitution of silkworm pupae (*Bombyx mori*) for soybean meal in hybrid catfish diet (*Clarias macrocephalus* x *Clarias gariepinus*). *Proceedings of 41st Kasetsart University Annual Conference*, 3–7 February, 2003, Bangkok, Thailand.
- Coimbra, M., Figueiredo-Fernandes, A. & Reis-Henriques, M.A. 2007. Nile tilapia (*Oreochromis niloticus*), liver morphology, CYP1A activity and thyroid hormones after endosulfan dietary exposure. *Pesticide Biochemistry and Physiology*, 89(3): 230–236.
- Coman, G.J., Sarac, H.Z., Fielder, D. & Thorne, M. 1996. Evaluation of crystalline amino acids, betaine and AMP as food attractants of the giant tiger prawn (*Penaeus monodon*). *Comparative Biochemistry and Physiology, Part A: Physiology*, 113(3):247–253.
- Cordova-Mureta, J.H. & Garcia-Carreño, F.L. 2001. The effect on growth and protein digestibility of shrimp *Penaeus stylirostris* fed with feeds supplemented with squid (*Dosidicus gigas*) meal dried by two different processes. *Journal of Aquatic Food Production Technology*, 10: 35–47.
- Cordova-Mureta, J.H. & Garcia-Carreño, F.L. 2002. Nutritive value of squid and hydrolysed protein supplement in shrimp feed. *Aquaculture*, 210: 371–384.
- Coutinho, P., Rema, P., Otero, A., pereira, O. & Fabregas, J. 2006. Use of biomass of the marine microalga *Isochrysis galbana* in the nutrition of goldfish (*Carassius auratus*) larvae as source of protein and vitamins. *Aquaculture Research*, 37(8): 793–798.
- Coutteau, P., Camara, M.R. & Sorgeloos, P. 1996. The effect of different levels and sources of dietary phosphatidylcholine on the growth, survival, stress resistance, and fatty acid composition of postlarval *Penaeus vannamei*. *Aquaculture*, 147: 261–273.
- Coutteau, P., Geurden, I., Camara, M.R., Bergot, P. & Sorgeloos, P. 1997. Review on the dietary effects of phospholipids in fish and crustacean larviculture. *Aquaculture*, 155: 149–16.
- Coutteau, P., Kontara, E.K.M. & Sorgeloos, P. 2000. Comparison of phosphatidylcholine purified from soybean and marine fish roe in the diet of postlarval *Penaeus vannamei* Boone. *Aquaculture*, 181 (3–4): 331–345.
- Coward-Kelly, G., Agbogbo, F.K. & Holtzapple, M.T. 2006. Lime treatment of shrimp head waste for the generation of highly digestible animal feed. *Bioresource Technology*, 97(13): 1515–1520.
- Craig, S.R. & Gatlin, D.M. 1995. Coconut oil and beef tallow, but not tricaprilyn, can replace menhaden oil in the diet of red drum (*Sciaenops ocellatus*) without adversely affecting growth or fatty acid composition. *The Journal of Nutrition*, 125: 3041–3048.
- Craig, S.R. & Gatlin, D.M. 1997. Growth and body composition of juvenile red drum (*Sciaenops ocellatus*) fed diets containing lecithin and supplemental choline. *Aquaculture*, 151(1–4): 259–267.

- Craig, S.R., Neill, W.H. & Gatlin, D.M. 1995. Effects of dietary-lipid and environmental salinity on growth, body composition, and cold tolerance of juvenile red drum (*Sciaenops ocellatus*). *Fish Physiology and Biochemistry*, 14(1): 49–61.
- Craig, S.R., Washburn, B.S. & Gatlin, D.M. 1999. Effects of dietary lipids on body composition and liver function in juvenile red drum, *Sciaenops ocellatus*. *Fish Physiology and Biochemistry*, 21(3): 249–255.
- Cruz-Suarez, L.E., Ricque-Marie, D., Nieto-Lopez, M. & Tapia-Salazar, M. 2000. Revision sobre la calidad de harinas y aceites de pescado para la nutrición de camarón, pp. 298–326. In: R. Civera-Cerecedo, C.J. Perez-Estrada, D. Ricque-Marie. And L.E. Cruz-Suarez (eds), *Avances en Nutrición Acuicola IV. Memorias del IV Simposio Internacional de Nutrición Acuicola*, Noviembre de 1998. Las Paz, B.C.S., Mexico.
- Cruz-Suarez, L.E., Ricque-Marie, D., Tapia-Salazar, M., McCallum, I.M. & Hickling, D. 2001. Assessment of differently processed feed pea (*Pisum sativum*) meals and canola meal (*Brassica* sp.) in diets for blue shrimp (*Litopenaeus stylirostris*). *Aquaculture*, 196(1–2): 87–104.
- Cruz-Suarez, L.E., Nieto-Lopez M., Ricque-Marie, D., Guajardo-Barbosa, C. & Scholz, U. 2004. Uso de harina de subproductos avícolas en alimentos para *L. vannamei*. In: I.E. Cruz-Suarez, D. Ricque-Marie, M.G. Nieto-Lopez, D. Villarreal, U. Scholz and M. González (eds), *Avances en Nutrición Acuicola VII. Memorias del Séptimo Simposio Internacional de Nutrición Acuicola*, 16–19 November 2004. Hermosillo Sonora, México.
- Cruz-Suarez, L.E., Tapia-Salazar, M., Nieto-Lopez, M. & Ricque-Marie, D. 2007a. Subproductos de la industria avícola, pp. 94–105. In: T.G. Galano, H. Villarreal-Colmenares and J.L. Fenucci (eds), *Manual de ingredientes proteicos y aditivos empleados en la formulación de alimentos balanceados para camarones peneidos*. Subprograma II “Acuicultura” Red Temática II.C, Proyecto II-8 Ciencia y Tecnología El Desarrollo (CYTED). Argentina, Universidad Nacional de Mar del Plata, 264 pp.
- Cruz-Suarez, L.E., Nieto-Lopez, M., Guajardo-Barbosa, C., Tapia-Salazar, M., Scholz, U., & Ricque-Marie, D. 2007b. Replacement of fish meal with poultry by-product meal in practical diets for *Litopenaeus vannamei*, and digestibility of the tested ingredients and diets. *Aquaculture* 272: 466–476
- Cruz-Suarez, L.E., Tapia-Salazar, M., Nieto-Lopez, M.G., Guajardo-Barbosa, C. & Ricque-Marie, D. 2008. Comparison of *Ulva clathrata* and the kelps *Macrocystis pyrifera* and *Ascophyllum nodosum* as ingredients in shrimp feeds. *Aquaculture Nutrition*, 15(4): 421–430.
- Cruz-Suarez, L.E., Tapia-Salazar, M., Villarreal-Cavazos, D., Beltran-Rochaa, J., Nieto-Lopez, M.G., Lemmeb, A. & Ricque-Marie, D. 2009. Apparent dry matter, energy, protein and amino acid digestibility of four soybean ingredients in white shrimp *Litopenaeus vannamei* juveniles. *Aquaculture*, 292(1–2): 87–94.
- D’Abramo, L.R., Ohs, C.L. & Taylor, J.B. 2000. Effects of reduced levels of dietary protein and menhaden fish meal on production, dressout, and biochemical composition of phase III Sunshine bass *Morone chrysops* x *M. saxatilis* cultured in earthen ponds. *Journal of the World Aquaculture Society*, 31(3): 316–325.
- Daggett, T.L., Pearce, C.M., Tingley, M., Robinson, S.M.C. & Chopin, T. 2005. Effect of prepared and macroalgal diets and seed stock source on somatic growth of juvenile green sea urchins (*Strongylocentrotus droebachiensis*). *Aquaculture*, 244(1–4): 263–281.
- Dall, W. 1995. Carotenoids versus retinoids (Vitamin A) as essential growth factors in penaeid prawns (*Penaeus semisulcatus*). Berlin, Heidelberg, *Marine Biology*. 124(2): 209–213.
- Dalsgaard, A., Huss, H.H., Kittikun, A.H. & Larsen, J.L. 1995. Prevalence of *Vibrio cholerae* and *Salmonella* in a major shrimp production area in Thailand. *International Journal of Food Microbiology*, 28(1): 101–113.
- Da Silva, L. & Barbosa, J.M. 2009. Seaweed meal as a protein source for the white shrimp *Litopenaeus vannamei*. *Journal of Applied Phycology*, 21(2): 193–197.
- Daskalov, H., Robertson, P.A.W. & Austin, B. 2000. Influence of oxidized lipids in diets on the development of rainbow trout fry syndrome. *Journal of Fish Diseases*, 23(1): 7–14.
- Davies, S.J. & Gouveia, A. 2006. Comparison of yttrium and chromic oxides as inert dietary markers for the estimation of apparent digestibility coefficients in mirror carp *Cyprinus carpio* fed on diets containing soybean-, maize- and fish-derived proteins. *Aquaculture Nutrition*, 12(6): 451–458.
- Davies, S.J. & Gouveia, A. 2008. Enhancing the nutritional value of pea seed meals (*Pisum sativum*) by thermal treatment or specific isogenic selection with comparison to soybean meal for African catfish, *Clarias gariepinus*. *Aquaculture*, 283(1–4): 116–122.
- Davies, S.J. & Morris, P.C. 1997. Influence of multiple amino acid supplementation on the performance of rainbow trout, *Oncorhynchus mykiss* (Walbaum), fed soya based diets. *Aquaculture Research*, 28(1): 65–74.
- Davies, S.J., Moris, P. C. & Baker, R.T.M. 1997a. Partial substitution of fish meal and full-fat soya bean meal with wheat gluten and influence of lysine supplementation in diets for rainbow trout, *Oncorhynchus mykiss* (Walbaum). *Aquaculture Research*, 28(5): 317–328.
- Davies, S.J., Brown, M.T. & Camilleri, M. 1997b. Preliminary assessment of the seaweed *Porphyra purpurea* in artificial diets for thick-lipped grey mullet (*Chelon labrosus*). *Aquaculture*, 152(1–4): 249–258.
- Davis, D.A. & Arnold, C.R. 1995. Effects of two extrusion processing conditions on the digestibility of four cereal grains for *Penaeus vannamei*. *Aquaculture* 133 (3–4): 287–294
- Davis, D.A. & Arnold, C.R. 2000. Replacement of fish meal in practical diets for the Pacific white shrimp, *Litopenaeus vannamei*. *Aquaculture*, 185: 291–298.
- Davis, D.A. & Arnold, C.R. 2004. Red Drum, *Sciaenops ocellatus*, production diets replacement of fish meal with soybean meal. *Journal of Applied Aquaculture*, 15(3–4): 173–181.
- Davis, D., Arnold, C. & McCallum, I. 2002. Nutritional value of feed peas (*Pisum sativum*) in practical diet formulations for *Litopenaeus vannamei*. *Aquaculture Nutrition*, 8(2): 87–94.

- Davis, D.A., Jirsa, D. & Arnold, C.R. 1995. Evaluation of soybean proteins as replacements for menhaden fish meal in practical diets for the red drum *Sciaenops ocellatus*. *Journal of the World Aquaculture Society*, 26(1): 48–58.
- Davis, D.A., Lazo, J.P. & Arnold, C.R. 1999. Response of juvenile red drum (*Sciaenops ocellatus*) to practical diets supplemented with medium chain triglycerides. *Fish Physiology and Biochemistry*, 21(3): 235–247.
- Davis, D.A., Miller, C.L. & Phelps, R.P. 2005. Replacement of fish meal with soybean meal in the production diets of juvenile red snapper, *Lutjanus campechanus*. *Journal of the World Aquaculture Society*, 36(1): 114–119.
- Day, O.J. & Gonzalez, H.G.P. 2000. Soybean protein concentrate as a protein source for turbot *Scophthalmus maximus* L. *Aquaculture Nutrition*, 6(4): 221–228.
- Day, O.J., Howell, B.R. & Jones, D.A. 1997. The effect of dietary hydrolysed fish protein concentrate on the survival and growth of juvenile Dover sole, *Solea solea* (L.), during and after weaning. *Aquaculture Research* 28(12): 911–921.
- Debnath, D., Pal, A.K., Sahu, N.P., Jain, K.K., Yengkokpam, S. & Mukherjee, S.C. 2005a. Effect of dietary microbial phytase supplementation on growth and nutrient digestibility of *Pangasius pangasius* (Hamilton) fingerlings. *Aquaculture Research*, 36(2): 180–187.
- Debnath, D., Sahu, N.P., Pal, A.K., Jain, K.K., Yengkokpam, S. & Mukherjee, S.C. 2005b. Mineral status of *Pangasius pangasius* (Hamilton) fingerlings in relation to supplemental phytase: absorption, whole-body and bone mineral content. *Aquaculture Research*, 36(4): 326–335.
- Debnath, D., Sahu, N.P., Pal, A.K., Baruah, K., Yengkokpam, S. & Mukherjee, S.C. 2005c. Present scenario and future prospects of phytase in aquafeed - Review. *Asian-Australasian Journal of Animal Sciences*, 18(12): 1800–1812.
- de Faria, A., Hayashi, C. & Soares, C.M. 2002. Poultry by-product meal in Nile tilapia (*Oreochromis niloticus*) fingerlings diets. *Revista Brasileira de Zootecnia – Brazilian Journal of Animal Science*, 31(2): 812–822.
- De Francesco, M., Parisi, G., Perez-Sanchez, J., Gomez-Requeni, P., Medale, F., Kaushik, S.J., Mecatti, M. & Poli, B.M. 2007. Effect of high-level fish meal replacement by plant proteins in gilthead sea bream (*Sparus aurata*) on growth and body/fillet quality traits. *Aquaculture Nutrition*, 13(5): 361–372.
- Degani, G. 2006. Digestible energy in dietary sorghum, wheat bran, and rye in the common carp (*Cyprinus carpio* L.). *Israeli Journal of Aquaculture–Bamidgeh*, 58(2): 71–77.
- de Koning, A. J. 1999. Quantitative quality tests for South African fish meal: An investigation into the validity of a number of quality indices. *International Journal of Food Properties*, 2(1): 79–92.
- de la Higuera, M., Akharbach, H., Hidalgo, M.C., Peragon, J., Lupianez, J.A. & Garcia-Gallego, M. 1999. Liver and white muscle protein turnover rates in the European eel (*Anguilla anguilla*): effects of dietary protein quality. *Aquaculture*, 179(1–4): 203–216.
- Del Barga, I., Frenzilli, G., Scarcelli, V., Nigro, M., Malmvarn, A., Asplund, L., Forlin, L. & Sturve, J. 2006. Effects of algal extracts (*Polysiphonia fucoides*) on rainbow trout (*Oncorhynchus mykiss*): A biomarker approach. *Marine Environmental Research*, 62 (S1): S283–S286.
- Del Carratore, C.R., Pezzato, L.E., Pezzato, A.C., Barros, M.M. & Ribeiro, P. 1996. Productive performance of raw full-fat soybean meal on feeding of the Nile tilapia fingerlings (*Oreochromis niloticus*). *Pesquisa Agropecuaria Brasileira*, 31(5): 369–374.
- Deng, J., Mai, K., Ai, Q., Zhang, W., Wang, X., Xu, W., Liufu, Z. 2006. Effects of replacing fish meal with soy protein concentrate on feed intake and growth of juvenile Japanese flounder, *Paralichthys olivaceus*. *Aquaculture*, 258(1–4): 503–513.
- Denstadli, V., Storebakken, T., Svihus, B., Skrede, A. 2007. A comparison of online phytase pre-treatment of vegetable feed ingredients and phytase coating in diets for Atlantic salmon (*Salmo salar* L.) reared in cold water. *Aquaculture*, 269(1–4): 414–426.
- de Oliveira, A.C.B., Pezzato, L.E., Barros, M.M., Pezzato, A.C. & Silveira, A.C. 1997. African palm kernel meal on Nile tilapia: Productive performance. *Pesquisa Agropecuaria Brasileira*, 32(4): 443–449.
- de Oliveira, A.C.B., Pezzato, L.E., Barros, M.M. & Graner, C.A.F. 1998. Apparent digestibility and macro-microscopic effect on Nile tilapia (*Oreochromis niloticus*) fed palm kernel meal. *Revista Brasileira de Zootecnia – Brazilian Journal of Animal Science*, 27(2): 210–215.
- de Seixas, J.T., Rostagno, H.S., de Queiroz, A.C., Euclides, R.F. & Barbarino, P. 1997a. Evaluation of the performance of post-larvae of the freshwater prawn *Macrobrachium rosenbergii* fed with balanced diets containing different binders. *Revista da Sociedade Brasileira de Zootecnia – Journal of the Brazilian Society of Animal Science*, 26(4): 638–644.
- de Seixas, J.T., Rostagno, H.S., de Queiroz, A.C., Euclides, R.F. & Barbarino, P. 1997b. Effect of binders on the hydrosolubility of balanced diets for freshwater prawns (*Macrobrachium rosenbergii*, de Man) in the best-larval stage. *Revista da Sociedade Brasileira de Zootecnia – Journal of the Brazilian Society of Animal Science*, 26(4): 629–637.
- de Souza, N.E., Stevanato, F.B., Garcia, E.E., Visentainer, J.E.L., Zara, R.F. & Visentainer, J.V. 2008. Supplemental dietary flaxseed oil affects both neutral and phospholipid fatty acids in cultured tilapia. *European Journal of Lipid Science and Technology*, 110(8): 707–713.
- Devi, B.C., Vijayaraghavan, S. & Srinivasulu, C. 1998. Soybean-meal as protein source in the diet of fingerling *Labeo rohita* (Hamilton). *Indian Journal of Animal Sciences*, 68(3): 281–283.
- Devi, C., Vijayaraghavan, S. & Srinivasulu, C. 1999. Effect of soybean meal (*Glycine max*) feeding on the biochemical composition of *Labeo rohita* fingerlings. *Journal of Aquaculture in the Tropics*, 14(3): 181–185.

- Diana, J.S. & Lin, C.K. 1998. The effects of fertilization and water management on growth and production of Nile tilapia in deep ponds during the dry season. *Journal of the World Aquaculture Society*, 29(4): 405–413.
- Dias, J., Alvarez, M.J., Arzel, J., Corraze, G., Diez, A., Bautista, J.M. & Kaushik, S.J. 2005. Dietary protein source affects lipid metabolism in the European seabass (*Dicentrarchus labrax*). *Comparative Biochemistry and Physiology, Part A: Molecular and Integrative Physiology*, 142(1): 19–31.
- Dias, J., Gomes, E.F. & Kaushik, S. J. 1997. Improvement of feed intake through supplementation with an attractant mix in European seabass fed plant-protein rich diets. *Aquatic Living Resources*, 10: 385–389.
- Dias, J., Conceição, L.E.C., Ramalho Ribeiro, A., Borges, P., Valente, L.M.P. & Dinis, M.T. 2009. Practical diet with low fish-derived protein is able to sustain growth performance in gilthead seabream (*Sparus aurata*) during the grow-out phase. *Aquaculture*, 293(3–4): 255–262.
- Diler, Z.A., Tekinay, A. Güroy, D., Güroy, B.K. & Soyutürk, M. 2007. Effects of *Ulva rigida* on the growth, feed intake and body composition of common carp, *Cyprinus carpio* L. *Journal of Biological Sciences*, 7(2): 305–308.
- Divakaran, S.D. 1999. *AFIA Laboratory Methods Compendium II. Vol. 4: Aquaculture*. Arlington, VA., USA, American Feed Industry Association, Arlington, VA., USA. 109 pp.
- Divakaran, S. & Velasco, M. 2002. Trials test cottonseed meal as soybean replacement in shrimp feed. *Global Aquaculture Advocate*, 5(4): 36
- Divakaran, S., Velasco, M., Beyer, E., Forster, I., Tacon, A.G.J. 2000. Soybean meal apparent digestibility for *Liopenaeus vannamei*, including a critique of methodology, pp 267–276 In: L.E. Cruz -Suárez, D. Ricque-Marie, M. Tapia-Salazar, M.A. Olvera-Novoa y R. Civera-Cerecedo (eds) *Avances en Nutrición Acuicola V. Memorias del V Simposium Internacional de Nutrición Acuicola*. 19–22 November 2000. Mérida, Yucatán, México.
- Djunaidah, I.S., Wille, M., Kontara, E.K. & Sorgeloos, P. 2003. Reproductive performance and offspring quality in mud crab (*Scylla paramamosain*) broodstock fed different diets. *Aquaculture International*, 11(1–2): 3–15.
- Dlaza, T.S., Maneveldt, G.W. & Viljoen, C. 2008. Growth of post-weaning abalone *Haliotis midae* fed commercially available formulated feeds supplemented with fresh wild seaweed. *African Journal of Marine Science*, 30(1): 199–203.
- Dominy, W.G., Cody, J.J., Tepstra, J.H., Obaldo, L.G., Chai, M.K., Takamora, T.I., Larsen, B. & Foster, I.P. 2004. A comparative study of the physical and biological properties of commercially-available binders for shrimp feeds. *Journal of Applied Aquaculture*, 14(3–4): 81–99.
- Dong, F.M. & Hardy, R.W. 2000. Feed evaluation, chemical, pp.340–349. In: R.R. Stickney (ed.), *The Encyclopedia of Aquaculture*. New York, USA, John Wiley & Sons Inc., New York, 1063 pp.
- Dong, F.M., Hardy, R.W. & Higgs, D.A. 2000. Antinutritional factors, pp.45–51. In: R.R. Stickney (ed.), *The Encyclopedia of Aquaculture*. New York, USA, John Wiley & Sons Inc., New York, 1063 pp.
- Dongmeza, E., Steinbronn, S., Francis, G., Focken, U. & Becker, K. 2009. Short communication: Investigations on the nutrient and antinutrient content of typical plants used as fish feed in small scale aquaculture in the mountainous regions of Northern Viet Nam. *Animal Feed Science and Technology*, 149(1–2): 162–178.
- Drew, M.D. 2004. Canola protein concentrate as a feed ingredient for salmonid fish. In: L.E. Cruz Suarez, D. Ricque Marie, M.G. Nieto Lopez, D. Villareal, U. Scholz And M. Gonzalez (eds), *Advances en Nutricion Acuicola VII. Memorias del VII Simposium Internacional de Nutricion Acuicola*. 16–19 November 2004. Hermosillo, Sonora, Mexico.
- Drew, M.D., Raxz, V.J., Gauthier, R. & Thiessne, D.L. 2005. Effect of adding protease to coextruded flax: pea or canola: pea products on nutrient digestibility and growth performance of rainbow trout (*Oncorhynchus mykiss*). *Animal Feed Science and Technology*, 119(1–2): 117–128.
- Drew, M.D., Ogunkoya, A.E., Janz, D.M. & Van Kessel, A.G. 2007. Dietary influence of replacing fish meal and oil with canola protein concentrate and vegetable oils on growth performance, fatty acid composition and organochlorine residues in rainbow trout (*Oncorhynchus mykiss*). *Aquaculture*, 267(1–4): 260–268.
- Drobna, Z., Zelenka, J., Mrkvicova, E., Kladroba, D. 2006. Influence of dietary linseed and sunflower oil on sensory characteristics of rainbow trout (*Oncorhynchus mykiss*). *Czech Journal of Animal Science*, 51: 475–482.
- D'Souza, F.M.L., Lecossois, D., Heasman, M.P., Diemar, J.A., Jackson, C.J. & Pendrey, R.C. 2000. Evaluation of centrifuged microalgae concentrates as diets for *Penaeus monodon* Fabricius larvae. *Aquaculture Research*, 31(8–9): 661–670.
- D'Souza, F.M.L., Knuckey, R.M., Hohmann, S. & Pendrey, R.C. 2002. Flocculated microalgae concentrates as diets for larvae of the tiger prawn *Penaeus monodon* Fabricius. *Aquaculture Nutrition*, 8(2): 113–120.
- D'Souza, N., Skonberg, D.I., Stone, A.J. Stone & Brown, P.B. 2006. Effect of soybean meal-based diets on the product quality of rainbow trout fillets. *Journal of Food Science*, 71(4): S337–S342.
- Du, L. & Niu, C.J. 2003. Effects of dietary substitution of soya bean meal for fish meal on consumption, growth, and metabolism of juvenile giant freshwater prawn, *Macrobrachium rosenbergii*. *Aquaculture Nutrition*, 9(2): 139–143.
- Du, Z.Y., Clouet, P., Zheng, W.H., Degrace, P., Tian, L.X. & Liu, Y.J. 2006. Biochemical hepatic alterations and body lipid composition in the herbivorous grass carp (*Ctenopharyngodon idella*) fed high-fat diets. *British Journal of Nutrition*, 95(5): 905–915.
- Du, Z.Y., Clouet, P., Huang, L.M., Degrace, P., Zheng, W.H., He, J.G. 2008. Utilization of different dietary lipid sources at high level in herbivorous grass carp (*Ctenopharyngodon idella*): mechanism related to hepatic fatty acid oxidation. *Aquaculture Nutrition*, 14(1): 77–92.

- Durazo Beltran, E. & Viana, M.T. 2001. Effect of the concentration of agar, alginate and carrageenan on the stability, toughness and nutrient leaching in artificial diets for abalone. *Ciencias Marinas*, 27(1): 1–19.
- Dworjanyan, S.A., Pirozzi, I. & Liu, W. 2007. The effect of the addition of algae feeding stimulants to artificial diets for the sea urchin *Tripneustes gratilla*. *Aquaculture*, 273(4): 624–633.
- EFSA. 2007. Transmissible Spongiform Encephalopathy (TSE) risk assessment of the use of bovine spray dried red cells in feeds for fish, in consideration of a report produced by the European Animal Protein Association – Scientific Opinion of the Panel on Biological Hazards. *EFSA J.* 596: 2–2. (www.efsa.europa.eu/EFSA/efsa_locale-1178620753812_1178672651256.htm)
- EFSA. 2008. Microbiological risk assessment in feedingstuffs for food-producing animals, Scientific Opinion of the Panel on Biological Hazards. Question No EFSA-Q-2007-045, adopted on 5 June 2008. *The EFSA Journal*, 720: 2–84.
- Egna, H.S. & Boyd, C.E. 1997. *Dynamics of pond aquaculture*. CRC Press. 437 pp.
- Ekanem, S.B. & Basse, P.O. 2003. Effect of pawpaw seed (*Carica papaya*) as antifertility agent in female Nile tilapia (*Oreochromis niloticus*). *Journal of Aquaculture in the Tropics*, 18(2): 181–188.
- El-Ebiary, E.H., Zaki, M.A. & Mabrook, H.A. 2001. The use of corn gluten meal as a partial replacement for fish meal in diets of sea bass (*Dicentrarchus labrax*) fry. *Bulletin of the National Institute of Oceanography and Fisheries* (Egypt), 27: 373–386.
- El-Haroun, E.R. & Bureau, D.P. 2007. Comparison of the bioavailability of lysine in blood meals of various origins to that of L-lysine HCL for rainbow trout (*Oncorhynchus mykiss*). *Aquaculture*, 262(2–4): 402–409.
- El-Haroun, E.R., Azevedo, P.A. & Bureau, D.P. 2009. High dietary incorporation levels of rendered animal protein ingredients in performance of rainbow trout (*Oncorhynchus mykiss* Walbaum, 1972). *Aquaculture*, 290(3–4): 269–274.
- Ellis, R.W., Clements, M., Tibbetts, A., Winfree, R. 2000. Reduction of the bioavailability of 20 µg/kg aflatoxin in trout feed containing clay. *Aquaculture*. 183: 179–188.
- El-Saidy, D., Dabrowski, K. & Bai, S.C. 2000. Nutritional effects of protein source in starter diets for channel catfish (*Ictalurus punctatus* Rafinesque) in suboptimal water temperature. *Aquaculture Research*, 31(12): 885–892.
- El-Saidy, D.M.S.D. & Gaber, M.M.A. 2002a. Evaluation of hulled sunflower meal as a dietary protein source for Nile tilapia, *Oreochromis niloticus* (L.), fingerlings. *Annals of Agricultural Science* (Moshtohor), 40(2): 831–841.
- El-Saidy, D.M.S.D. & Gaber, M.M.A. 2002b. Complete replacement of fish meal by soybean meal with dietary L-lysine supplementation for Nile tilapia *Oreochromis niloticus* (L.) fingerlings. *Journal of the World Aquaculture Society*, 33(3): 297–306.
- El-Saidy, D.M.S.D. & Gaber, M.M.A. 2003. Replacement of fish meal with a mixture of different plant protein sources in juvenile Nile tilapia, *Oreochromis niloticus* (L.) diets. *Aquaculture Research*, 34(13): 1119–1127.
- El-Saidy, D.M.S.D. & Gaber, M.M.A. 2004. Use of cottonseed meal supplemented with iron for detoxification of gossypol as a total replacement of fish meal in Nile tilapia, *Oreochromis niloticus* (L.) diets. *Aquaculture Research*, 35(9): 859–865.
- El-Saidy, D.M.S.D., Gaber, M.M.A. & Abd-Elshafy, A.S. 2005. Evaluation of cluster bean meal *Cyamopsis tetragonoloba* as a dietary protein source for common carp *Cyprinus carpio* L. *Journal of the World Aquaculture Society*, 36(3): 311–319.
- El-Saidy, D.M.S.D. & Saad, A.S. 2008. Evaluation of cow pea seed meal, *Vigna sinensis*, as a dietary protein replacer for Nile tilapia, *Oreochromis niloticus* (L.), fingerlings. *Journal of the World Aquaculture Society*, 39(5): 636–645.
- El-Sayed, A.F.M. 1998. Total replacement of fish meal with animal protein sources in Nile tilapia, *Oreochromis niloticus* (L.), feeds. *Aquaculture Research*, 29(4): 275–280.
- El-Sayed, A.F.M. 2003. Effects of fermentation methods on the nutritive value of water hyacinth for Nile tilapia *Oreochromis niloticus* (L.) fingerlings. *Aquaculture*, 218(1–4): 471–478.
- El-Sayed, A.F.M. 2006. *Tilapia culture*. London, UK, CABI Publishing Series, CABI International Publishers, London, 277 pp.
- El-Sayed, A.F.M. 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in Egypt, pp. 410–422. In: M.R. Hasan, T. Hecht, S.S. De Silva and A.G.J Tacon (eds). Study and analysis of feeds and fertilizers for sustainable aquaculture development. *FAO Fisheries Technical Paper* No. 497. Rome, FAO. 510 pp.
- El-Sayed, A.F.M., Mansour, C.R. & Ezzat, A.A. 2005. Effects of dietary lipid source on spawning performance of Nile tilapia (*Oreochromis niloticus*) broodstock reared at different water salinities. *Aquaculture* 248(1–4): 187–196.
- El-Sayed, Y.S., Khalil, R.H., & Saad, T.T. 2009. Acute toxicity of ochratoxin-A in marine water-reared sea bass (*Dicentrarchus labrax* L.). *Chemosphere*, 75(7): 878–882.
- El-Shafai, S.A., El-Gohary, F.A., Verreth, J.J., Schrama, J.W. & Gijzen, H.J. 2004. Apparent digestibility coefficient of duckweed (*Lemna minor*), fresh and dry for Nile tilapia (*Oreochromis niloticus* L.). *Aquaculture Research*, 35(6): 574–586.
- El-Sheekh, M.M. & Fathy, A.A. 2009. Variation of some nutritional constituents and fatty acid profiles of *Chlorella vulgaris* (Beijerinck) grown under auto and heterotrophic conditions. *International Journal of Botany*, 5(2): 153–159.

- Emre, Y., Sevgili, H. & Diler, I. 2003. Replacing fish meal with poultry by-product meal in practical diets for mirror carp (*Cyprinus carpio*) fingerlings. *Turkish Journal of Fisheries and Aquatic Sciences*, 3(2): 81–85.
- Engin, K. & Carter, C.G. 2002. Ingredient apparent digestibility coefficients for the Australian short-finned eel (*Anguilla australis australis*, Richardson). *Animal Science*, 75: 401–413.
- Engin, K. & Carter, C.G. 2005. Fish meal replacement by plant and animal by-products in diets for the Australian short-finned eel, *Anguilla australis australis* (Richardson). *Aquaculture Research*, 36(5): 445–454.
- Ergun, S., Yigit, M., Turker, A. & Harmantepe, B. 2008. Partial replacement of fishmeal by defatted soybean meal in diets for Black Sea turbot (*Psetta maeotica*): Growth and nutrient utilization in winter. *Israeli Journal of Aquaculture – Bamidgeh*, 60(3): 177–184.
- Ergun, S., Yigit, M., Turker, A. & Harmantepe, B. 2008a. Incorporation of soybean meal and hazelnut meal in diets for Black Sea turbot (*Scophthalmus maeoticus*). *Israeli Journal of Aquaculture – Bamidgeh* 60(1):27–36.
- Ergun, S., Yigit, M., Turker, A. & Harmantepe, B. 2008b. Partial replacement of fishmeal by defatted soybean meal in diets for Black Sea turbot (*Psetta maeotica*): Growth and nutrient utilization in winter. *Israeli Journal of Aquaculture – Bamidgeh*, 60(3): 177–184.
- Erturk, M.M. & Sevgili, H. 2003. Effects of replacement of fish meal with poultry by-product meals on apparent digestibility, body composition and protein efficiency ratio in a practical diets for rainbow trout, *Oncorhynchus mykiss*. *Asian-Australasian Journal of Animal Sciences*, 16(9): 1355–1359.
- Escaffre, A.M. & Kaushik, S.J. 1995. Survival and growth of first-feeding common carp larvae fed artificial diets containing soybean protein concentrate. *Aquaculture*, 129(1–4): 253.
- Escaffre, A.M., Zambonino Infante, J.L., Cahu, C.L., Mambrini, M., Bergot, P. & Kaushik, S.J. 1997. Nutritional value of soy protein concentrate for larvae of common carp (*Cyprinus carpio*) based on growth performance and digestive enzyme activities. *Aquaculture*, 153(1–2): 63–80.
- Escaffre, A.M., Kaushik, S. & Mambrini, M. 2007. Morphometric evaluation of changes in the digestive tract of rainbow trout (*Oncorhynchus mykiss*) due to fish meal replacement with soy protein concentrate. *Aquaculture*, 273(1): 127–138.
- Espe, M., Lemme, A., Petri, A. & El-Mowafi, A. 2006. Can Atlantic salmon (*Salmo salar*) grow on diets devoid of fish meal? *Aquaculture*, 255(1–4): 255–262.
- Espe, M., Lemme, A., Petri, A. & El-Mowafi, A. 2007. Assessment of lysine requirement for maximal protein accretion in Atlantic salmon using plant protein diets. *Aquaculture*, 263(1–4): 168–178.
- Eusebio, P.S. & Coloso, R.M. 1998. Evaluation of leguminous seed meals and leaf meals as plant protein sources in diets for juvenile *Penaeus indicus*. *Israeli Journal of Aquaculture – Bamidgeh*, 50(2): 47–54.
- Evans, J.J., Pasnik, D.J., Peres, H., Lim, C. & Klesius, P.H. 2005. No apparent differences in intestinal histology of channel catfish (*Ictalurus punctatus*) fed heat-treated and non-heat-treated raw soybean meal. *Aquaculture Nutrition*, 11(2): 123–129.
- Eya, J.C. & Lovell, R.T. 1997. Net absorption of dietary phosphorus from various inorganic sources and effect of fungal phytase on net absorption of plant phosphorus by channel catfish *Ictalurus punctatus*. *Journal of the World Aquaculture Society*, 28(4): 386–391.
- Eyo, A.A., Sikoki, F.D. & Solomon, G.S. 1995. Studies on the effect of replacement of fish meal with soybean meal, groundnut cake and blood meal in the diet on growth and food utilisation of *Clarias anguillaris* fingerlings. *Annu. Rep. Natl. Inst. Freshwat. Fish. Res. (Niger.)*, 1994: 108–113.
- Eyo, J.E. 2005. Effects of substituting soybean meal for maggot meal on acceptability of diets, growth performance and cost benefit of diets fed to hybrid catfish (*Heterobranchus bioersalis* x *Claris gariepinus*). *Journal of Science and Technology Research*, 4: 37–42.
- Ezieshi, E.V. & Olomu, J.M. 2007. Nutritional evaluation of palm kernel meal types: 1. Proximate composition and metabolizable energy values. *African Journal of Biotechnology*, 6(21): 2484–2486.
- Ezquerro-Brauer, J.H., Diaz, A.C. & Fenucci, J.L. 2007a. Harina de calamar, pp. 41–55. In: T.G. Galano, H. Villarreal-Colmenares and J.L. Fenucci (eds), *Manual de ingredientes proteicos y aditivos empleados en la formulacion de alimentos balanceados para camarones peneidos*. Subprograma II “Acuicultura” Red Tematica II.C, Proyecto II-8 Ciencia y Tecnologia El Desarrollo (CYTED). Argentina, Universidad Nacional de Mar del Plata, Argentina, 264 pp.
- Fafioye, O.O., Fagade, S.O., Adebisi, A.A., Jenyo, O. & Omoyinmi, G.A.K. 2005. Effects of dietary soybeans (*Glycine max* (L.) Merr.) on growth and body composition of African catfish (*Clarias gariepinus*, Burchell) fingerlings. *Turkish Journal of Fisheries and Aquatic Sciences*, 5(1): 11–15.
- Fagbenro, O.A. 1995. Evaluation of heat-processed cocoa pod husk meal as an energy feedstuff in production diets for the clariid catfish, *Clarias isheriensis* (Sydenham). *Aquaculture Nutrition*, 1(4): 221–225.
- Fagbenro, O.A. 1999a. Equi-protein replacement of soybean meal with winged bean meals in diets for the African clariid catfish, *Clarias gariepinus* (Burchell). *Journal of Aquaculture in the Tropics*, 14(2): 93–99.
- Fagbenro, O.A. 1999b. Formulation and evaluation of diets for the African catfish, *Clarias gariepinus* (Burchell), made by partial replacement of fish meal with winged bean (*Psophocarpus tetragonolobus* L. DC) seed meal. *Aquaculture Research*, 30(4): 249–257.
- Fagbenro, O.A. 1999c. Comparative evaluation of heat-processed Winged bean (*Psophocarpus tetragonolobus*) meals as partial replacement for fish meal in diets for the African catfish (*Clarias gariepinus*). *Aquaculture*, 170(3–4): 297–305.
- Fagbenro, O. 1999d. Apparent digestibility of various cereal grain by-products in common carp diets. *Aquaculture International* 7(4): 277–281.

- Fagbenro, O.A. 2004. Soybean meal replacement by roquette (*Eruca sativa* Miller) seed meal as protein feedstuff in diets for African cCatfish, *Clarias gariepinus* (Burchell 1822), fingerlings. *Aquaculture Research*, 35(10): 917–923.
- Fagbenro, O.A. & Bello-Olusoji, O.A. 1997. Preparation, nutrient composition and digestibility of fermented shrimp head silage. *Food Chemistry*, 60(4): 489–493.
- Fagbenro, O.A. & Davies, S.J. 2001. Use of soybean flour (dehulled, solvent-extracted soybean) as a fish meal substitute in practical diets for African catfish, *Clarias gariepinus* (Burchell 1822): growth, feed utilization and digestibility. *Journal of Applied Ichthyology*, 17(2): 64–69.
- Fagbenro, O.A. & Davies, S.J. 2004. Use of high percentage of soy protein concentrate as fish meal substitute in practical diets for African catfish, *Clarias gariepinus* (Burchell 1822): growth, diet utilization and digestibility. *Journal of Applied Aquaculture*, 16(1–3): 113–124.
- Fagbenro, O.A. & Jauncey, K. 1995a. Growth and protein utilization by juvenile catfish (*Clarias gariepinus*) fed dry diets containing co-dried lactic acid-fermented fish-silage and protein feedstuffs. *Bioresource Technology*, 51(1): 29–35.
- Fagbenro, O.A. & Jauncey, K. 1995b. Water stability, nutrient leaching and nutritional properties of moist fermented fish silage diets. *Aquacultural Engineering*, 14(2): 143–153.
- Fagbenro, O.A. & Jauncey, K. 1998. Physical and nutritional properties of moist fermented fish silage pellets as a protein supplement for tilapia (*Oreochromis niloticus*). *Animal Feed Science and Technology*, 71(1–2): 11–18.
- Fagbenro, O.A., Jauncey, K. & Krueger, R. 1997. Nutritive value of dried lactic acid fermented fish silage and soybean meal in dry diets for juvenile catfish, *Clarias gariepinus* (Burchell, 1822). *Journal of Applied Ichthyology – Zeitschrift Fur Angewandte Ichthyologie*, 13(1): 27–30.
- Fagbenro, O.A., Smith, M. A. K. & Amoo, A. I. 2000. Acha (*Digitaria exilis* stapf) meal compared with maize and sorghum meals as a dietary carbohydrate source for Nile tilapia (*Oreochromis niloticus* L.). *Israeli Journal of Aquaculture – Bamidgeh*, 52(1): 3–10.
- Falaye, A.E. & Jauncey, K. 1999. Acceptability and digestibility by tilapia (*Oreochromis niloticus*) of feeds containing cocoa husk. *Aquaculture Nutrition*, 5(3).
- Falaye, A.E. & Oloruntuyi, O.O. 1998. Nutritive potential of plantain peel meal and replacement value for maize in diets of African Catfish (*Clarias gariepinus*) fingerlings. *Tropical Agriculture*, 75(4): 488–492.
- FAO. 1998. *Animal feeding and food safety*. Food and Nutrition Paper 69. Rome, FAO. 48 pp. (www.fao.org/docrep/w8901e/w8901e00.htm).
- FAO/NACA/WHO. 1999. *Report of the FAO/NACA/WHO Study Group on Food Safety Issues Associated with Products from Aquaculture*. WHO Technical Report Series 883, WHO-HQ, Geneva, Switzerland, 55 pp. (www.who.int/fsf/trs883.pdf).
- FAO/WHO. 2003. *Code of Practice for Fish and Fishery Products*. Joint FAO/WHO Foods Standards Programme. Report CAC/RCP 52-2003. Rome, FAO. (Rev. 2004, 2005, 2007.).
- FAO/WHO. 2004. *Code of Practice for Good Animal Feeding*. Joint FAO/WHO Foods Standards Programme. Report CAC/RCP 54/2004. FAO, Rome.
- FAO/WHO. 2005. *Code of Practice to Minimise and Contain Antimicrobial Resistance*. Joint FAO/WHO Foods Standards Programme. Report CAC/RCP 61/2005. FAO, Rome.
- FAO/WHO. 2006. *Maximum Residue Limits for Veterinary Drugs*. Joint FAO/WHO Foods Standards Programme. Report CAC/MRL 2/2006. FAO, Rome.
- Farhangi, M. & Carter, C.G. 2001. Growth, physiological and immunological responses of rainbow trout (*Oncorhynchus mykiss*) to different dietary inclusion levels of dehulled lupin (*Lupinus angustifolius*). *Aquaculture Research*, 32(s1): 329–340.
- Faria, A.C.E.A., Hayashi, C., Galdioli, E.M. & Soares, C.M. 2001. Fishmeal in the diets of Nile tilapia fingerlings *Oreochromis niloticus* (L.), Thai strains. *Acta scientiarum*, 23(4): 903–908.
- Fasakin, E.A., Balogun, A.M. & Fasuru, B.E. 1999. Use of duckweed, *Spirodela polyrrhiza* L-Schleiden, as a protein feedstuff in practical diets for tilapia, *Oreochromis niloticus* (L.). *Aquaculture Research*, 30(5): 313–318.
- Fasakin, E.A., Balogun, A.M. & Ajayi, O.O. 2003. Evaluation of full-fat and defatted maggot meals in the feeding of clariid catfish *Clarias gariepinus* fingerlings. *Aquaculture Research*, 34(9): 733–738.
- Fasakin, E.A., Serwata, R.D. & Davies, S.J. 2005. Comparative utilization of rendered animal derived products with or without composite mixture of soybean meal in hybrid tilapia (*Oreochromis niloticus* x *Oreochromis mossambicus*) diets. *Aquaculture*, 249(1–4): 329–338.
- FDA (U.S. Food & Drug Administration). 2007. *GC-MS Method for Screening and Confirmation of Melamine and Related Analogs*, Version 2, May 7, 2007, U.S Food and Drug Administration, www.fda.gov/AboutFDA/CentersOffices/CVM/WhatWeDo/ucm134743.htm
- Felix, N. & Sudharsan, M. 2004. Effect of glycine betaine, a feed attractant affecting growth and feed conversion of juvenile freshwater prawn *Macrobrachium rosenbergii*. *Aquaculture Nutrition*, 10(3): 193–197.
- Feng, J. & Wang, M. 2004. Effects of feeding stimulant-shrimp peptides on growth performance of *Peneaus vannamei* fed plant protein-based diet. *Marine sciences/Haiyang Kexue*, 28(4): 48–51.
- Fenucci, J.L. 2007. Harina de pescado, pp. 18–40. In: T.G. Galano, H. Villarreal-Colmenares and J.L. Fenucci (eds), *Manual de ingredientes proteicos y aditivos empleados en la formulacion de alimentos balanceados para camarones peneidos*. Subprograma II “Acuicultura” Red Tematica II.C, Proyecto II-8 Ciencia y Tecnologia El Desarrollo (CYTED). Argentina, Universidad Nacional de Mar del Plata. , Argentina, 264 pp.

- Fernandez, C.H. & Sukumaran, N.S. 1995. Effect of crystalline amino acids on the growth performance of Indian white shrimp, *Penaeus indicus* (Milne Edwards). *Journal of Aquaculture in the Tropics*, .Calcutta, 10(3): 245–260.
- Figueiredo-Silva, A., Rocha, E., Dias, J., Silva, P., Rema, P., Gomes, E. & Valente, L.M.P. 2005. Partial replacement of fish oil by soybean oil on lipid distribution and liver histology in European sea bass (*Dicentrarchus labrax*) and rainbow trout (*Oncorhynchus mykiss*) juveniles. *Aquaculture Nutrition*, 11(2): 147–155.
- Fletcher, A. & Warburton, K. 1997. Consumption of fresh and decomposed duckweed *Spirodela* sp. by Redclaw crayfish, *Cherax quadricarinatus* (von Martens). *Aquaculture Research*, 28(5): 379–382.
- Floreto, E.A.T., Bayer, R.C. & Brown, P.B. 2000. The effects of soybean-based diets, with and without amino acid supplementation, on growth and biochemical composition of juvenile American lobster, *Homarus americanus*. *Aquaculture*, 189(3–4): 211–235.
- Floreto, E.A.T., Brown, P.B. & Bayer, R.C. 2001. The effects of krill hydrolysate-supplemented soybean based diets on the growth, colouration, amino and fatty acid profiles of juvenile American lobster, *Homarus americanus*. *Aquaculture Nutrition*, 7(1): 33–43.
- Folador, J.F., Karr-Lilienthal, L.K., Parsons, C. M., Bauer, L.L., Utterback, P.L., Schasteen, C.S., Bechtel, P.J. & Fahey, G.C. 2006. Fish meals, fish components, and fish protein hydrolysates as potential ingredients in pet foods. *Journal of Animal Science*, 84: 2752–2765.
- Folch, J., Lees, R. & Sloane-Stanley, G.H. 1957. A simple method for isolation and purification of total lipids for animal tissues. *Journal of Biological Chemistry*, 226: 497–509
- Fonseca-Madrigal, J., Karalazos, V., Campbell, P.J., Bell, J. G. & Tocher, D.R. 2005. Influence of dietary palm oil on growth, tissue fatty acid compositions, and fatty acid metabolism in liver and intestine in rainbow trout (*Oncorhynchus mykiss*). *Aquaculture Nutrition*, 11(4): 241–250.
- Fontagné, S., Bazin, D., Brèque, J., Vachot, C., Bernarde, C., Rouault, T., Bergot, P. 2006. Effects of dietary oxidized lipid and vitamin A on the early development and antioxidant status of Siberian sturgeon (*Acipenser baeri*) larvae. *Aquaculture*, 257(1–4): 400–411.
- Fontainhas-Fernandes, A., Gomes, E., Reis-Henriques, M.A. & Coimbra, J. 1999. Replacement of fish meal by plant proteins in the diet of Nile tilapia: digestibility and growth performance. *Aquaculture International*, 7(1): 57–67.
- Forde-Skjaervik, O., Refstie, S., Aslaksen, M.A. & Skrede, A. 2006. Digestibility of diets containing different soybean meals in Atlantic cod (*Gadus morhua*); comparison of collection methods and mapping of digestibility in different sections of the gastrointestinal tract. *Aquaculture*, 261(1): 241–258.
- Forster, I., Higgs, D.A., Dosanjh, B.S., Rowshandeli, M. & Parr, J. 1999. Potential for dietary phytase to improve the nutritive value of canola protein concentrate and decrease phosphorus output in rainbow trout (*Oncorhynchus mykiss*) held in 11 degree C fresh water. *Aquaculture*, 179(1–4): 109–125.
- Forster, I., Babbitt, J.K. & Smiley, S. 2003. Nutritional quality of Alaska white fish meals made with different levels of hydrolyzed stickwater for Pacific threadfin (*Polydactylus sexfilis*). In: P.J. Bechtel (ed.), *Advances in Seafood Byproducts: 2002 Conference Proceedings*. Fairbanks, Alaska, USA, Alaska Sea Grant College Program, University of Alaska Fairbanks, . Fairbanks, 566 pp.
- Forster, I., Babbitt, J.K. & Smiley, S. 2005. Comparison of the nutritional quality of fish meals made from by-products of the Alaska fishing industry for Pacific threadfin (*Polydactylus sexfilis*). *Journal of the World Aquaculture Society*, 36(4): 530–537.
- Forster, I.P. & Dominy, W.G. 2006. Efficacy of three methionine sources in diets for Pacific white shrimp, *Litopenaeus vannamei*. *Journal of the World Aquaculture Society*, 37(4): 474–480.
- Forster, I.P., Dominy, W. & Tacon, A.G.J. 2002. The use of concentrates and other soy products in shrimp feeds, pp. 527–540. In: L.E. Cruz-Suarez, D. Ricque-Mari, M. Tapia-Salazar, M.G. Gaxiola-Cortes and N. Simeos (eds), *Advances en Nutricion Acuicola VI*. Memorias de VI Simposium Internacional de Nutricion Acuicola. 3–6 September 2002. Cancun, Quintana Roo, Mexico.
- Forster, I.P., Dominy, W., Obaldo, L. & Tacon, A.G. J. 2003. Rendered meat and bone meals as ingredients of diets for shrimp *Litopenaeus vannamei* (Boone, 1931). *Aquaculture*, 219(1–4): 655–670.
- Fotedar, R. 2004. Effect of dietary protein and lipid source on the growth, survival, condition indices, and body composition of marron, *Cherax tenuimanus* (Smith). *Aquaculture*, 230(1–4): 439–455.
- Fountoulaki, E., Vasilaki, A., Hurtado, R., Grigorakis, K., Karacostas, I., Nengas, I., Rigos, G., Kotzamanis, Y., Venou, B. & Alexis, M.N. 2009. Fish oil substitution by vegetable oils in commercial diets for gilthead sea bream (*Sparus aurata* L.); effects on growth performance, flesh quality and fillet fatty acid profile Recovery of fatty acid profiles by a fish oil finishing diet under fluctuating water temperatures. *Aquaculture*, 289(3–4): 317–326.
- Fournier, V., Huelvan, C. & Desbruyeres, E. 2004. Incorporation of a mixture of plant feedstuffs as substitute for fish meal in diets of juvenile turbot (*Psetta maxima*). *Aquaculture*, 236(1–4): 451–465.
- Fournier, V., Gouillou-Coustans, M.F., Métailler, R., Vachot, C., Moriceau, J., Le Delliou, H., Huelvan, C., Desbruyeres, E. & Kaushik, S.J. 2002. Nitrogen utilisation and ureogenesis as affected by dietary nucleic acid in rainbow trout (*Oncorhynchus mykiss*) and turbot (*Psetta maxima*). *Fish Physiology and Biochemistry*, 26(2): 177–188.
- Fox, J.M., Li-Chan, E. & Lawrence, A. L. 1995. Carbodiimide-mediated covalent attachment of lysine to wheat gluten and its apparent digestibility by penaeid shrimp. *Journal of Agricultural and Food Chemistry*, 43(3): 733–737.

- Fox, J.M., Lawrence, A. L. & Li-Chan, E. 2009. Tail muscle free amino acid concentration of Pacific White Shrimp, *Litopenaeus vannamei*, fed diets containing protein-bound versus crystalline amino acids. *Journal of the World Aquaculture Society*, 40(2): 171–181.
- Fracalossi, D.M. & Lovell, R.T. 1995. Growth and liver polar fatty-acid composition of year 1 channel catfish fed various lipid sources at two water temperatures. *Progressive Fish-Culturist*, 57(2): 107–113.
- Fraga, I., Galindo, J., Reyes, R., Alvarez, S., Gallardo, N., Forrellat, A. & Gonzalez, R. 1996. Assessment of different protein sources for feeding white shrimp *Penaes schmitti*. *Rev. Cub. Invest. Pesq.* 20(1): 6–9.
- Francis, D.S., Turchini, G.M., Jones, P.L., De Silva, S.S. 2006. Effects of dietary oil source on the growth and muscle fatty acid composition of Murray cod, *Maccullochella peelii peelii*. *Aquaculture*, 253: 547–556.
- Francis, D.S., Turchini, G.M., Jones, P.L., De Silva, S.S. 2007a. Dietary lipid source modulates in vivo fatty acid metabolism in the freshwater fish, Murray cod (*Maccullochella peelii peelii*). *Journal of Agricultural and Food Chemistry*, 55: 1582–1591.
- Francis, D.S., Turchini, G.M., Jones, P.L., De Silva, S.S. 2007b. Effects of fish oil substitution with a mix blend vegetable oil on nutrient digestibility in Murray cod, *Maccullochella peelii peelii*. *Aquaculture*, 269: 447–455.
- Francis, D.S., Turchini, G.M., Jones, P.L., De Silva, S.S. 2007c. Growth performance, feed efficiency and fatty acid composition of juvenile Murray cod, *Maccullochella peelii peelii*, fed graded levels of canola and linseed oil. *Aquaculture Nutrition*, 13: 335–350.
- Francis, G., Makar, H.P.S. & Becker, K. 2001. Antinutritional factors present in plant-derived alternate fish feed ingredients and their effects in fish. *Aquaculture*, 199(3–4): 197–227.
- Francis, G., Makkar, H.P.S. & Becker, K. 2005. Quillaja saponins -- a natural growth promoter for fish. *Animal Feed Science and Technology*, 121(1–2): 147–157.
- Fraser, A.J., Tocher, D.R. & Sargent, J.R. 1985. Thin layer chromatography, flame ionization detection and the quantification of marine neutral lipids and phospholipids. *Journal of Experimental Marine Biology and Ecology*, 88: 91–99.
- Fredette, M., Batt, J. & Castell, J. 2000. Feeding stimulant for juvenile winter flounders. *North American Journal of Aquaculture*, 62(2): 157–160.
- Froystad, M.K., Lilleeng, E., Bakke-McKellep, A.M., Vekterud, K., Hemre, G.I. & Krogdahl, A. 2008. Gene expression in distal intestine of Atlantic salmon (*Salmo salar* L.) fed genetically modified soybean meal. *Aquaculture Nutrition*, 14(3): 204–214.
- Fujii, K., Imazato, E., Nakashima, H., Ooi, O. & Saeki, A. 2006. Isolation of the non-fastidious microalga with astaxanthin-accumulating property and its potential for application to aquaculture. *Aquaculture*, 261(1): 285–293.
- Funge-Smith, S., Lindebo, E. & Staples, D. 2005. *Asian fisheries today: The production and use of low value/trash fish from marine fisheries in the Asia-Pacific region*. Bangkok, FAO Regional Office for Asia and the Pacific (RAP), RAP Publication 2005/16., Bangkok, Thailand, 38 pp.
- Furuichi, M., Furusho, Y., Hossain, M.A., Matsui, S. & Azuma, R. 1997a. Essentiality of Ca supplement to white fish meal diet for tiger puffer. *Journal of the Faculty of Agriculture, Kyushu University*, 42(1–2): 69–76.
- Furuichi, M., Furusho, Y., Matsui, S. & Kitajima, C. 1997b. Essentiality of mineral mixture supplement to white fish meal diet for tiger puffer. *Journal of the Faculty of Agriculture, Kyushu University*, 42(1–2): 77–85.
- Furuya, V.R.B., Hayashi, C. & Furuya, W.M. 1997. Canola meal as feeding for Nile tilapia (*Oreochromis niloticus* L.) during sexual reversion period. *Revista da Sociedade Brasileira de Zootecnia – Journal of the Brazilian Society of Animal Science*, 26(6): 1067–1073.
- Furuya, W.M., Pezzato, L.E., de Miranda, E.C., Furuya, V.R.B., Barros, M.M. & Lanna, E.A.T. 2001. Apparent nutrient and energy digestibility of canola meal for Nile tilapia (*Oreochromis niloticus*). *Revista Brasileira De Zootecnia – Brazilian Journal of Animal Science*, 30(3): 611–616.
- Gaber, M.M. 2005. The effect of different levels of krill meal supplementation of soybean-based diets on feed intake, digestibility, and chemical composition of juvenile Nile tilapia *Oreochromis niloticus*, L. *Journal of the World Aquaculture Society*, 36(3): 346–353.
- Gaber, M.M. 2006. Partial and complete replacement of fish meal by broad bean meal in feeds for Nile tilapia, *Oreochromis niloticus*, L., fry. *Aquaculture Research*, 37(10): 986–993.
- Gabriel, U.U., Akinrotimi, O.A., Anyanwu, P.E., Bekibele, D.O. & Onunkwo, D.N. 2007. The role of dietary phytase in formulation of least cost and less polluting fish feed for sustainable aquaculture development in Nigeria. *African Journal of Agricultural Research*, 2(7): 279–286.
- Gabrielsen, B.O. & Austreng, E. 1998. Growth, product quality and immune status of Atlantic salmon, *Salmo salar* L., fed wet feed with alginate. *Aquaculture Research*, 29(6): 397–401.
- Galano, T.G., Villarreal-Colmenares, H. & Fenucci, J.L. (eds). 2007. *Manual de ingredientes proteicos y aditivos empleados en la formulacion de alimentos balanceados para camarones peneidos*. Subprograma II “Acuicultura” Red Tematica II.C, Proyecto II-8 Ciencia y Tecnologia El Desarrollo (CYTED). Argentina, Universidad Nacional de Mar del Plata. 264 pp.
- Gallagher, M.L. & LaDouceur, M. 1995. The use of blood meal and poultry products as partial replacements for fish meal in diets for juvenile palmetto bass (*Morone saxatilis* x *M. chrysops*). *Journal of Applied Aquaculture*, 5: 357–66.

- Gallardo, P.P., Pedroza-Islas, R., Garcia-Galano, T., Pascual, C., Rosal, C., Sanchez, A. & Gaxiola, G. 2002. Replacement of live food with a microbound diet in feeding *Litopenaeus setiferus* (Burkenroad) larvae. *Aquaculture Research*, 33(9): 681–691.
- Ganesh, P., Mohan, M., Subha, R. & Vijayalakshmi, G.S. 2003. Earthworm meal for fish feed formulation and its influence on growth of mrigal fingerlings. *Journal of Ecobiology*, 15(3): 181–184.
- Ganga, R., Bell, J.G., Montero, D., Robaina, L., Caballero, M.J., Izquierdo, M.S. 2005. Effect of dietary lipids on plasma fatty acid profiles and prostaglandin and leptin production in gilthead seabream (*Sparus aurata*). *Comparative Biochemistry and Physiology*, Part B 142: 410–418.
- Gangadhara, B., Nandeesh, M. C., Keshavanath, P., Singh, K. P. & Maniserry, J. K. 2002. Evaluation of rapeseed meal as a feed ingredient in Catla (*Catla catla*) diets. *Journal of Aquaculture in the Tropics*, 17(4): 261–272.
- Ganuza, E., Benitez-Santana, T., Atalah, E., Vega-Orellana, O., Ganga, R. & Izquierdo, M.S. 2008. *Cryptocodinium cobui* and *Schizochytrium* sp as potential substitutes to fisheries-derived oils from seabream (*Sparus aurata*) microdiets. *Aquaculture*, 277(1–2): 109–116.
- Gao, L., Shi, Z. & Ai, C. 2005. Effect of dietary lipid sources on the serum biochemical indices of *Acipenser schrenckii* juvenile. *Marine fisheries/Haiyang Yuye*, 27(4): 319–323.
- Garcia, T., Marquez, G., Carrillo, O., Gelabert, R., Vidal, L. & Becquer, U. 1997. Evaluacion de la levadura torula seca en dietas artificiales para la alimentacion de larvas y postlarvas de camarón blanco *Penaeus schmitti*. En: *Memorias IV Congreso Ecuatoriano de Acuicultura*, Guayaquil, Oct. 1997.
- Garcia-Gallego, M., Akharbach, H. & de la Higuera, M. 1998. Use of protein sources alternative to fish meal in diets with amino acids supplementation for the European eel (*Anguilla anguilla*). *Animal Science*, 66: 285–292.
- Garcia-Esquivel, Z. & Felbeck, H. 2009. Comparative performance of juvenile red abalone, *Haliotis rufescens*, reared in laboratory with fresh kelp and balanced diets. *Aquaculture Nutrition*, 15(2): 209–217.
- Garcia-Galano, T. 2007. Levaduras, pp. 186–193. In: T.G. Galano, H. Villarreal-Colmenares and J.L. Fenucci (eds), *Manual de ingredientes proteicos y aditivos empleados en la formulacion de alimentos balanceados para camarones peneidos*. Subprograma II “Acuicultura” Red Tematica II.C, Proyecto II-8 Ciencia y Tecnologia El Desarrollo (CYTED). Argentina, Universidad Nacional de Mar del Plata. 264 pp.
- Garcia-Ulloa, G.M., Lopez-Chavarin, H.M., Rodriguez-Gonzalez, H. & Villarreal-Colmenares, H. 2003. Growth of redclaw crayfish *Cherax quadricarinatus* (Von Martens 1868) (Decapoda: Parastacidae) juveniles fed isoproteic diets with partial or total substitution of fish meal by soya bean meal: preliminary study. *Aquaculture Nutrition*, 9(1): 25–31.
- Garcia-Ulloa Gomez, M., Lopez-Aceves, L. A. & Ponce-Palafox, J.T. 2008. Growth of fresh-water prawn *Macrobrachium tenellum* (Smith, 1871) juveniles fed isoproteic diets substituting fish meal by soya bean meal. *Brazilian Archives of Biology and Technology*, 51(1): 57–65.
- Garduno-Lugo, M. & Olvera-Novoa, M.A. 2008. Potential of the use of peanut (*Arachis hypogaea*) leaf meal as a partial replacement for fish meal in diets for Nile tilapia (*Oreochromis niloticus* L.). *Aquaculture Research*, 39(12): 1299–1306.
- Garg, S.K. & Bhatnagar, A. 2000. Effect of fertilization frequency on pond productivity and fish biomass in still water ponds stocked with *Cirrhinus mrigala* (Ham.). *Aquaculture Research*, 31: 409–414.
- Garg, S.K., Kalla, A. & Bhatnagar, A. 2002. Evaluation of raw and hydrothermally processed leguminous seeds as supplementary feed for the growth of two Indian major carp species. *Aquaculture Research*, 33(3): 151–163.
- Gatlin III, D., Barrows, F., Bellis, D., Brown, P., Campen, J., Dabrowski, K., Gaylord, T. G., Hardy, R.W., Herman, E.M., Hu, G., Krogdahl, A., Nelson, R., Overturf, K.E., Rust, M., Sealey, W., Skonberg, D., Souza, E.J., Stone, D., Wilson, R.F. 2007. Expanding the utilization of sustainable plant products in aquafeeds: a review. *Aquaculture Research*, 38: 551–579.
- Gaxiola, G. 2007. Subproductos cáncinos, pp. 82–93. In: T.G. Galano, H. Villarreal-Colmenares and J.L. Fenucci (eds), *Manual de ingredientes proteicos y aditivos empleados en la formulacion de alimentos balanceados para camarones peneidos*. Subprograma II “Acuicultura” Red Tematica II.C, Proyecto II-8 Ciencia y Tecnologia El Desarrollo (CYTED). Argentina, Universidad Nacional de Mar del Plata. 264 pp.
- Gaylord, T.G. & Barrows, F.T. 2009. Multiple amino acid supplementations to reduce dietary protein in plant-based rainbow trout, *Oncorhynchus mykiss*, feeds. *Aquaculture*, 287(1–2): 180–184.
- Gaylord, T.G. & Gatlin, D.M. 1996. Determination of digestibility coefficients of various feedstuffs for red drum (*Sciaenops ocellatus*). *Aquaculture*, 139(3–4): 303–314.
- Gaylord, T.G. & Rawles, S.D. 2005. The modification of poultry by-product meal for use in hybrid striped bass *Morone chrysops* X *M. saxatilis* diets. *Journal of the World Aquaculture Society*, 36(3): 363–374.
- Gaylord, T.G., Sealey, W.M. & Gatlin, D.M. 2002. Evaluation of protein reduction and lysine supplementation of production diets for channel catfish. *North American Journal of Aquaculture*, 64(3): 175–181.
- Gaylord, T.G., Rawles, S.D. & Gatlin, D.M. 2004. Amino acid availability from animal, blended, and plant feedstuffs for hybrid striped bass (*Morone chrysops* x *M. saxatilis*). *Aquaculture Nutrition*, 10(5): 345–352.
- Gaylord, T.G., Schwarz, M.H., Davitt, G.M., Cool, R.W., Jahncke, M.L. & Craig, S.R. 2003. Dietary lipid utilization by juvenile summer flounder *Paralichthys dentatus*. *Journal of the World Aquaculture Society*, 34(2): 229–235.

- Gaylord, G.T., Barrows, F.T., Teague, A.M., Johansen, K.A., Overturf, K.E., Shepherd, B. 2007. Supplementation of taurine and methionine to all-plant protein diets for rainbow trout (*Oncorhynchus mykiss*). *Aquaculture*, 269(1–4): 514–524.
- Gebeyehu, G.M., Saad, C.R., Kamarudin, M.S., Halim R.A. & Alimon, R.A. 2004. Effect of inclusion level of *Gliricidia sepium* Jacquin leaf meal on growth and feed utilization in the diet of Mozambique tilapia, *Oreochromis mossambicus* Peters. *Journal of Aquaculture in the Tropics*, 19(4): 267–276.
- Genc, E., Yilmaz, E., Akyurt, I. 2005. Effects of dietary fish oil, soy-acid oil, and yellow grease on growth and hepatic lipidosis of hybrid tilapia fry. *Israeli Journal of Aquaculture – Bamidgeh*, 57(2): 90–96.
- Genodepa, J., Zeng, C. & Southgate, P.C. 2007. Influence of binder type on leaching rate and ingestion of microbound diets by mud crab, *Scylla serrata* (Forsskal), larvae. *Aquaculture Research*, 38(14): 1486–1494.
- Geurden, I., Charlon, N., Marion, D. & Bergot, P. 1995a. Dietary phospholipids and body deformities in carp *Cyprinus carpio* L. larvae. In: P. Lavens, E. Jaspers and I. Roelants (eds), Larvi '95 – Fish and Shellfish Symposium. Gent, Belgium, *Europ. Aquacult. Soc., Spec. Publ. 24* (1995), pp. 162–165.
- Geurden, I., Coutteau, P. & Sorgeloos, P. 1995b. Dietary phospholipids for European sea bass (*Dicentrarchus labrax* L.) during first on-growing. In: P. Lavens, E. Jaspers and I. Roelants (eds), Larvi '95 – Fish and Shellfish Symposium. Gent, Belgium, *Europ. Aquacult. Soc., Spec. Publ. 24* (1995), pp. 175–178.
- Geurden, I., Radünz-Neto, J. & Bergot, P. 1995c. Essentiality of dietary phospholipids for carp (*Cyprinus carpio*) larvae. *Aquaculture*, 131: 303–314.
- Geurden, I., Corraze, G., Boujard, T. 2007. Self-feeding behavior of rainbow trout, *Oncorhynchus mykiss*, offered diets with distinct feed oils. *Applied Animal Behavioural Science*, 108: 313–326.
- Geurden, I., Kaushik, S. & Corraze, G. 2008. Dietary phosphatidylcholine affects postprandial plasma levels and digestibility of lipid in common carp (*Cyprinus carpio*). *British Journal of Nutrition*, 100(3): 512–517.
- Geurden, I., Jutfelt, F., Olsen, R.E. & Sundell, K.S. 2009. A vegetable oil feeding history affects digestibility and intestinal fatty acid uptake in juvenile rainbow trout *Oncorhynchus mykiss*. *Comparative Biochemistry and Physiology, Part A – Molecular and Integrative Physiology*, 152(4): 552–559.
- Ghaffar, A., Afzal, M. & Iqbal, M. 2002. Fish pond fertilization: comparison of ecological conditions under different fertilizer regimes. *Journal of Biological Sciences*, 2(9): 620–622.
- Gibbs, V.K., Watts, S.A., Lawrence, A.L. & Lawrence, J.M. 2009. Dietary phospholipids affect growth and production of juvenile sea urchin *Lytechinus variegatus*. *Aquaculture*, 292: 95–103.
- Gilchrist, M.J., Greko, C., Wallinga, D.B., Beran, G.W., Riley, D.G. & Thorne, P.S. 2007. The potential role of concentrated animal feeding operations in infectious disease epidemics and antibiotic resistance. *Environmental Health Perspectives*, 115(2): 313–316.
- Gildberg, A., Johansen, A. & Bogwald, J. 1995. Growth and survival of Atlantic salmon (*Salmo salar*) fry given diets supplemented with fish protein hydrolysate and lactic acid bacteria during a challenge trial with *Aeromonas salmonicida*. *Aquaculture*, 138: 23–34.
- Gill, N., Higgs, D.A., Skura, B.J., Rowshandeli, M., Dosanjh, B.S., Mann, J. & Gannam, A.L. 2006. Nutritive value of partially dehulled and extruded sunflower meal for post-smolt Atlantic salmon (*Salmo salar* L.) in sea water. *Aquaculture Research*, 37(13): 1348–1359.
- Gill, T.A. 2000. Waste from processing aquatic animals and animal products: implications on aquatic pathogen transfer. FAO Fisheries Circular, No. 956. Rome, FAO. 26 pp.
- Giri, S.S., Sahoo, S.K., Lenka, S., Rangacharyulu, P.V., Pul, B.N., Sahu, A.K., Mohanty, S.N., Mukhopadhyay, P.K. 2005. Effects of partial replacement of dietary fish-meal by meat-meal, goat liver and shrimp-meal on growth and survival of *Clarias batrachus* (Linn.). *Indian Journal of Animal Sciences*, 75(8): 977–981.
- Gjoenen, T., Obach, A., Roesjoe, C., Helland, B.G., Rosenlund, G., Hvattum, E. & Ruyter, B. 2004. Effect of dietary lipids on macrophage function, stress susceptibility and disease resistance in Atlantic Salmon (*Salmo salar*). *Fish Physiology and Biochemistry*, 30(2): 149–161.
- Glencross, B.D. 2009. Exploring the nutritional demand for essential fatty acids by aquaculture species. *Reviews in Aquaculture*, 1(2): 71–124.
- Glencross, B. & Hawkins, W. 2004. A comparison of the digestibility of lupin (*Lupinus* sp.) kernel meals as dietary protein resources when fed to either, rainbow trout, *Oncorhynchus mykiss* or red seabream, *Pagrus auratus*. *Aquaculture Nutrition*, 10(2): 65–73.
- Glencross, B.D., Smith, D.M. & Williams, K.C. 1998. Effect of dietary phospholipids on digestion of neutral lipid by the prawn *Penaeus monodon*. *Journal of the World Aquaculture Society*, 29(3): 365–369.
- Glencross, B.D., Curnow, J. & Hawkins, W. 2003a. Evaluation of the variability in chemical composition and digestibility of different lupin (*Lupinus angustifolius*) kernel meals when fed to rainbow trout (*Oncorhynchus mykiss*). *Animal Feed Science and Technology*, 107(1–4): 117–128.
- Glencross, B.D., Boujard, T. & Kaushik, S.J. 2003b. Influence of oligosaccharides on the digestibility of lupin meals when fed to rainbow trout, *Oncorhynchus mykiss*. *Aquaculture*, 219(1–4): 703–713.
- Glencross, B.D., Hawkins, W.E., Curnow, J.G. 2003c. Evaluation of canola oils as alternative lipid resources in diets for juvenile red seabream, *Pagrus auratus*. *Aquaculture Nutrition*, 9: 305–315.
- Glencross, B.D., Hawkins, W.E., Curnow, J.G. 2003d. Restoration of the fatty acid composition of red seabream (*Pagrus auratus*) using a fish oil finishing diet after grow-out on plant oil based diets. *Aquaculture Nutrition*, 9: 409–418.

- Glencross, B.D., Curnow, J., Hawkins, W., Kissil, G.W. & Peterson, D. 2003e. Evaluation of the feed value of a transgenic strain of the narrow-leaf lupin (*Lupinus angustifolius*) in the diet of the marine fish, *Pagrus auratus*. *Aquaculture Nutrition*, 9(3): 197–206.
- Glencross, B.D., Hawkins, W. & Curnow, J. 2004a. Nutritional assessment of Australian canola meals. I. Evaluation of canola oil extraction method and meal processing conditions on the digestible value of canola meals fed to the red seabream (*Pagrus auratus*, Paulin). *Aquaculture Research*, 35(1): 15–24.
- Glencross, B.D., Hawkins, W. & Curnow, J. 2004b. Nutritional assessment of Australian canola meals. II. Evaluation of the influence of the canola oil extraction method on the protein value of canola meals fed to the red seabream (*Pagrus auratus*, Paulin). *Aquaculture Research*, 35(1): 25–34.
- Glencross, B.D., Carter, C.G., Duijster, N., Evans, D.R., Dods, K., McCafferty, P., Hawkins, W.E., Maas, R. & Sipsas, S. 2004c. A comparison of the digestibility of a range of lupin and soybean protein products when fed to either Atlantic salmon (*Salmo salar*) or rainbow trout (*Oncorhynchus mykiss*). *Aquaculture*, 237(1–4): 333–346.
- Glencross, B.D., Evans, D., Hawkins, W. & Jones, B. 2004d. Evaluation of dietary inclusion of yellow lupin (*Lupinus luteus*) kernel meal on the growth, feed utilisation and tissue histology of rainbow trout (*Oncorhynchus mykiss*). *Aquaculture*, 235(1–4): 411–422.
- Glencross, B.D., Evans, D., Dods, K., McCafferty, P., Hawkins, W., Maas, R. & Sipsas, S. 2005. Evaluation of the digestible value of lupin and soybean protein concentrates and isolates when fed to rainbow trout, *Oncorhynchus mykiss*, using either stripping or settlement faecal collection methods. *Aquaculture*, 245(1–4): 211–220.
- Glencross, B.D., Hawkins, W., Evans, D., Rutherford, N., Dods, K., Maas, R., McCafferty, P. & Sipsas, S. 2006. Evaluation of the nutritional value of prototype lupin protein concentrates when fed to rainbow trout (*Oncorhynchus mykiss*). *Aquaculture*, 251(1): 66–77.
- Glencross, B.D., Hawkins, W., Veitch, C., Dods, K., McCafferty, P. & Hauler, R. 2007a. The influence of dehulling efficiency on the digestible value of lupin (*Lupinus angustifolius*) kernel meal when fed to rainbow trout (*Oncorhynchus mykiss*). *Aquaculture Nutrition*, 13: 462–470.
- Glencross, B.D., Hawkins, W., Evans, D., Rutherford, N., Dods, K., McCafferty, P. & Sipsas, S. 2007b. Evaluation of the influence of drying process on the nutritional value of lupin protein concentrates when fed to rainbow trout (*Oncorhynchus mykiss*). *Aquaculture*, 265(1–4): 218–229.
- Glencross, B.D., Hawkins, W., Evans, D., Rutherford, N., Dods, K., McCafferty, P. & Sipsas, S. 2008a. Evaluation of the influence of *Lupinus angustifolius* kernel meal on dietary nutrient and energy utilization efficiency by rainbow trout (*Oncorhynchus mykiss*). *Aquaculture Nutrition*, 14(2): 129–138.
- Glencross, B.D., Hawkins, W., Evans, D., Rutherford, N., Dods, K., McCafferty, P. & Sipsas, S. 2008b. Assessing the implications of variability in the digestible protein and energy value of lupin kernel meals when fed to rainbow trout, *Oncorhynchus mykiss*. *Aquaculture*, 277(3–4): 251–262.
- Glover, C.N., Petri, D., Tollefsen, K-E., Jorum, N., Handy, R.D. & Berntssen, M.H.G. 2007. The sensitivity of Atlantic salmon (*Salmo salar*) to dietary endosulfan exposure using tissue biochemistry and histology. *Aquatic Toxicology*, 84(3): 346–355.
- Goda, A.M.A.S. 2007. Effect of dietary soybean meal and phytase levels on growth, feed utilization and phosphorus discharge for Nile tilapia *Oreochromis niloticus* (L.). *Journal of Fisheries and Aquatic Science*, 2(4): 248–263.
- Goda, A.M.A.S., Wafa, M.E., El-Haroun, E.R., Chowdhury, M.A.K. 2007. Growth performance and feed utilization of Nile tilapia *Oreochromis niloticus* (Linnaeus, 1758) and tilapia galilae *Sarotherodon galilaeus* (Linnaeus, 1758) fingerlings fed plant protein-based diets. *Aquaculture Research*, 38(8): 827–837.
- Goda, A.M.A.S., El-Haroun, E.R. & Chowdhury, M.A.K. 2007b. Effect of totally or partially replacing fish meal by alternative protein sources on growth of African catfish *Clarias gariepinus* (Burchell, 1822) reared in concrete tanks. *Aquaculture Research*, 38(3): 279–287.
- Golez, N.V. 2002. Processing of feedstuffs and aquafeeds, pp.125–147. In: O.M. Millamena, R.M. Coloso and F.P. Pascual (eds), *Nutrition in Tropical Aquaculture*. Tigbauan, Iloilo, Philippines, Aquaculture Department, Southeast Asian Fisheries Development Center. 221 pp.
- Gomes, E.F., Rema, P. & Kaushik, S.J. 1995. Replacement of fish meal by plant proteins in the diet of rainbow trout (*Oncorhynchus mykiss*): Digestibility and growth performance. *Aquaculture*, 130(2–3): 177–186.
- Gomes, E., Dias, J. & Kaushik, S.J. 1997. Improvement of feed intake through supplementation with an attractant mix in European seabass fed plant-protein rich diets. *Aquat. Living Resour./Ressour. Vivantes Aquat.*, 10(6): 385–389.
- Gomez, M.G., Lopez-Aceves, L.A., Ponce-Palafox, J.T., Rodriguez-Gonzalez, H. & Arredondo-Figueroa, J.L. 2008. Growth of fresh-water prawn *Macrobrachium tenellum* (Smith, 1871) juveniles fed isoproteic diets substituting fish meal by soya bean meal. *Brazilian Archives of Biology and Technology*, 51(1): 57–65.
- Goncalves, L.U. & Viegas, E.M.M. 2007. Production, characterization and biological evaluation of shrimp waste silage for Nile tilapia. *Arquivo Brasileiro de Medicina Veterinaria e Zootecnia*, 59(4): 1021–1028.
- Gong, H., Lawrence, A.L., Jiang, D.-H. & Gatlin, D.M. 2000a. Lipid nutrition of juvenile *Litopenaeus vannamei*: I. Dietary cholesterol and de-oiled soy lecithin requirements and their interaction. *Aquaculture*, 190: 307–326.
- Gong, H., Lawrence, A.L., Jiang, D.-H. & Gatlin, D.M. 2000b. Lipid nutrition of juvenile *Litopenaeus vannamei*: II. Active components of soybean lecithin. *Aquaculture*, 190(3–4): 325–342.

- Gong, H., Lawrence, A.L., Gatlin, D.M., Jiang, D.-H. & Zhang, F. 2001. Comparison of different types and levels of commercial soybean lecithin supplemented in semipurified diets for juvenile *Litopenaeus vannamei* (Boone). *Aquaculture Nutrition*, 7: 11–17.
- Gong, H., Jiang, D.-H., Lawrence, A.L., González-Félix, M. & Perez-Velazquez, M. 2004. Nuevos Avances en el Estudio de Fosfolípidos Nutrimientales para Camarón In: L.E. Cruz Suarez, D. Ricque Marie, M.G. Nieto Lopez, D. Villareal, U. Scholz And M. Gonzalez (eds), *Avances en Nutrición Acuicola VII. Memorias del VII Simposium Internacional de Nutrición Acuicola*. 16–19 November 2004. Hermosillo, Sonora, México. pp. 329–343.
- Gonzalez-Duran, E., Castell, J.D., Robinson, S.M.C. & Blair, T.J. 2008. Effects of dietary lipids on the fatty acid composition and lipid metabolism of the green sea urchin *Strongylocentrotus droebachiensis*. *Aquaculture*, 276: 120–129.
- González-Félix, M.L., Lawrence, A.L., Gatlin, D.M. & Perez-Velazquez, M. 2002. Growth, survival and fatty acid composition of juvenile *Litopenaeus vannamei* fed different oils in the presence and absence of phospholipids. *Aquaculture*, 205: 325–343.
- Gouveia, A. & Davies, S.J. 1998. Preliminary nutritional evaluation of pea seed meal (*Pisum sativum*) for juvenile European sea bass (*Dicentrarchus labrax*). *Aquaculture*, 166(3–4): 311–320.
- Gouveia, A. & Davies, S.J. 2000. Inclusion of an extruded dehulled pea seed meal in diets for juvenile European sea bass (*Dicentrarchus labrax*). *Aquaculture*, 182(1–2): 183–193.
- Goytortua-Bores, E., Civera-Cerecedo, R., Rocha-Meza S. & Green-Yee, A. 2006. Partial replacement of red crab (*Pleuroncodes planipes*) meal for fish meal in practical diets for the white shrimp *Litopenaeus vannamei*. Effects on growth and in vivo digestibility. *Aquaculture*, 256(1–4): 414–422.
- Goytortua, E. 2007a. Harina de camarón, pp. 56–65. In: T.G. Galano, H. Villarreal-Colmenares and J.L. Fenucci (eds), *Manual de ingredientes proteicos y aditivos empleados en la formulación de alimentos balanceados para camarones peneidos*. Subprograma II “Acuicultura” Red Temática II.C, Proyecto II-8 Ciencia y Tecnología El Desarrollo (CYTED). Argentina, Universidad Nacional de Mar del Plata. 264 pp.
- Goytortua, E. 2007b. Harina de krill, pp. 66–71. In: T.G. Galano, H. Villarreal-Colmenares and J.L. Fenucci (eds), *Manual de ingredientes proteicos y aditivos empleados en la formulación de alimentos balanceados para camarones peneidos*. Subprograma II “Acuicultura” Red Temática II.C, Proyecto II-8 Ciencia y Tecnología El Desarrollo (CYTED). Argentina, Universidad Nacional de Mar del Plata. 264 pp.
- Goytortua, E. 2007c. Harina de langostilla, pp. 72–81. In: T.G. Galano, H. Villarreal-Colmenares and J.L. Fenucci (eds), *Manual de ingredientes proteicos y aditivos empleados en la formulación de alimentos balanceados para camarones peneidos*. Subprograma II “Acuicultura” Red Temática II.C, Proyecto II-8 Ciencia y Tecnología El Desarrollo (CYTED). Argentina, Universidad Nacional de Mar del Plata. 264 pp.
- Grant, A.A.M., Baker, D., Higgs, D.A., Brauner, C.J., Richards, J.G., Balfry, S.K. & Schulte, P.M. 2008. Effects of dietary canola oil level on growth, fatty acid composition and osmoregulatory ability of juvenile fall chinook salmon (*Oncorhynchus tshawytscha*). *Aquaculture*, 277(3–4): 303–312.
- Green, B.W. & Boyd, C.W. 1995. Chemical budgets for organically fertilized fish ponds in the dry tropics. *Journal of the World Aquaculture Society*, 26(3): 284–296.
- Grigorakis, K., Fountoulaki, E., Giogios, I. & Alexis, M.N. 2009. Volatile compounds and organoleptic qualities of gilthead sea bream (*Sparus aurata*) fed commercial diets containing different lipid sources. *Aquaculture*, 290(1–2): 116–121.
- Grisdale-Helland, B., Helland, S.J., Baeverfjord G. & Berge, G.M. 2002a. Full-fat soybean meal in diets for Atlantic halibut: growth, metabolism and intestinal histology. *Aquaculture Nutrition*, 8(4): 265–270.
- Grisdale-Helland, B., Ruyter, B., Rosenlund, G., Obach, A., Helland, S.J., Sandberg, M.G., Standal, H. and C. Røsjø, C. 2002b. Influence of high contents of dietary soybean oil on growth, feed utilization, tissue fatty acid composition, heart histology and standard oxygen consumption of Atlantic salmon (*Salmo salar*) raised at two temperatures. *Aquaculture*, 207 (3–4): 311–329.
- Grisdale-Helland, B., Shearer, K.D., Gatlin III, D.M. & Helland, S. J. 2008. Effects of dietary protein and lipid levels on growth, protein digestibility, feed utilization and body composition of Atlantic cod (*Gadus morhua*). *Aquaculture*, 283(1–4): 156–162.
- Guil-Guerrero, J.L. & Reboloso-Fuentes, M.M. 2008. Nutrient composition of *Chlorella* spp. and *Monodus subterraneus* cultured in a bubble column bioreactor. *Food Biotechnology*, 22(3): 218–233.
- Guilherme, R.D., Cavalheiro, J.M.O. & de Souza P.A.S. 2007. Chemical characterization and profile of the amino acids of the flour of shrimp head. *Ciencia e Agrotecnologia*, 31(3): 793–797.
- Guillou, A., Soucy, P., Khalil, M., Adamounou, L. 1995. Effects of dietary vegetable and marine lipid on growth, muscle fatty acid composition and organoleptic quality of flesh of brook charr (*Salvelinus fontinalis*). *Aquaculture*, 136: 351–362.
- Guimaraes, I.G., Pezzato, L.E. & Barros, M.M. 2008. Amino acid availability and protein digestibility of several protein sources for Nile tilapia, *Oreochromis niloticus*. *Aquaculture Nutrition*, 14(5): 396–404.
- Gunasekera, R.M., Leelarasamee, K., De Silva, S.S. 2002. Lipid and fatty acid digestibility of three oil types in the Australian shortfin eel, *Anguilla australis*. *Aquaculture*, 203: 335–347.
- Guo, J., Wang, Y. & Bureau, D.P. 2007. Inclusion of rendered animal ingredients as fishmeal substitutes in practical diets for cuneate drum, *Nibea miichthioides* (Chu, Lo et Wu). *Aquaculture Nutrition*, 13(2): 81–87.
- Haard, N.F., Dimes, L.E., Arndt, R.E. & Dong, F.M. 1996. Estimation of protein digestibility – 4. Digestive proteinases from the pyloric caeca of coho salmon (*Oncorhynchus kisutch*) fed diets containing soybean meal. *Comparative Biochemistry and Physiology – Part B: Biochemistry & Molecular Biology*, 115B(4): 533–540.

- Habib, M.A.B., Parvin, M., Huntington, T.C. & Hasan, M.R. 2008. *A review on culture, production and use of spirulina as food for humans and feeds for domestic animals and fish*. FAO Fisheries and Aquaculture Circular. No. 1034. Rome, FAO. 33 pp.
- Halverson, H. & Alstin, F. 1981. Crude fat determination by combined acid hydrolysis and solvent extraction. *Am. Lab*, 12: 74–87
- Hamre, K., Kolas, K., Sandnes, K., Julshamn, K. & Kiessling, A. 2001. Feed intake and absorption of lipid oxidation products in Atlantic salmon (*Salmo salar*) fed diets coated with oxidised fish oil. *Fish Physiology and Biochemistry*, 25(3): 209–219.
- Han, Q., Tian, Z.C., Xia, W.F., Luo, Y.S. & Wu, M.L. 2005. Optimal dietary lipid requirement of Yellow catfish *Pelteobagrus fulvidraco*. *Fisheries Science/Shuichan Kexue*, 24(7): 8–11.
- Hansen, A.C., Rosenlund, G., Karlsten, O., Olsvik, P.A. & Hemre, G.I. 2006. The inclusion of plant protein in cod diets, its effects on macronutrient digestibility, gut and liver histology and heat shock protein transcription. *Aquaculture Research*, 37(8): 773–784.
- Hansen, A.C., Karlsten, O., Rosenlund, G., Rimbach, M. & Hemre, G.I. 2007a. Dietary plant protein utilization in Atlantic cod, *Gadus morhua* L. *Aquaculture Nutrition*, 13(3): 200–215.
- Hansen, A.C., Rosenlund, G., Karlsten, O., Koppe, W. & Hemre, G.I. 2007b. Total replacement of fish meal with plant proteins in diets for Atlantic cod (*Gadus morhua* L.) I – Effects on growth and protein retention. *Aquaculture*, 272(1–4): 599–611.
- Hansen, J.O. & Storebakken, T. 2007. Effects of dietary cellulose level on pellet quality and nutrient digestibilities in rainbow trout (*Oncorhynchus mykiss*). *Aquaculture*, 272(1–4): 458–465.
- Hansen, J.Ů., Berge, G.M., Hillestad, M., Krogdahl, S., Galloway, T.F., Holm, H., Holm, J.R. & Ruyter, B. 2008. Apparent digestion and apparent retention of lipid and fatty acids in Atlantic cod (*Gadus morhua*) fed increasing dietary lipid levels. *Aquaculture*, 284(1–4): 159–166.
- Harada, K., Miyasaki, T. & Karimata, A. 1996. Attraction activities of terrestrial vegetable extracts for aquatic animals. *Fisheries Science*, 62(5): 675–682.
- Hardy, R.W. & Roley, D.D. 2000. Lipid oxidation and antioxidants, pp. 470–476. In: R.R. Stickney (ed.), *The encyclopedia of aquaculture*. New York, USA, John Wiley and Sons.
- Hardy, R.W., Sealey, W. M. & Gatlin, D.M. 2005. Fisheries by-catch and by-product meals as protein sources for rainbow trout *Oncorhynchus mykiss*. *Journal of the World Aquaculture Society*, 36(3):3 93–400.
- Harel, M., Koven, W., Lein, I., Bar, Y., Behrens, P., Stubblefield, J., Johar, Y. & Place, A.R. 2002. Advanced DHA, EPA and ArA enrichment materials for marine aquaculture using single cell heterotrophs. *Aquaculture*, 213(1): 347–362.
- Harpaz, S. 1997. Enhancement of growth in juvenile freshwater prawns, *Macrobrachium rosenbergii*, through the use of a chemoattractant. *Aquaculture*, 156(3–4): 221–227.
- Harris, L.E. 1980. Feedstuffs, pp. 111–170. In: *Fish Feed Technology*, FAO field document, Aquaculture Development and Coordination Programme Report ADCP/REP/80/11, Rome, FAO.
- Hasan, M.R., Haq, M.S., Das, P.M. & Mowlah, G. 1997a. Evaluation of poultry-feather meal as a dietary protein source for Indian major carp, *Labeo rohita* fry. *Aquaculture*, 151(1–4): 47–54.
- Hasan, M.R., Macintosh, D.J. & Jauncey, K. 1997b. Evaluation of some plant ingredients as dietary protein sources for common carp (*Cyprinus carpio* L) fry. *Aquaculture*, 151(1–4): 55–70.
- 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. *Aquaculture* 124(1–4): 65–66.
- Hasan, M.R., Hecht, T., De Silva, S.S. & Tacon, A.G.J. (eds). 2007. *Study and analysis of feeds and fertilizers for sustainable aquaculture development*. FAO Fisheries Technical Paper, No. 497. Rome, FAO. 510 pp.
- Hasimoglu, A., Erteken, A., Kino, S. & Nakagawa, H. 2007. Evaluation of anchovy meal and soybean meal as dietary protein sources for the Black Sea turbot, *Psetta maxima*. *Israeli Journal of Aquaculture – Bamidgeh*, 59(2): 73–80.
- Has-Schon, E., Bogut, I., Kralik, D. & Vukovic, B. 2004. Mutual influence of protein and lipid feed content on European catfish (*Silurus glanis*) growth. *Journal of Applied Ichthyology*, 20(2): 92–98.
- Hatlen, B., Storebakken, T., Hong, K.N. & Krogdahl, A. 1992. Carotenoid accumulation in Atlantic Salmon fed diets with maize gluten, pea or rapeseed. *Fiskeridirektoratets Skrifter, Serie Ernaering*, 5(2): [np].
- Haugen, T., Kiessling, A., Olsen, R.E., Rora, M.B., Slinde, E., Nortvedt, R. 2006. Seasonal variations in muscle growth dynamics and selected quality attributes in Atlantic halibut (*Hippoglossus hippoglossus* L.) fed dietary lipids containing soybean and /or herring oil under different rearing regimes. *Aquaculture*, 261: 565–579.
- Heikkinen, J., Vielma, J., Kemilainen, O., Tiirola, M., Eskelinen, P., Kiuru, T., Navia-Paldanius, D. & von Wright, A. 2006. Effects of soybean meal based diet on growth performance, gut histopathology and intestinal microbiota of juvenile rainbow trout (*Oncorhynchus mykiss*). *Aquaculture*, 261: 259–268.
- Helland, S.J. & Grisdale-Helland, B. 1998. The influence of replacing fish meal in the diet with fish oil on growth, feed utilization and body composition of Atlantic salmon (*Salmo salar*) during the smoltification period. *Aquaculture*, 162(1–2): 1–10.
- Helland, S.J. & Grisdale-Helland, B. 2006. Replacement of fish meal with wheat gluten in diets for Atlantic halibut (*Hippoglossus hippoglossus*): Effect on whole-body amino acid concentrations. *Aquaculture*, 261(4): 1363–1370.
- Hem, S., Toure, S., Sagbla, C. & Legendre, M. 2008. Bioconversion of palm kernel meal for aquaculture: Experiences from the forest region (Republic of Guinea). *African Journal of Biotechnology*, 7(8): 1192–1198.

- Hemre, G.I. & Sandnes, K. 2008. Seasonal adjusted diets to Atlantic salmon (*Salmo salar*): Evaluations of a novel feed based on heat-coagulated fish mince, fed throughout 1 year in sea: Feed utilisation, retention of nutrients and health parameters. *Aquaculture*, 274(1): 166–174.
- Hemre, G.I., Sanden, M., Bakke-Mckellep, A.M., Sagstad, A. & Krogdahl, A. 2005. Growth, feed utilization and health of Atlantic salmon *Salmo salar* L. fed genetically modified compared to non-modified commercial hybrid soybeans. *Aquaculture Nutrition*, 11(3): 157–167.
- Hemre, G.I., Sagstad, A., Bakke-Mckellep, A.M., Danieli, A., Acierno, R., Maffia, M., Froystad, M., Krogdahl, A. & Sanden, M. 2007a. Suitability of genetically modified soybean meal in rainbow trout diets. *Aquaculture Nutrition*, 13(3): 186–199.
- Hemre, G.I., Sagstad, A., Bakke-Mckellep, A.M., Danieli, A., Acierno, R., Maffia, M., Froeystad, M., Krogdahl, A. & Sanden, M. 2007b. Nutritional, physiological, and histological responses in Atlantic salmon, *Salmo salar* L. fed diets with genetically modified maize. *Aquaculture Nutrition*, 13(3): 186–199.
- Hernandez, C., Aguilar-Vejar, K., González-Rodríguez, B., Abdo de la Parra, I. 2004a. Respuesta de crecimiento del camarón blanco *Litopenaeus vannamei* alimentado con dietas formuladas a distintos niveles de reemplazo de harina de pescado, con harina de carne de origen porcícola, pp. 17–20. In: A. Cruz-Suárez and C. Hernández (eds), *Reciclaje*, 16. Virginia, USA, National Renderers Association.
- Hernandez, C., Sarmiento-Pardo, J., Gonzalez-Rodríguez, B. & Abdo de la Parra, I. 2004b. Replacement of fish meal with co-extruded wet tuna viscera and corn meal in diets for white shrimp (*Litopenaeus vannamei* Boone). *Aquaculture Research*, 35(12): 1153–1157.
- Hernandez, C., Olvera-Novoa, M.A., Aguilar-Vejar, K., Gonzalez-Rodríguez, B. & Abdo de la Parra, I. 2008. Partial replacement of fish meal by porcine meat meal in practical diets for Pacific white shrimp (*Litopenaeus vannamei*). *Aquaculture*, 277(3–4): 244–250.
- Hernandez, M.D., Martínez, F.J., Jover, M. & Garcia Garcia, B. 2007. Effects of partial replacement of fish meal by soybean meal in sharpnose seabream (*Diplodus puntazzo*) diet. *Aquaculture*, 263: 159–167.
- Hernandez-Vergara, M.P., Rouse, D.B., Olvera-Novoa, M.A. & Davis, D.A. 2003. Effects of dietary lipid level and source on growth and proximate composition of juvenile redclaw (*Cherax quadricarinatus*) reared under semi-intensive culture conditions. *Aquaculture*, 223(1–4): 107–115.
- Herrero, M.J., Martínez, F.J., Miguez, J.M. & Madrid, J.A. 2007. Response of plasma and gastrointestinal melatonin, plasma cortisol and activity rhythms of European sea bass (*Dicentrarchus labrax*) to dietary supplementation with tryptophan and melatonin. *Journal of Comparative Physiology*, B 177(3): 319–326.
- Hertrampf, J.W. & Pascual, F.P. 2000. *Handbook on ingredients for aquaculture feeds*. Boston, USA, Kluwer Academic Publishers.
- Hevroy, E.M., Sandnes, K. & Hemre, G.I. 2004. Growth, feed utilisation, appetite and health in Atlantic salmon (*Salmo salar* L.) fed a new type of high lipid fish meal, Sea Grain(R), processed from various pelagic marine fish species. *Aquaculture*, 235(1–4): 371–392.
- Hevroy, E.M., Espe, M., Waagboe, R., Sandnes, K., Ruud, M. & Hemre, G.I. 2005. Nutrient utilization in Atlantic salmon (*Salmo salar* L.) fed increased levels of fish protein hydrolysate during a period of fast growth. *Aquaculture Nutrition*, 11(4): 301–313.
- Hickling, D. 2001. *Canola meal feed industry guide*. Third edition. Winnipeg, MB, Canada, Canola Council of Canada.
- Hidalgo, M.C., Skalli, A., Abellan, E., Arizcun, M. & Cardenete, G. 2006. Dietary intake of probiotics and maslinic acid in juvenile dentex (*Dentex dentex* L.): effects on growth performance, survival and liver proteolytic activities. *Aquaculture Nutrition*, 12(4): 256–266.
- Higgs, D.A. & Dong, F.M. 2000. Lipids and fatty acids, pp. 476–496. In: R.R. Stickney (ed.), *The encyclopedia of aquaculture*. New York, USA, John Wiley and Sons.
- Higgs, D., Dosanjh, A., Prendergast, B.S., Beames, A.F., Hardy, R.M., Riley, R.W. & Deacon, G. 1994. Use of rapeseed/canola protein products in finfish diets, pp. 130–156. In: C. Lim and D.J. Sessa (eds), *Nutrition and Utilization Technology in Aquaculture*. Champaign, Illinois, USA, AOCS Press.
- Higgs, D.A., Balfry, S.K., Oakes, J.D., Rowshandeli, M., Skura, B.J. & Deacon, G. 2006. Efficacy of an equal blend of canola oil and poultry fat as an alternate dietary lipid source for Atlantic salmon (*Salmo salar* L.) in sea water. I: effects on growth performance, and whole body and fillet proximate and lipid composition. *Aquaculture Research*, 37(2): 180–191.
- Hites, R.A., Foran, J.A., Carpenter, D.O., Hamilton, M.C., Knuth, B.A., Schwager, S.J. 2004. Global assessment of organic contaminants in farmed salmon. *Science*, 303(5655): 226–229.
- Hoffman, L.C., Prinsloo, J.F. & Rukan, G. 1997. Partial replacement of fish meal with either soybean meal, brewers yeast or tomato meal in the diets of African sharpnose catfish *Clarias gariepinus*. *Water S.A.*, 23(2): 181–186.
- Hoglund, E., Bakke, M.J., Overli, O., Winberg, S. & Nilsson, G.E. 2005. Suppression of aggressive behaviour in juvenile Atlantic cod (*Gadus morhua*) by L-tryptophan supplementation. *Aquaculture*, 249(1–4): 525–531.
- Hoglund, E., Sorensen, C., Bakke, M.J., Nilsson, G.E. & Overli, O. 2007. Attenuation of stress-induced anorexia in brown trout (*Salmo trutta*) by pre-treatment with dietary L-tryptophan. *British Journal of Nutrition*, 97(4): 786–789.
- Holler, S. 2005. Natural antioxidants assessment: stabilizing effect on marine lipids. *International Aquafeed*, 8(5): 38–42.
- Holme, M.H., Southgate, P.C. & Zeng, C. 2007. Survival, development and growth response of mud crab, *Scylla serrata*, megalopae fed semi-purified diets containing various fish oil:corn oil ratios. *Aquaculture*, 269(1–4): 427–435.

- Hoq, M.E., Bhuiyan, A.K.M.A. & Mansur, M.A. 1995. Quality aspects of fish silage and fish meal from marine trash fish. *Indian Journal of Marine Sciences*, 24: 158–161.
- Hoq, M.E., Bhuiyan, A.K.M.A., Begum, M. & Zaher, M. 1995. Efficacy of fish silage and fish meal on the growth performance of Nile tilapia, *Oreochromis niloticus* fry. *Pakistan Journal of Scientific and Industrial Research*, 38(5–6): 211–214.
- Hoshikawa, H., Takahashi, K., Sugimoto, T., Tuji, K. & Nobuta, S. 1998. The effects of fish meal feeding on the gonad quality of cultivated sea urchins, *Strongylocentrotus nudus* (A. Agassiz). *Sci. Rep. Hokkaido Fish. Exp. Stn.*, no.52(52): 17–24.
- Hossain, M.A., Focken, U. & Becker, K. 2001. Evaluation of an unconventional legume seed, *Sesbania aculeata*, as a dietary protein source for common carp, *Cyprinus carpio* L. *Aquaculture*, 198: 129–140.
- Hossain, M.A. & Islam, S.F. 2007. Meat and bone meal as partial substitute for fish meal in nursery diet for giant freshwater prawn, *Macrobrachium rosenbergii* (de Man). *Journal of the World Aquaculture Society*, 38(2): 272–280.
- Hossain, M.A., Pandey, A. & Satoh, S. 2007b. Effects of organic acids on growth and phosphorus utilization in red sea bream *Pagrus major*. *Fisheries Science*, 73(6): 1309–1317.
- Hseu, J.R., Lu, F.L., Su, H.M., Wang, L.S., Tsai, C.L. & Hwang, P.P. 2003. Effect of exogenous tryptophan on cannibalism, survival and growth in juvenile grouper, *Epinephelus coioides*. *Aquaculture*, 218(1–4): 251–263.
- Hsieh, S.L., Hu, C.Y., Hsu, Y.T. & Hsieh, T.J. 2007a. Influence of dietary lipids on the fatty desaturase expression in hybrid tilapia acid composition and stearoyl-CoA (*Oreochromis niloticus* x *O. aureus*) under cold shock. *Comparative Biochemistry and Physiology, Part B – Biochemistry and Molecular Biology*, 147(3): 438–444.
- Hsieh, S.L., Hu, C.Y., Hsu, Y.T. & Hsieh, T.J. 2007b. Influence of dietary lipids on the fatty acid composition and stearoyl-CoA desaturase expression in hybrid tilapia (*Oreochromis niloticus* x *O. aureus*) under cold shock. *Comparative Biochemistry and Physiology, Part B: Biochemistry and Molecular Biology*, 147(3): 438–444.
- Hu, J., Chen, X. & Hong, H. 1995. Evaluation of soybean cake as a substitute for partial fish meal in artificial diets for *Lateolabrax japonicus*. *Journal of Oceanography in Taiwan Strait/Taiwan Haixia. Xiamen*, 14(4): 418–421.
- Hu, M.H., Wang, Y.J., Wang, Q., Zhao, M., Xiong, B.X., Qian, X.Q., Zhao, Y.J. & Luo, Z. 2008a. Replacement of fish meal by rendered animal protein ingredients with lysine and methionine supplementation to practical diets for gibel carp, *Carassius auratus gibelio*. *Aquaculture*, 275(1–4): 260–265.
- Hu, M.H., Wang, Y.J., Wang, Q., Zhao, M., Xiong, B.X., Qian, X.Q., Zhao, Y.J. & Luo, Z. 2008b. Evaluation of rendered animal protein ingredients for replacement of fish meal in practical diets for gibel carp, *Carassius auratus gibelio* (Bloch). *Aquaculture Research*, 39(14): 1475–1482.
- Huang, C.H., Huang, M.C. & Hou, P.C. 1998. Effect of dietary lipids on fatty acid composition and lipid peroxidation in sarcoplasmic reticulum of hybrid tilapia, *Oreochromis niloticus* x *O. aureus*. *Comparative Biochemistry and Physiology, Part B: Biochemistry and Molecular Biology*, 120(2): 331–336.
- Huang, C.H., Shyong, W.L. & Lin, W.Y. 2001. Dietary lipid supplementation affects the body fatty acid composition but not the growth of juvenile river chub, *Zacco barbata* (Regan). *Aquaculture Research*, 32(12): 1005–1010.
- Huang, H.Q., Shao, N., Wang, Y.R., Luo, H.Y., Yang, P.L., Zhou, Z.G., Zhan, Z.C. & Yao, B. 2009. A novel beta-propeller phytase from *Pedobacter nyackensis* MJ11 CGMCC 2503 with potential as an aquatic feed additive. *Applied Microbiology and Biotechnology*, 83(2): 249–259.
- Huang, S.S.Y., Oo, A.N., Higgs, D.A., Brauner, C.J., Satoh, S. 2007. Effect of dietary canola oil level on the growth performance and fatty acid composition of juvenile red sea bream, *Pagrus major*. *Aquaculture*, 271: 420–431.
- Huang, S.S.Y., Fu, C.H.L., Higgs, D.A., Balfry, S.K., Schulte, P.M. & Brauner, C.J. 2008. Effects of dietary canola oil level on growth performance, fatty acid composition and ionoregulatory development of spring chinook salmon parr, *Oncorhynchus tshawytscha*. *Aquaculture*, 274(1): 109–117.
- Hughes K.P. & Soares, J.H.J. 1998. Efficacy of phytase on phosphorus utilization in practical diets fed to striped bass *Morone saxatilis*. *Aquaculture Nutrition*, 4: 133–140.
- Hung, L.T. & Huy, H.P.V. 2007. *Analysis of feeds and fertilizers for sustainable aquaculture development in Viet Nam*, pp. 331–361. In: M.R. Hasan, T. Hecht, S.S. De Silva and A.G.J. Tacon (eds). Study and analysis of feeds and fertilizers for sustainable aquaculture development. *FAO Fisheries Technical Paper No. 497*. Rome. 510 pp.
- Hunter, B.J., Allan, G.L. & Roberts, D.C.K. 2000. Meat meal replacement in diets for Silver perch, *Bidyanus bidyanus*: effect on growth, protein and lipid composition. *Journal of Applied Aquaculture*, 10(3): 51–68.
- Hwang, D.-F., Lin, J.-H. & Cheng, H.-M. 1995. Level of synthetic antioxidant in cultured fish and fish feed. *Journal of Food and Drug Analysis*, 3(1): 27–32.
- Hynes, N., Egeland, E.S., Koppe, W., Baardsen, G. & Kiron, V. 2009. Calanus oil as a natural source for flesh pigmentation in Atlantic salmon (*Salmo salar* L.). *Aquaculture Nutrition*, 15(2): 202–208.
- Imorou Toko, I., Fiogbe, E.D. & Kestemont, P. 2008. Mineral status of African catfish (*Clarias gariepinus*) fed diets containing graded levels of soybean or cottonseed meals. *Aquaculture*, 275: 298–305.
- Ittoop, G., Jose, S., Dinesh, K., Nair, C.M. & Joseph, A. 2006. Use of fish silage as an alternate protein source for the spawn rearing of *Cirrhinus mrigala* (Ham.). *Fisbery Technology, Society of Fisheries Technologists*, (India), 43(2): 176–179.

- Iwashita, Y., Suzuki, N., Yamamoto, T., Shibata, J.I., Isokawa, K., Soon, A.H., Ikehata, Y., Furuita, H., Sugita, Y. & Goto, T. 2008. Supplemental effect of cholytaurine and soybean lecithin to a soybean meal-based fish meal-free diet on hepatic and intestinal morphology of rainbow trout *Oncorhynchus mykiss*. *Fisheries Science*, 74(5): 1083–1095.
- Izquierdo, M.S., Obach, A., Arantzamendi, L., Montero, D., Robaina, L., Rosenlund, G. 2003. Dietary lipid sources for seabream and seabass: growth performance, tissue composition and flesh quality. *Aquaculture Nutrition*, 9: 397–407.
- Izquierdo, M.S., Montero, D., Robaina, L., Caballero, R., Rosenlund, G., Gines, R. 2005. Alterations in fillet fatty acid profile and flesh quality in gilthead seabream (*Sparus aurata*) fed vegetable oils for a long term period. Recovery of fatty acid profiles by fish oil feeding. *Aquaculture*, 250: 431–444.
- Izquierdo, M.S., Forster, I., Divakaran, S., Conquest, L., Decamp, O. & Tacon, A.G.J. 2006. Effect of green and clear water and lipid source on survival, growth and biochemical composition of Pacific white shrimp *Litopenaeus vannamei*. *Aquaculture Nutrition*, 12: 192–202.
- Izquierdo, M.S., Robaina, L., Juarez-Carrillo, E., Oliva, V., Hernandez-Cruz, C.M., Afonso, J.M. 2008. Regulation of growth, fatty acid composition and delta 6 desaturase expression by dietary lipids in gilthead seabream larvae (*Sparus aurata*). *Fish Physiol Biochem.*, (2008) 34: 117–127.
- Jackson L.S., Li, M. & Robinson, E.H. 1996. Use of microbial phytase in channel catfish *Ictalurus punctatus* diets to improve utilization of phytate phosphorus. *Journal of the World Aquaculture Society*, 27: 309–313.
- Jahan, P., Watanabe, T., Satoh, S. & Kiron, V. 2000. Effect of dietary fish meal levels on environmental phosphorus loading from carp culture. *Fisheries Science*, 66(2): 204–210.
- Jahan, P., Watanabe, T., Kiron, V. & Satoh, S. 2003. Improved Carp diets based on plant protein sources reduce environmental phosphorus loading. *Fisheries Science*, 69(2): 219–225.
- Jaime-Ceballos, B., Villarreal-Colmenares, H., García-Galano, T., Civera-Cerecedo, R. & Gaxiola-Cortés, G. 2004. Empleo del polvo de *Spirulina platensis* en la alimentación de zoeas y mysis de *Litopenaeus schmitti* (Pérez-Farfante and Kensley, 1997), pp. 617–635. In: L.E. Cruz-Suárez, D. Ricque Marie, M.G. Nieto López, D. Villarreal, U. Scholz and M. González (eds), *Avances en Nutrición Acuicola VII, Memorias del VII Simposium Internacional de Nutrición Acuicola*, 16–19 November 2004, Hermosillo, Sonora, México.
- Jaime-Ceballos, B., Villarreal, H., Garcia T., Pérez-Jar, L. & Alfonso, E. 2005. *Spirulina platensis* meal as feed additive for *Litopenaeus schmitti* larvae. *Rev. Invest. Mar.*, 26(3): 235–241.
- Jaime-Ceballos, B., Hernandez-Llamas, A., Garcia-Galano, T. & Villarreal, H. 2006. Substitution of *Chaetoceros muelleri* by *Spirulina platensis* meal in diets for *Litopenaeus schmitti* larvae. *Aquaculture*, 260: 215–220.
- Jang, H.K., Ok, I.H. & Bai, S.C. 1999. Effects of dietary chromic oxide and possible use of the animal by-product mixture as a dietary fish meal replacer (*Oncorhynchus mykiss*). *Journal of the Korean Fisheries Society*, 32(4): 470–475.
- Jaouen-Madoulet, A., Abarnou, A., Le Guellec, A.-M., Loizeau, V. & Leboulenger, F. 2000. Validation of an analytical procedure for polychlorinated biphenyls, coplanar polychlorinated biphenyls and polycyclic aromatic hydrocarbons in environmental samples. *Journal of Chromatography A*, 886: 153–173.
- Jasmine, G.I. 2000. Suitability of different binders in feed formulation for *Penaeus indicus*. *Journal of the Marine Biological Association of India*, 42(1–2): 62–73.
- Jena, J.K., Mukhopadhyay, P.K. & Aravindakshan, P.K. 1998. Dietary incorporation of meat meal as a substitute for fish meal in carp fry rearing. *Indian Journal of Fisheries*, 45(1): 43–49.
- Jensen, C., Birk, E., Jokumsen, A., Skibsted, L.H. & Bertelsen, G. 1998. Effect of dietary levels of fat, alpha-tocopherol and astaxanthin on colour and lipid oxidation during storage of frozen rainbow trout (*Oncorhynchus mykiss*) and during chill storage of smoked trout. *Z. Lebensm.-Unters.-Forsch. (A Food Res. Technol.)*, 207(3): 189–196.
- Ji, S.C., Takaoka, O., Biswas, A.K., Seoka, M., Ozaki, K., Kohbara, J., Ukawa, M., Shimeno, S., Hosokawa, H. & Takii, K. 2008. Dietary utility of enzyme-treated fish meal for juvenile Pacific bluefin tuna *Thunnus orientalis*. *Fisheries Science*, 74(1): 54–61.
- Jiang, G. & Zhou, X. 2005a. The effects of soybean protein on protein retention in juvenile Jian carp (*Cyprinus carpio* Var. Jian). *Journal of Dalian Fisheries University/Dalian Shuichan Xueyuan Xuebao*, 20(2): 81–86.
- Jiang, G. & Zhou, X. 2005b. The effects of soybean protein isolate on hepatopancreas weight and intestinal proteinase activity of juvenile Jian carp (*Cyprinus carpio* Var. Jian). *Journal of Dalian Fisheries University/Dalian Shuichan Xueyuan Xuebao*, 20(3): 198–202.
- Jin, Z. & Xiao-Ling, L. 2004. The Use of peptidoglycan as an immune stimulant for turbot (*Scophthamus maximus*). *Journal of the Fisheries Society of Taiwan*, 31(2): 155–158.
- Jobling, M. & Bendiksen, E.A. 2003. Dietary lipids and temperature interact to influence tissue fatty acid compositions of Atlantic salmon, *Salmo salar* L., parr. *Aquaculture Research*, 34(15): 1423–1441.
- Jobling, M., Larsen, A.V., Andreassen, B., Sigholt, T. & Olsen, R.L. 2002. Influence of a dietary shift on temporal changes in fat deposition and fatty acid composition of Atlantic salmon post-smolt during the early phase of seawater rearing. *Aquaculture Research*, 33(11): 875–889.
- Jobling, M., Leknes, O., Saether, B.S. & Bendiksen, E.A. 2008. Lipid and fatty acid dynamics in Atlantic cod, *Gadus morhua*, tissues: Influence of dietary lipid concentrations and feed oil sources. *Aquaculture*, 281(1–4): 87–94.

- Johnson, J.A. & Summerfelt, R.C. 2000. Spray-dried blood cells as a partial replacement for fishmeal in diets for rainbow trout *Oncorhynchus mykiss*. *Journal of the World Aquaculture Society*, 31(1): 96–104.
- Johnston, M.D. & Johnston, D.J. 2007. Stability of formulated diets and feeding response of stage I western spiny lobster, *Panulirus cygnus*, phyllosomata. *Journal of the World Aquaculture Society*, 38(2): 262–271.
- Jones, P.L., De Silva, S.S. & Mitchell, B.D. 1996a. Effects of replacement of animal protein by soybean meal on growth and carcass composition in juvenile Australian freshwater crayfish. *Aquaculture International*, 4(4): 339–359.
- Jones, P.L., De Silva, S.S. & Mitchell, B.D. 1996b. The effect of dietary protein source on growth and carcass composition in juvenile Australian freshwater crayfish. *Aquaculture International*, 4(4): 361–376.
- Jones, P., Chavez, J.R. & Mitchell, B.D. 2002. Production of Australian freshwater crayfish in earthen-based systems using pelleted diets and forage crops as food. *Aquaculture International*, 10(2): 157–175.
- Jordal, A.E.O., Torstensen, B.E., Tsoi, S., Tocher, D.R., Lall, S.P. & Douglas, S.E. 2005. Dietary rapeseed oil affects the expression of genes involved in hepatic lipid metabolism in Atlantic salmon (*Salmo salar* L.). *Journal of Nutrition*, 135(10): 2355–2361.
- Jordal, A.E.O., Hordvik, I., Pelsers, M., Bemlohr, D.A. & Torstensen, B.E. 2006. FABP3 and FABP10 in Atlantic salmon (*Salmo salar* L.) – General effects of dietary fatty acid composition and life cycle variations. *Comparative Biochemistry and Physiology, Part B: Biochemistry & Molecular Biology*, 145(2): 147–158.
- Jordal, A., Lie, E.O. & Torstensen, B.E. 2007. Complete replacement of dietary fish oil with a vegetable oil blend affect liver lipid and plasma lipoprotein levels in Atlantic salmon (*Salmo salar* L.). *Aquaculture Nutrition*, 13: 114–130.
- Jose, S., Mohan, M.V., Shyama, S., Nair, K.G.R. & Mathew, P.T. 2006. Effect of soybean meal based diets on the growth and survival rate of the Indian major carp, *Cirrhinus mrigala* (Ham.). *Journal of Aquaculture in the Tropics*, 21(1–2): 93–100.
- Jose, S., Mohan, M.V., Shyama, S., Nair, K.G.R. & Mathew, P.T. 2006. Effect of soybean-meal-based diets on the growth and survival rate of the Indian major carp, *Cirrhinus mrigala* (Ham.). *Aquaculture Nutrition*, 12(4): 275–279.
- Jouany, J.P. 2007. Methods for preventing, decontaminating and minimizing the toxicity of mycotoxins in feeds. *Animal Feed Science and Technology*, 137, 342–362.
- Ju, Z.Y., Forster, I.P. & Dominy, W.G. 2009. Effects of supplementing two species of marine algae or their fractions to a formulated diet on growth, survival and composition of shrimp (*Litopenaeus vannamei*). *Aquaculture*, 292(3–4): 237–243.
- Julshamn, K., Malde, M.K., Bjorvatn, K. & Krogedal, P. 2004. Fluoride retention of Atlantic salmon (*Salmo salar*) fed krill meal. *Aquaculture Nutrition*, 10(1): 9–13.
- Jutfelt, F., Olsen, R.E., Björnsson, B.T., Sundell, K. 2007. Parr-smolt transformation and dietary vegetable lipids affect intestinal nutrient uptake, barrier function and plasma cortisol levels in Atlantic salmon. *Aquaculture*, 273: 298–311.
- Kalinowski, C.T., Izquierdo, M.S., Schuchardt, D. & Robaina, L.E. 2007. Dietary supplementation time with shrimp shell meal on red porgy (*Pagrus pagrus*) skin colour and carotenoid concentration. *Aquaculture*, 272(1–4): 451–457.
- Kalita, P., Mukhopadhyay, P.K. & Mukherjee, A.K. 2007. Evaluation of the nutritional quality of four unexplored aquatic weeds from northeast India for the formulation of cost-effective fish feeds. *Food Chemistry*, 103(1): 204–209.
- Kalita, P., Mukhopadhyay, P.K. & Mukherjee, A.K. 2008. Supplementation of four non-conventional aquatic weeds to the basal diet of *Catla catla* and *Cirrhinus mrigala* fingerlings: effect on growth, protein utilization and body composition of fish. *Acta Ichthyologica et Piscatoria*, 38(1): 21–27.
- Kalla, A., Garg, S.K., Kaushik, C.P., Arasu, A.R.T. & Dinodia, G.S. 2003. Effect of replacement of fish meal with processed soybean on growth, digestibility and nutrient retention in *Mugil cephalus* (Linn.) fry. *Indian Journal of Fisheries*, 50(4): 509–518.
- Kamarudin, N., Moslim, R., Arshad, O., Wahid, M.B. & Chong, A. 2007. Potential of utilizing rhinoceros beetles (*Oryctes rhinoceros*) as an ornamental fish feed supplement. *Journal of Oil Palm Research*, 19: 313–318.
- Karalazos, V., Bendiksen, E.A., Dick, J.R., Bell, J.G. 2007. Effects of dietary protein, and fat level and rapeseed oil on growth and tissue fatty acid composition and metabolism in Atlantic salmon (*Salmo salar* L.) reared at low water temperatures. *Aquaculture Nutrition*, 13: 256–265.
- Karapanagiotidis, I.T., Bell, M.V., Little, D.C. & Yakupitiyage, A. 2007. Replacement of dietary fish oils by alpha-linolenic acid-rich oils lowers omega 3 content in tilapia flesh. *Lipids*, 42(6): 547–559.
- Kasper, C.S., Watkins, B.A. & Brown, P.B. 2007. Evaluation of two soybean meals fed to yellow perch (*Perca flavescens*). *Aquaculture Nutrition*, 13(6): 431–438.
- Kasumyan, A.O. & Morsi, A.M.K. 1996. Gustatory sensitivity of carp to free amino acids and classical taste substances. *Voprosy Ikhtiologii*, 36(3): 386–399.
- Katersky, R.S. & Carter, C.G. 2009. Growth and protein synthesis of barramundi, *Lates calcarifer*, fed lupin as a partial protein replacement. *Comparative Biochemistry and Physiology – Part A: Molecular & Integrative Physiology*, 152(4): 513–517.
- Katz, S.A., Jenniss, S.W. & Mount, T. 1981. Comparisons of sample preparation methods for the determination of metals in sewage sludges by flame atomic absorption spectrometry. *Intern.J. Environ. Anal. Chem.*, 9: 209–220.

- Kaur, V.I. & Saxena, P.K. 2005. Incorporation of maize gluten in supplementary feed and its impact on growth and flesh quality of some carps. *Aquaculture International*, 13(6): 555–573.
- Kaushik, S.J., Cravedi, J.P., Lalles, J.P., Sumpter, J., Fauconneau, B. & Laroche, M. 1995. Partial or total replacement of fish meal by soybean protein on growth, protein utilization, potential estrogenic or antigenic effects, cholesterolemia and flesh quality in rainbow trout, *Oncorhynchus mykiss*. *Aquaculture*, 133: 257–274.
- Keembiyehetty, C.N. & Gatlin, D.M. 1997. Performance of sunshine bass fed soybean-meal-based diets supplemented with different methionine compounds. *Progressive Fish Culturist*, 59(1): 25–30.
- Keer, J.T. & Brich, L. (eds). *Essentials of nucleic acid analysis*. London, Royal Society of Chemistry, RSC Publishing, 272 pp.
- Kennari, A.M.A., Oveisipour, M.R. & Nazari, R.M. 2007. Effects of n3-HUFA enriched *Daphnia magna* on growth, survival, stress resistance, and fatty acid composition of larvae of Persian sturgeon (*Acipenser persicus*). *Iranian Journal of Fisheries Sciences*, 7(1): 1–14.
- Kennedy, S.R., Leavera, M.J., Campbell, P.J., Zheng, X.Z., Dick, J.R. & Tocher, D.R. 2006. Influence of dietary oil content and conjugated linoleic acid (CLA) on lipid metabolism enzyme activities and gene expression in tissues of Atlantic salmon (*Salmo salar* L.). *Lipids*, 41(5): 423–436.
- Kestemont, P., Vandeloise, E., Melard, C., Fontaine, P. & Brown, P.B. 2001. Growth and nutritional status of Eurasian perch *Perca fluviatilis* fed graded levels of dietary lipids with or without added ethoxyquin. *Aquaculture*, 203(1–2): 85–99.
- Khajarern, J. & Khajarern, S. 1999. *Manual of Feed Microscopy and Quality Control (3rd Edition)*. In collaboration with the American Soybean Association and the U.S. Grains Council. Khon Kaen, Thailand, Klang Nana Wittaya Co. Ltd. 252 pp.
- Khan, M.A., Jafri, A.K., Chadha, N.K. & Usmani, N. 2003. Growth and body composition of rohu (*Labeo rohita*) fed diets containing oilseed meals: partial or total replacement of fish meal with soybean meal. *Aquaculture Nutrition*, 9(6): 391–396.
- Khan, N., Khan, S.H., Masroor, J.I. & Ahmed, I. 2002. Effect of different doses of fertilizer (nitrophos) on the growth performance of major carps. *International Journal of Agriculture and Biology*, 4: 407–409.
- Kikuchi, K. 1999. Partial replacement of fish meal with corn gluten meal in diets for Japanese flounder *Paralichthys olivaceus*. *Journal of the World Aquaculture Society*, 30(3): 357–363.
- Kikuchi, K. 1999b. Use of defatted soybean meal as a substitute for fish meal in diets of Japanese flounder (*Paralichthys olivaceus*). *Aquaculture*, 179: 3–11.
- Kikuchi, K. & Furuta, T. 2009. Inclusion of blue mussel extract in diets based on fish and soybean meals for tiger puffer *Takifugu rubripes*. *Fisheries Science*, 75(1): 183–189.
- Kikuchi, K., Sato, T., Furuta, T., Sakaguchi, I. & Deguchi, Y. 1997. Use of meat and bone meal as a protein source in the diet of juvenile Japanese flounder. *Fisheries Science*, 63(1): 29–32.
- Kikuchi, K., Ueda, A., Sugita, H. & Takeda, S. 2002. Effect of dietary inclusion of blue mussel extract on growth and body composition of Japanese flounder *Paralichthys olivaceus*. *Journal of the World Aquaculture Society*, 33(1): 41–47.
- Kim, J.D., Breque, J. & Kaushik, S.J. 1998a. Apparent digestibilities of feed components from fish meal or plant protein based diets in common carp as affected by water temperature. *Aquatic Living Resources*, 11(4): 269–272.
- Kim, J.D., Kim, K.S., Jeong, K.S., Song, J.S., Lee, S.B., Woo, Y.B. & Lee, J.Y. 1997. Effects of partial substitution of dietary fish meal with fish protein concentrate or blood meal on growth and pollution loads of Israeli strain of common carp (*Cyprinus carpio*). *Korean Journal of Animal Nutrition and Feedstuffs*, 21(3): 237–244.
- Kim, J.D., Tibbetts, S.M., Milley, J.E. & Lall, S.P. 2007. Effect of the incorporation level of dehulled soybean meal into test diet on apparent digestibility coefficients for protein and energy by juvenile haddock, *Melanogrammus aeglefinus* L. *Aquaculture*, 267: 308–314.
- Kim, J.K. & Lee, B.K. 2000. Mass production of *Rhodopseudomonas palustris* as diet for aquaculture. *Aquacultural Engineering*, 23(4): 281–293.
- Kim, K.D., Lee, S.M., Park, H.G., Bai, S.C.C. & Lee, Y.H. 2002. Essentiality of dietary n-3 highly unsaturated fatty acids in juvenile Japanese flounder *Paralichthys olivaceus*. *Journal of the World Aquaculture Society*, 33(4): 432–440.
- Kim, K.D., Kim, K.M., Kim, K.W., Jin Kang, Y. & Lee, S.M. 2006. Influence of lipid level and supplemental lecithin in diet on growth, feed utilization and body composition of juvenile flounder (*Paralichthys olivaceus*) in suboptimal water temperatures. *Aquaculture*, 251(2–4): 484–490.
- Kim, K.W., Bai, S.C.C., Koo, J.W., Wang, X.J. & Kim, S.K. 2002. Effects of dietary *Chlorella ellipsoidea* supplementation on growth, blood characteristics, and whole-body composition in juvenile Japanese flounder *Paralichthys olivaceus*. *Journal of the World Aquaculture Society*, 33(4): 425–431.
- Kim, S.S. & Lee, K.J. 2008. Effects of dietary kelp (*Ecklonia cava*) on growth and innate immunity in juvenile olive flounder *Paralichthys olivaceus* (Temminck et Schlegel). *Aquaculture Research*, 39(15): 1687–1690.
- Kim, S.S., Galaz, G.B., Pham, M.A., Jang, J.W., Oh, D.H., Yeo, I.K. & Lee, K.J. 2009. Effects of dietary supplementation of a meju, fermented soybean meal, and *Aspergillus oryzae* for juvenile Parrot fish (*Oplegnathus fasciatus*). *Asian-Australasian Journal of Animal Sciences*, 22(6): 849–856.
- Kim, Y.C., Yoo, G.Y., Wang, X., Lee, S., Shin, I.S. & Bai, S.C. 2008. Long term feeding effects of dietary dehulled soybean meal as a fish meal replacer in growing olive flounder *Paralichthys olivaceus*. *Asian-Australasian Journal of Animal Sciences*, 21(6): 868–872.

- Kiron, V., Puangkaew, J., Ishizaka, K., Satoh, S. & Watanabe, T. 2004. Antioxidant status and nonspecific immune responses in rainbow trout (*Oncorhynchus mykiss*) fed two levels of vitamin E along with three lipid sources. *Aquaculture*, 234(1–4): 361–379.
- Kissil, G.W. & Lupatsch, I. 2003. Replacement of fishmeal by plant protein sources in gilthead seabream (*Sparus aurata*) diets. *Israeli Journal of Aquaculture – Bamidgeh*, 55(4): 239.
- Kissil, G.W. & Lupatsch, I. 2004. Successful replacement of fishmeal by plant proteins in diets for the gilthead seabream, *Sparus aurata* L. *Israeli Journal of Aquaculture – Bamidgeh*, 56(3): 188–199.
- Kissil, G.W., Lupatsch, I., Higgs, D.A. & Hardy, R.W. 1997. Preliminary evaluation of rapeseed protein concentrate as an alternative to fish meal in diets for gilthead seabream (*Sparus aurata*). *Israeli Journal of Aquaculture – Bamidgeh*, 49(3): 135–143.
- Kissil, G.W., Lupatsch, I., Higgs, D.A. & Hardy, R.W. 2000. Dietary substitution of soy and rapeseed protein concentrates for fish meal, and their effects on growth and nutrient utilization in gilthead seabream *Sparus aurata* L. *Aquaculture Research*, 31(7): 595–601.
- Klinger, R.E.C., Blazer, V.S. & Echevarria, C. 1996. Effects of dietary lipid on the hematology of channel catfish, *Ictalurus punctatus*. *Aquaculture*, 147(3–4): 225–233.
- Knud-Hansen, C.F. 1998. *Pond fertilization: ecological approach and practical applications*. Pond dynamics/Aquaculture collaborative research support program. Corvallis, OR., USA, Oregon State University. 125 pp.
- Knudsen, D., Uran, P., Arnous, A., Koppe, W. & Froekiaer, H. 2007. Saponin-containing subfractions of soybean molasses induce enteritis in the distal intestine of Atlantic salmon. *Journal of Agricultural and Food Chemistry*, 55(6): 2261–2267.
- Kolkovski, S. & Tandler, A. 2000. The use of squid protein hydrolysate as a protein source in microdiets for gilthead seabream *Sparus aurata* larvae. *Aquaculture Nutrition*, 6(1): 11–15.
- Kolkovski, S., Czesny, S. & Dabrowski, K. 2000. Use of krill hydrolysate as a feed attractant for fish larvae and juveniles. *Journal of the World Aquaculture Society*, 31(1): 81–88.
- Kontara, E.K.M., Coutteau, P. & Sorgeloos, P. 1997. Effect of dietary phospholipid on requirements for and incorporation of n–3 highly unsaturated fatty acids in postlarval *Penaeus japonicus* Bate. *Aquaculture*, 158: 305–320.
- Koprucu, K. & Ozdemir, Y. 2005. Apparent digestibility of selected feed ingredients for Nile tilapia (*Oreochromis niloticus*). *Aquaculture*, 250(1–2): 308–316.
- Kotzamanis, Y.P., Alexis, M.N., Andriopoulou, A., Castritsi-Cathariou, I. & Fotis, G. 2001. Utilization of waste material resulting from trout processing in gilthead bream (*Sparus aurata* L.) diets. *Aquaculture Research*, 32: 288–295.
- Kousoulaki, K., Albrektsen, S., Langmyhr, E., Olsen, H. J., Campbell, P. & Aksnes, A. 2009. The water soluble fraction in fish meal (stickwater) stimulates growth in Atlantic salmon (*Salmo salar* L.) given high plant protein diets. *Aquaculture*, 289(1–2): 74–83.
- Kraugerud, O.F., Penn, M., Storebakken, T., Refstie, S., Krogdahl, A. & Svihus, B. 2007. Nutrient digestibilities and gut function in Atlantic salmon (*Salmo salar*) fed diets with cellulose or non-starch polysaccharides from soy. *Aquaculture*, 273(1): 96–107.
- Krogdahl, A., Bakke-McKellep, A., Roed, K. & Baeverfjord, G. 2000. Feeding Atlantic salmon *Salmo salar* L. soybean products: effects on disease resistance (furunculosis), and lysozyme and IgM levels in the intestinal mucosa. *Aquaculture Nutrition*, 6(2): 77–84.
- Krogdahl, A., Bakke-McKellep, A. & Baeverfjord, G. 2003. Effects of graded levels of standard soybean meal on intestinal structure, mucosal enzyme activities, and pancreatic response in Atlantic salmon (*Salmo salar* L.). *Aquaculture Nutrition*, 9(6): 361–371.
- Kumar, M.S., Thanh Luu, L., Van Ha, M. & Quang Dieu, N. 2005. The nutrient profile in organic fertilizers biological response to nitrogen and phosphorus management in tanks. *Journal of Applied Aquaculture*, 16(3 & 4): 45–60.
- Kumaraguru Vasagam, K.P., Ramesh, S. & Balasubramanian, T. 2005. Dietary value of different vegetable oil in black tiger shrimp *Penaeus monodon* in the presence and absence of soy lecithin supplementation: Effect on growth, nutrient digestibility and body composition. *Aquaculture*, 250(1–2): 317–327.
- Kumaran, S., Lochmann, R., Stone, N., Kachowski, A. & Lee, Y.W. 2007. Effects of diets with or without menhaden fish meal and oil on egg size, hatchability, and fry size for rosy red fathead minnow. *North American Journal of Aquaculture*, 69(4): 419–428.
- Kureshy, N., Davis, D.A. & Arnold, C.R. 2000. Partial replacement of fish meal with meat-and-bone meal, flash-dried poultry by-product meal, and enzyme-digested poultry by-product meal in practical diets for juvenile red drum. *North American Journal of Aquaculture*, 62(4): 266–272.
- Kut Guroy, B., Curuk, S., Guroy, D., Sanver, F. & Tekunay, A.A. 2007. Effects of *Ulva rigida* and *Cystoseira barbata* meals as a feed additive on growth performance, feed utilization, and body composition of Nile Tilapia, *Oreochromis niloticus*. *Turk. J. Vet. Anim. Sci.*, 31(2): 91–97.
- Kvale, A., Harboe, T., Mangor-Jensen, A. & Hamre, K. 2009. Effects of protein hydrolysate in weaning diets for Atlantic cod (*Gadus morhua* L.) and Atlantic halibut (*Hippoglossus hippoglossus* L.). *Aquaculture Nutrition*, 15(2): 218–227.
- Lacerda, L.D., Santos, J.A. & Madrid, R.M. 2006. Copper emission factors from intensive shrimp aquaculture. *Marine Pollution Bulletin*, 52(12): 1823–1826.
- Laining, A., Rachmansyah, D.K.K. & Ahmad, T. 2001. The use of shrimp head meal as a substitute to fish meal in grower feed for barramundi cod. *Aquaculture Asia*, 6(2): 31–32.
- Lanari, D. & D'Agaro, E. 2005. Alternative plant protein sources in sea bass diets. *Italian Journal of Animal Science*, 4(4): 365–374.

- Lanari, D., D'Agaro, E. & Ballestrazzi, R. 1998. Use of alternative plant protein source in European sea bass feeding. Proceedings: Investigations on Fisheries and Aquaculture within the Framework of Law Number 41/82. Part 3: Aquaculture, hygiene, economy. Rome, 15–16 December 1998. Atti. 'Le Ricerche sulla Pesca e sull'Acquacoltura nell'ambito della L. 41/82'. Parte terza: Acquacoltura, igiene, economia. Roma, 15–16 Dicembre 1998. pp. 2044–2053. *Biologia Marina Mediterranea*, 5(3).
- Lane, R.L., Trushenski, J.T., Kohler, C.C. 2006. Modification of fillet composition and evidence of differential fatty acid turnover in sunshine bass *Morone chrysops* · *M. saxatilis* following change in dietary lipid source. *Lipids*, 41: 1029–1038.
- Lanna, E.A. T., Pezzato, L.E., Furuya, W.M., Vicentini, C.A., Cecon, P.R. & Barros, M.M. 2004. Crude fiber and oil in diets for Nile Tilapia (*Oreochromis niloticus*). *Revista Brasileira De Zootecnia – Brazilian Journal of Animal Science*, 33(6): 2177–2185.
- Laohabanjong, R., Tantikitti, C., Benjakul, S., Supamattaya, K. & Boonyaratpalin, M. 2009. Lipid oxidation in fish meal stored under different conditions on growth, feed efficiency and hepatopancreatic cells of black tiger shrimp (*Penaeus monodon*). *Aquaculture*, 286(3–4): 283–289.
- Lara-Flores, M., Olvera-Novoa, M.A., Guzman-Mendez, B.E. & Lopez-Madrid, W. 2003. Use of the bacteria *Streptococcus faecium* and *Lactobacillus acidophilus*, and the yeast *Saccharomyces cerevisiae* as growth promoters in Nile tilapia (*Oreochromis niloticus*). *Aquaculture*, 216(1–4): 193–201.
- Lazo, J.P. & Davis, D. 2000. Ingredients and feed evaluation, pp. 453–463. In: R.R. Stickney (ed.). *The Encyclopedia of Aquaculture*. New York, USA, John Wiley & Sons Inc. 1063 pp.
- Lee, K. 2002. Nutritional and physiological studies of rainbow trout following utilization of cottonseed meal-based diets. *Aquaculture*, 290(3–4): 283–289.
- Lee, K.J. & Bai, S.C. 1997. Haemoglobin powder as a dietary fish meal replacer in juvenile Japanese eel, *Anguilla japonica* (Temminck et Schlegel). *Aquaculture Research*, 28(7): 509–516.
- Lee, K.J., Dabrowski, K. and Blom, J.H. 2001. Replacement of fish meal by a mixture of animal by-products in juvenile rainbow trout diets. *North American Journal of Aquaculture*, 63(2): 109–117.
- Lee, K.J., Dabrowski, K., Blom, J.H., Bai, S.C. & Stromberg, P.C. 2002. A mixture of cottonseed meal, soybean meal and animal byproduct mixture as a fish meal substitute: growth and tissue gossypol enantiomer in juvenile rainbow trout (*Oncorhynchus mykiss*). *Journal of Animal Physiology and Animal Nutrition*, 86(7–8): 201–213.
- Lee, K.J., Dabrowski, K., Rinchar, J., Gomez, C., Guz, L. & Vilchez, C. 2004. Supplementation of maca (*Lepidium meyenii*) tuber meal in diets improves growth rate and survival of rainbow trout *Oncorhynchus mykiss* (Walbaum) alevins and juveniles. *Aquaculture Research*, 35(3): 215–223.
- Lee, K.J., Rinchar, J., Dabrowski, K., Babiak, I., Ottobre, J. S. & Christensen, J.E. 2006. Long-term effects of dietary cottonseed meal on growth and reproductive performance of rainbow trout: Three-year study. *Animal Feed Science and Technology*, 126(1–2): 93–106.
- Lee, S.M. 2002. Apparent digestibility coefficients of various feed ingredients for juvenile and grower rockfish (*Sebastes schlegeli*). *Aquaculture*, 207(1–2): 79–95.
- Lee, S.M. 2004. Utilization of dietary protein, lipid, and carbohydrate by abalone *Haliotis discus hannai*: A review. *Journal of Shellfish Research*, 23(4): 1027–1030.
- Lee, S.M. & Jeon, I.G. 1996. Evaluation of soybean meal as a partial substitute for fish meal in formulated diets for Korean rockfish *Sebastes schlegeli*. *Journal of the Korean Fisheries Society*, 29(5): 586–594.
- Lee, S.M., Yoo, J.H. & Lee, J.Y. 1996. The use of soybean meal, corn gluten meal, meat meal, meat and bone meal, or blood meal as a dietary protein source replacing fish meal in Korean rockfish (*Sebastes schlegeli*). *Korean Journal of Animal Nutrition and Feedstuffs*, 20(1): 21–30.
- Lee, S., Lim, Y., Lee, J., Park, S., Myeong, J., & Park, Y. 1999. Effects of supplemental squid meal, attractant, herb or lecithin in the formulated diets on growth performance in juvenile abalone (*haliotis discus hannai*). *J.Korean Fish.Soc.*, 32(3): 290–294.
- Lee, S.M., Lee, J.H. & Kim, K.D. 2003. Effect of dietary essential fatty acids on growth, body composition and blood chemistry of juvenile starry flounder (*Platichthys stellatus*). *Aquaculture*, 225(1–4): 269–281.
- Lee, S.M., Kim, K.D. & Kim, T.J. 2004. Utilization of fermented skipjack tuna viscera as a dietary protein source replacing fish meal or soybean meal for juvenile abalone *Haliotis discus hannai*. 5. *Intl. Symp. on Abalone Biology, Fisheries and Culture, Qingdao (China)*, 12–17 October 2003, 23(4): 1059–1063.
- Legendre, M., Kerdchuen, N., Corraze, G., Bergot, P. 1995. Larval rearing of an African catfish, *Heterobranchus longifilis* (Teleostei, Clariidae): effect of dietary lipids on growth, survival and fatty acid composition of fry. *Aquatic Living Resources*, 8: 355–363.
- Lepage, O., Tottmar, O. & Winberg, S. 2002. Elevated dietary intake of L-tryptophan counteracts the stress-induced elevation of plasma cortisol in rainbow trout (*Oncorhynchus mykiss*). *Journal of Experimental Biology*, 205(23): 3679–3687.
- Lepage, O., Molina-Vilchez, I., Pottinger, T. G. & Winberg, S. 2003. Time-course of the effect of dietary L-tryptophan on plasma cortisol levels in rainbow trout *Oncorhynchus mykiss*. *Journal of Experimental Biology*, 206(20):3589–3599.
- Lewis, H.A. & Kohler, C.C. 2008a. Corn gluten meal partially replaces dietary fish meal without compromising growth or fatty acid composition of sunshine bass. *North American Journal of Aquaculture*, 70(1): 50–60.
- Lewis, H.A. & Kohler, C.C. 2008b. Minimizing fish oil and fish meal with plant-based alternatives in sunshine bass diets without negatively impacting growth and muscle fatty acid profile. *Journal of the World Aquaculture Society*, 39(5): 573–585.

- Lewis-McCrea, L.M. & Lall, S.P. 2007. Effects of moderately oxidized dietary lipid and the role of vitamin E on the development of skeletal abnormalities in juvenile Atlantic halibut (*Hippoglossus hippoglossus*). *Aquaculture*, 262(1): 142–155.
- Li, E.-C., Yu, F.-J., Chen, L.-Q., Li, K., Guo, H., Cai, Y.-J. & Cai, C.-F. 2005. Effects of soy protein concentrate as a protein source on nitrogen and phosphorus excretion in Chinese mitten-handed crab (*Eriocheir sinensis*). *Fisheries Science/Shuichan Kexue*, 24(4): 1–3.
- Li, E., Chen, L., Cai, Y., Gu, S., Hong, M., Zhang, L. & Liu, C. 2006. Effects of soy protein concentrate as a dietary protein source on digestive enzyme activities of *Eriocheir sinensis*. *Journal of Zhanjiang Ocean University/Zhanjiang Haiyang Daxue Xuebao*, 26(4): 14–21.
- Li, H., Lv, X.W., Wang, J., Li, J.G., Yang, H.F. & Qin, Y.C. 2007. Quantitative determination of soybean meal content in compound feeds: comparison of near-infrared spectroscopy and real-time PCR. *Analytical and Bioanalytical Chemistry*, 389(7–8): 2313–2322.
- Li, K., Wang, Y., Zheng, Z.-X., Jiang, R.-L., Xie, N.-X. & Bureau, D.B. 2009. Replacing fish meal with rendered animal protein ingredients in diets for Malabar grouper, *Epinephelus malabaricus*, reared in net pens. *Journal of the World Aquaculture Society*, 40(1): 67–75.
- Li, M.H., Raverty, S.A. & Robinson, E.H. 1994. Effects of dietary mycotoxins produced by the mold *fusarium moniliforme* on channel catfish (*Ictalurus punctatus*). *Journal of the World Aquaculture Society*, (25): 512–516.
- Li, M.H. & Robinson, E.H. 1998. Effects of supplemental lysine and methionine in low protein diets on weight gain and body composition of young channel catfish *Ictalurus punctatus*. *Aquaculture*, 163(3–4): 297–307.
- Li, M.H., Hardy, R.W. & Robinson, E.H. 2000. Protein sources for feeds, pp. 688–695. In: R.R. Stickney (ed.), *The Encyclopedia of Aquaculture*. New York, USA, John Wiley and Sons Inc.
- Li, M.H., Peterson, B.C., Janes, C.L. & Robinson, E.H. 2006. Comparison of diets containing various fish meal levels on growth performance, body composition, and insulin-like growth factor-I of juvenile channel catfish *Ictalurus punctatus* of different strains. *Aquaculture*, 253: 628–635.
- Li, M.H., Robinson, E.H., Peterson, B.C. & Bates, T.D. 2008. Growth and feed efficiency of juvenile channel catfish reared at different water temperatures and fed diets containing various levels of fish meal. *North American Journal of Aquaculture*, 70(3): 347–352.
- Li, M.H., Hartnell, G.F., Robinson, E.H., Kronenberg, J.M., Healy, C.E., Oberle, D.F. & Hoberg, J.R. 2008b. Evaluation of cottonseed meal derived from genetically modified cotton as feed ingredients for channel catfish, *Ictalurus punctatus*. *Aquaculture Nutrition*, 14(6): 490–498.
- Li, M.H., Robinson, E.H., Tucker, C.S., Manning, B.B. & Khoo, L. 2009. Effects of dried algae *Schizochytrium* sp., a rich source of docosahexaenoic acid, on growth, fatty acid composition, and sensory quality of channel catfish *Ictalurus punctatus*. *Aquaculture*, 292(3–4): 232–236.
- Li, P. & Gatlin, D.M. 2003. Evaluation of brewers yeast (*Saccharomyces cerevisiae*) as a feed supplement for hybrid striped bass (*Morone chrysops* x *M. saxatilis*). *Aquaculture*, 219: 681–692.
- Li, P. & Gatlin, D.M. 2004. Dietary brewers yeast and the prebiotic GroBiotic™ AE influence growth performance, immune responses and resistance of hybrid striped bass (*Morone chrysops* x *M. saxatilis*) to *Streptococcus iniae* infection. *Aquaculture*, 231(1–4): 445–456.
- Li, P. & Gatlin, D.M. 2005. Evaluation of the prebiotic GroBiotic®-A and brewers yeast as dietary supplements for sub-adult hybrid striped bass (*Morone chrysops* x *M. saxatilis*) challenged in situ with *Mycobacterium marinum*. *Aquaculture*, 248(1–4): 197–205.
- Li, P. & Gatlin, D.M. 2006. Nucleotide nutrition in fish: Current knowledge and future applications. *Aquaculture*, 251(2–4): 141–152.
- Li, P., Wang, X., Hardy, R.W. & Gatlin, D.M. 2004. Nutritional value of fisheries by-catch and by-product meals in the diet of red drum (*Sciaenops ocellatus*). *Aquaculture*, 236(1–4): 485–496.
- Li, P., Burr, G.S., Jonathan, G., Whiteman, K.W., Davis, K.B., Vega, R.R., Neill, W.H. & Gatlin, D.M. 2005. A preliminary study on the effects of dietary supplementation of brewers yeast and nucleotides, singularly or in combination, on juvenile red drum (*Sciaenops ocellatus*). *Aquaculture Research*, 36(11): 1120–1127.
- Li, P., Wang, X.X. & Gatlin, D.M. 2006. Evaluation of levamisole as a feed additive for growth and health management of hybrid striped bass (*Morone chrysops* x *Morone saxatilis*). *Aquaculture*, 251(2–4): 201–209.
- Li, P., Gatlin, D.M. & Neill, W.H. 2007. Dietary supplementation of a purified nucleotide mixture transiently enhanced growth and feed utilization of juvenile red drum, *Sciaenops ocellatus*. *Journal of the World Aquaculture Society*, 38(2): 281–286.
- Li, P., Mai, K.S., Trushenski, J. & Wu, G.Y. 2009. New developments in fish amino acid nutrition: towards functional and environmentally oriented aquafeeds. *Amino Acids*, 37(1): 43–53.
- Li, Y. & Yamamoto, T. 2000. Acceptabilities of common carp, *Cyprinus carpio*, to the diets flavored with amino acids, betaine and quinine using self-feeders. *The Ninth International Symposium on Nutrition and Feeding in Fish, Miyazaki, Japan, 21–25 May 2000*: 124.
- Lian, P.Z., Lee, C.M., Bengtson D.A. 2008. Characterization of squid hydrolysate for its potential as aquaculture feed ingredient. *Journal of the World Aquaculture Society*, 39(2): 196–204.
- Liang, M. & Anders, A. 2001. Influence of fish meal quality on growth, feed conversion rate and protein digestibility in shrimp (*Penaeus chinensis*) and red seabream (*Pagrosomus major*). *Marine Fisheries Research/Haiyang Shuichan Yanjiu*, 22(4): 75–79.
- Liang, M. Q., Wang, J.L., Chang, Q. & Mai, K.S. 2006. Effects of different levels of fish protein hydrolysate in the diet on the nonspecific immunity of Japanese sea bass, *Lateolabrax japonicus* (Cuvier et Valenciennes, 1828). *Aquaculture Research*, 37(1): 102–106.

- Lie, Ø. 2008. (ed.). *Improving farmed fish quality and safety*. Cambridge, UK, Woodhead Publishing Limited. 500 pp.
- Liener, I.E. 1980. *Toxic constituents of plant foodstuffs*. Second edition, New York and London, Academic Press. 502 pp.
- Liener, I.E. 1989. Antinutritional factors in legume seeds: state of the art, pp. 6–13. In: J. Huisman, T.F.B. Van de Poel and I.E. Liener (eds), *Recent advances of Research in Antinutritional Factors in Legume Seeds*. Pudoc, Wageningen, Holland.
- Lilleeng, E., Froystad, M.K., Ostby, G.C., Valen, E.C. & Krogdahl, A. 2007a. Effects of diets containing soybean meal on trypsin mRNA expression and activity in Atlantic salmon (*Salmo salar* L). *Comparative Biochemistry and Physiology, Part A: Molecular and Integrative Physiology*, 147(1): 25–36.
- Lilleeng, E., Froystad, M. K., Vekterud, K., Valen, E.C. & Krogdahl, A. 2007b. Comparison of intestinal gene expression in Atlantic cod (*Gadus morhua*) fed standard fish meal or soybean meal by means of suppression subtractive hybridization and real-time PCR. *Aquaculture*, 267: 269–283.
- Lim, C. 1996. Substitution of cottonseed meal for marine animal protein in diets for *Penaeus vannamei*. *Journal of the World Aquaculture Society*, 27(4): 402–409.
- Lim, C. 1997. Replacement of marine animal protein with peanut meal in diets for juvenile white shrimp, *Penaeus vannamei*. *Journal of Applied Aquaculture*, 7: 67–78.
- Lim, C., Sealey, W.M. & Klesius, P.H. 1996. Iron methionine and iron sulfate as sources of dietary iron for channel catfish *Ictalurus punctatus*. *Journal of the World Aquaculture Society*, 27(3): 290–296.
- Lim, C., Beames, R.M., Eales, J.G., Prendergast, A.F., McLeese, J.M., Shearer, K.D. & Higgs, D.A. 1997. Nutritive values of low and high fibre canola meals for shrimp (*Penaeus vannamei*). *Aquaculture Nutrition* 3(4): 269–279.
- Lim, C., Klesius, P.H. & Higgs, D.A. 1998. Substitution of canola meal for soybean meal in diets for channel catfish, *Ictalurus punctatus*. *J. World Aquaculture Soc.*, 29: 161–168.
- Lim, C., Yildirim-Aksoy, M. & Klesius, P.H. 2009. Growth response and resistance to *Edwardsiella ictaluri* of Channel Catfish, *Ictalurus punctatus*, fed diets containing distiller's dried grains with solubles. *Journal of the World Aquaculture Society*, 40(2):182–193.
- Lim, E.H., Lam, T.J. & Ding, J.L. 2005. Single-cell protein diet of a novel recombinant vitellogenin yeast enhances growth and survival of first-feeding tilapia (*Oreochromis mossambicus*) larvae. *Journal of Nutrition*, 135(3): 513–518.
- Lim, H.A., Ng, W.K., Lim, S.L. & Ibrahim, C.O. 2001. Contamination of palm kernel meal with *Aspergillus flavus* affects its nutritive value in pelleted feed for tilapia, *Oreochromis mossambicus*. *Aquaculture Research* 32(11): 895–905.
- Lim, H.A., Bai, S.C. & Wing-Keong, N.G. 2005. Apparent nutrient digestibility and amino acid availability of several novel protein sources for tilapia, *Oreochromis mossambicus*. *Journal of Aquaculture in the Tropics*, 20(3): 209–222.
- Lim, P.K., Boey, P.L., Ng, W.K. 2001. Dietary palm oil level affects growth performance, protein retention and tissue vitamin E concentration of African catfish, *Clarias gariepinus*. *Aquaculture*, 202: 101–112.
- Lim, S.J. & Lee, K.J. 2008. Supplemental iron and phosphorus increase dietary inclusion of cottonseed and soybean meal in olive flounder (*Paralichthys olivaceus*). *Aquaculture Nutrition*, 14(5): 423–430.
- Lim, S.J. & Lee, K.J. 2009. Partial replacement of fish meal by cottonseed meal and soybean meal with iron and phytase supplementation for parrot fish (*Oplegnathus fasciatus*). *Aquaculture*, 290(3–4): 283–289.
- Lim, S.R., Choi, S.M., Wang, X.J., Kim, K.W., Shin, I.S., Min, T.S. & Bai, S.C. 2004. Effects of dehulled soybean meal as a fish meal replacer in diets for fingerling and growing Korean rockfish *Sebastes schlegelii*. *Aquaculture*, 231: 457–468.
- Limsuwan, T. & Lovell, R.T. 1985. Determination of crude fat in fish feeds. *Progressive Fish Culturist*, 47: 165–169.
- Lin, H.Z., Liu, Y.J., Tian, L.X., Wang, J.T., Zheng, W.H., Huang, J.N. & Chen, P. 2004. Apparent digestibility coefficients of various feed ingredients for grouper *Epinephelus coioides*. *Journal of the World Aquaculture Society*, 35(2): 134–142.
- Lin, H.Z., Guo, Z.X., Ynag, Y.Y., Zheng, W.H. & Li, Z.J.J. 2004b. Effect of dietary probiotics on apparent digestibility coefficients of nutrients of white shrimp *Litopenaeus vannamei* Boone. *Aquaculture Research*, 35(15): 1441–1447.
- Lin, H.Z., Liu, Y.J., He, J.G., Zheng, W.H. & Tian, L.X. 2007. Alternative vegetable lipid sources in diets for grouper, *Epinephelus coioides* (Hamilton): effects on growth, and muscle and liver fatty acid composition. *Aquaculture Research*, 38: 1605–1611.
- Lin, S., Luo, L. & Yie, Y. 2001. Apparent digestibility of crude proteins and crude fats in 17 feed ingredients in grass carp. *Journal of Fishery Sciences of China/Zhongguo Shuichan Kexue*, 8(3): 59–64.
- Lin, Y. & Shiau, S. 2003. Dietary lipid requirement of grouper, *Epinephelus malabaricus*, and effects on immune responses. *Aquaculture*, 225(1–4): 243–250.
- Lin, Y.-H. & Shiau, S.-Y. 2007. Effects of dietary blend of fish oil with corn oil on growth and non-specific immune responses of grouper, *Epinephelus malabaricus*. *Aquaculture Nutrition*, 13(2): 137–144.
- Lin, W.Y., Chen, C.C., Du, M.C. & Hunag, C.H. 2004. Replacement of fish meal with de-hulled soybean meal in diets on growth of subadult hybrid tilapia, *Oreochromis niloticus* x *O. aureus*. *Journal of the Fisheries Society of Taiwan*, 31(4): 263–268.
- Liti, D.M., Waidbacher, H., Straif, M., Mbaluka, R. K., Munguti, J.M. & Kyenze, M.M. 2006. Effects of partial and complete replacement of freshwater shrimp meal (*Caridinea niloticus* Roux) with a mixture of plant protein sources on growth performance of Nile tilapia (*Oreochromis niloticus* L.) in fertilized ponds. *Aquaculture Research*, 37(5): 477–483.

- Liti, D.M., Mugo, R.M., Munguti, J.M. & Waidbacher, H. 2006b. Growth and economic performance of Nile tilapia (*Oreochromis niloticus* L.) fed on three brans (maize, wheat and rice) in fertilized ponds. *Aquaculture Nutrition*, 12(3): 239–245.
- Little, D., Milwain, G. & Price, C. 2008. Pesticide contamination in farmed fish: assessing risks and reducing contamination. In: Ø. Lie (ed.), *Improving farmed fish quality and safety*. Cambridge, U.K., Woodhead Publishing Limited. 500 pp.
- Liu, D., Liu, Y., Feng, J., Tian, L. 2002. Evaluation of soy protein concentrate as replacement for fishmeal in tiger shrimp feeds. *Journal of Fisheries of China/Shuichan Xuebao*, 26: 49–55.
- Liu, F., Ai, Q.H., Mai, K.S., Tan, B.P., Ma, H.M., Xu, W., Zhang, W.B. & Liufu, Z.G. 2008. Effects of dietary binders on survival and growth performance of postlarval tongue sole, *Cynoglossus semilaevis* (Gunther). *Journal of the World Aquaculture Society*, 39(4): 500–509.
- Liu, J., Caballero, M.J., El-Sayed Ali, T., Izquierdo, M.S., Hernández Cruz, C.M., Valencia, A. & Fernández-Palacios, H. 2003. Necessity of dietary lecithin and eicosapentaenoic acid for growth, survival, stress resistance and lipoprotein formation in gilthead sea bream (*Sparus aurata*). *Fisheries Science*, 68: 1165–1172.
- Liu, K.K., Barrows, F.T., Hardy, R.W. & Dong, F.M. 2004. Body composition, growth performance, and product quality of rainbow trout (*Oncorhynchus mykiss*) fed diets containing poultry fat, soybean/corn lecithin, or menhaden oil. *Aquaculture*, 238(1–4): 309–328.
- Liu, Y., Liu, D., Tian, L. & Cao, J. 1999. Effect of fish food with coating and crystallizing lysine on *Ctenopharyngodon idellus*. *J.Fish.China/Shuichan Xuebao*, 23(Suppl.): 51–56.
- Liu, Y. & Yu, Y. 2003. Reemplazo parcial de harina de pescado por harina de carne y hueso en dietas prácticas para camarón blanco del Pacífico, pp.1–4. In: A. Tacon and R. Hardy (eds), *Reciclaje*, 15. Virginia, USA, National Renderers Association.
- Liu, Z., Li, Z., Chen, Q., Qiao, F. & Li, J. 1995. On farming Tilapia with yeast instead of Peru fish meal. *Shandong Fisheries/Qilu Yuy. Yantai*, 12(2): 30–32.
- Lodemel, J.B., Mayhew, T.M., Myklebust, R., Olsen, R.E., Espelid, S. & Ringo, E. 2001. Effect of three dietary oils on disease susceptibility in Arctic charr (*Salvelinus alpinus* L.) during cohabitant challenge with *Aeromonas salmonicida* ssp *salmonicida*. *Aquaculture Research*, 32(12): 935–945.
- Lopez, C., Velasco, M., Hinrichsen, J., Lawrence, A. & Rutman, M. 1998. Effect of krill meal on *Penaeus vannamei* growth. Baton Rouge, LA 70803, USA, Louisiana State University. World Aquaculture Society. (Retrieved from www.csa.com).
- Lopez, L.M., Torres, A.L., Durazo, E., Drawbridge, M. & Bureau, D.P. 2006. Effects of lipid on growth and feed utilization of white seabass (*Atractoscion nobilis*) fingerlings. *Aquaculture*, 253(1–4): 557–563.
- Lopez, L.M., Durazo, E., Viana, M.T., Drawbridge, M. & Bureau, D.P. 2009. Effect of dietary lipid levels on performance, body composition and fatty acid profile of juvenile white seabass, *Atractoscion nobilis*. *Aquaculture*, 289: 101–105.
- Lorentzen, M., Maage, A. & Julshamn, K. 1996. Manganese supplementation of a practical, fish meal based diet for Atlantic salmon parr. *Aquaculture Nutrition*, 2(2): 121–125.
- Lorentzen, M. & Maage, A. 1999. Trace element status of juvenile Atlantic salmon *Salmo salar* L. fed a fish-meal based diet with or without supplementation of zinc, iron, manganese and copper from first feeding. *Aquaculture Nutrition*, 5(3): 163–171.
- Losekann, M.E., Neto, J.R., Emanuelli, T., Pedron, F.D., Lazzari, R., Bergamin, G.T., Correia, V. & Simoes, R.S. 2008. Feeding of jundia with diets containing rice, canola or soybean oils. *Ciencia Rural*, 38(1): 225–230.
- Lovell, R.T. 2000. Mycotoxins, pp.579–582. In: R.R. Stickney (ed.), *The Encyclopedia of Aquaculture*. New York, USA, John Wiley & Sons Inc. 1063 pp.
- Lozano, N.B., Vidal, A., Martínez-Llorens, S., Merida, S., Blanco, J., Lopez, A., Torres, M. Torres & Cerda, M. 2007. Growth and economic profit of gilthead sea bream (*Sparus aurata*, L.) fed sunflower meal. *Aquaculture*, 272: 528–534.
- Lu, S.F., Zhao, N., Zhao, A. & He, R.G. 2008. Effect of soybean phospholipid supplementation in formulated microdiets and live food on foregut and liver histological changes of *Pelteobagrus fulvidraco* larvae. *Aquaculture*, 278: 119–127.
- Lückstädt, C. 2008. *The use of acidifiers in fish nutrition*. CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources 2008 3, No. 044 (available at www.cababstractsplus.org).
- Lumlerdacha, S. & Lovell, R.T. 1995. Fumonisin contaminated dietary corn reduced survival and antibody production by channel catfish challenged with *Edwardsiella ictaluri*. *J. Aquat. Anim. Health*, 7(1): 1–8.
- Lumlerdacha, S., Lovell, R.T., Shelby, R.A., Lenz, S.D. & Kemppainen, B.W. 1995. Growth, hematology, and histopathology of channel catfish (*Ictalurus punctatus*), fed toxins from *Fusarium moniliforme*. *Aquaculture*, 130: 210–218.
- Lunestad B. & Samuelsen, O. 2008. *Veterinary drug use in aquaculture*. In: Ø. Lie (ed.), *Improving farmed fish quality and safety*. Cambridge, UK, Woodhead Publishing Limited. 500 pp.
- Lunestad, B.T., Nesse, L., Lassen, J., Svihus, B., Nesbakken, T., Fossum, K., Rosnes, J.T., Kruse, H., Yasdankhah, S. 2007. Salmonella in fish feed; occurrence and implications for fish and human health in Norway. *Aquaculture*, 265:1-8
- Lunger, A.N., Craig, R.S. & Mclean, E. 2006. Replacement of fish meal in cobia (*Rachycentron canadum*) diets using an organically certified protein. *Aquaculture*, 257(1–4): 393–399.

- Lunger, A.N., McLean, E. & Craig, S.R. 2007a. The effects of organic protein supplementation upon growth, feed conversion and texture quality parameters of juvenile cobia (*Rachycentron canadum*). *Aquaculture*, 264(1-4): 342-352.
- Lunger, A.N., McLean, E., Gaylord, T.G., Kuhn, D. & Craig, S.R. 2007b. Taurine supplementation to alternative dietary proteins used in fish meal replacement enhances growth of juvenile cobia (*Rachycentron canadum*). *Aquaculture*, 271(1-4): 401-410.
- Luo, A., Liu, Y., Mai, K., Tian, L., Liu, D. & Tan, X. 2004. Partial replacement of fish meal by soybean protein in diets for grouper *Epinephelus coioides* juveniles. *Journal of Fisheries of China/Shuichan Xuebao*, 28(2): 175-181.
- Luo, L., Xue, M., Wu, X., Cai, X., Cao, H. & Liang, Y. 2006. Partial or total replacement of fishmeal by solvent-extracted cottonseed meal in diets for juvenile rainbow trout (*Oncorhynchus mykiss*). *Aquaculture Nutrition* 12(6): 418-424.
- Luo, Z., Li, X.-D., Gong, S.Y. & Xi, W.-Q. 2009. Apparent digestibility coefficients of four feed ingredients for *Synechogobius hasta*. *Aquaculture Research*, 40: 558-565.
- Luzier, J.M., Summerfelt, R.C. & Ketola, H.G. 1995. Partial replacement of fish meal with spray-dried blood powder to reduce phosphorus concentrations in diets for juvenile rainbow trout, *Oncorhynchus mykiss* (Walbaum). *Aquaculture Research*, 26(8): 577-587.
- Luzzana, U., Moretti, V.M. & Valfrè, F. 1995. Fish meal use in aquaculture: evaluation of the effects of thermal treatment on nutritional quality of proteins. *Rivista Italiana di Acquacoltura*, 30(4): 163-172.
- Luzzana, U., Valfrè, F., Mangiarotti, M., Domeneghini, C., Radaelli, G., Moretti, V.M. & Scolari, M. 2005. Evaluation of different protein sources in fingerling grey mullet *Mugil cephalus* practical diets. *Aquaculture International*, 13(4): 291-303.
- Luzzana, U., Scolari, M., Campo Dall'Orto, B., Caprino, F., Turchini, G., Orban, E., Sinesio, F. & Valfrè, F. 2003. Growth and product quality of European eel (*Anguilla anguilla*) as affected by dietary protein and lipid sources. *Journal of Applied Ichthyology*, 19: 74-78.
- Mahajan, A. & Dua, S. 1998. Improvement of functional properties of rapeseed (*Brassica campestris* var *toria*) meal by reducing antinutritional factors employing enzymatic modification. *Food Hydrocolloids*, 12(3): 349-355.
- Mahboob, S. & Sheri, A.N. 1997. Growth performance of major, common and some Chinese carps under composite culture system with special reference to pond fertilization. *J. Aqua. Trop.*, 12: 201-207.
- Mai, K.S. & Tan, B.P. 2000a. Iron methionine (FeMET) and iron sulfate (FeSO₄) as sources of dietary iron for juvenile abalone, *Haliotis discus hannai* Ino. *Journal of Shellfish Research*, 19(2): 861-868.
- Mai, K. & Tan, B. 2000b. Zn and Fe in the forms of methionine chelation or sulphates as sources of dietary minerals for juvenile abalone, *Haliotis discus hannai* ino. 4. International Abalone Symposium, Cape Town, South Africa, February 2000, 19(1): 536-537.
- Mai, K., Li, H., Ai, Q., Duan, Q., Xu, W., Zhang, C., Zhang, L., Tan, B. & Liufu, Z. 2006a. Effects of dietary squid viscera meal on growth and cadmium accumulation in tissues of Japanese seabass, *Lateolabrax japonicus* (Cuvier 1828). *Aquaculture Research*, 37(11): 1063-1069.
- Mai, K.S., Wan, J.L., Ai, Q.H., Xu, W., Liufu, Z.G., Zhang, L., Zhang, C.X. & Li, H.T. 2006b. Dietary methionine requirement of large yellow croaker, *Pseudosciaena crocea* R. *Aquaculture*, 253(1-4): 564-572.
- Maina, J.G., Beames, R.M., Higgs, D., Mbugua, P.N., Iwama, G. & Kisia, S.M. 2003. Partial replacement of fishmeal with sunflower cake and corn oil in diets for tilapia *Oreochromis niloticus* (Linn): effect on whole body fatty acids. *Aquaculture Research*, 34(8): 601-608.
- Malek, M.A., Khan, M.J. & Islam, K.M.S. 2008. Nutritional improvement of ensiled rice straw through supplementation of urea, molasses, soybean seed meal and aquatic plants. *Indian Journal of Animal Sciences*, 78(12): 1404-1407.
- Manning, B.B. 2001. Mycotoxins in fish feeds. In: C. Lim, C. and C.D. Webster (eds), *Nutrition and Fish Health*. New York, USA, Food Products Press. 365 pp.
- Manning, B.B., Ulloa, R.M., Li, M.H., Robinson, E.H., Rottinghaus, G.E. 2003a. Ochratoxin A fed to channel catfish (*Ictalurus punctatus*) causes reduced growth and lesions of hepatopancreatic tissue. *Aquaculture*, 219: 739-750.
- Manning, B.B., Li, M.H., Robinson, E.H., Gaunt, P.S., Camus, A.C., Rottinghaus, G.E. 2003b. Response of catfish to diets containing T-2 toxin. *Journal of Aquatic Animal Health*, 15(3): 229-238.
- Manning, B.B., Li, M.H., Robinson, E.H. 2005a. Aflatoxins from moldy corn cause no reductions in channel catfish (*Ictalurus punctatus*) performance. *J. World Aquacult. Soc.*, 36(1): 59-67.
- Manning, B.B., Terhune, J.S., Li, M.H., Robinson, E.H., Wise, D.J., Rottinghaus, G.E. 2005b. Exposure to feedborne mycotoxins T-2 toxin or ochratoxin A causes increased mortality of channel catfish challenged with *Edwardsiella ictaluri*. *Journal of Aquatic Animal Health*, 17(2): 147-152.
- Manning, B.B., Li, M.H. & Robinson, E.H. 2007. Feeding channel catfish, *Ictalurus punctatus*, diets amended with refined marine fish oil elevates omega-3 highly unsaturated fatty acids in filets. *Journal of the World Aquaculture Society*, 38(1): 49-58.
- Marinho-Soriano, E., Camara, M.R., Cabral, T.D. & Carneiro, M.A.D. 2007. Preliminary evaluation of the seaweed *Gracilaria cervicornis* (Rhodophyta) as a partial substitute for the industrial feeds used in shrimp (*Litopenaeus vannamei*) farming. *Aquaculture Research*, 38(2): 182-187.
- Mariotti, F., Tome, D. & Mirand, P.P. 2008. Converting nitrogen into protein – beyond 6.25 and Jones' factors. *Critical Reviews in Food Science and Nutrition*, 48: 177-184.

- Martinez-Llorens, S., Monino, A.V., Vidal, A.T., Salvador, V.J.M., Torres, M.P. & Cerda, M.J. 2007. Soybean meal as a protein source in gilthead sea bream (*Sparus aurata* L.) diets: effects on growth and nutrient utilization. *Aquaculture Research* 38(1): 82–90.
- Martinez-Llorens, S., Vidal, A.T., Monino, A.V., Torres, M.P. & Cerda, M.J. 2007b. Effects of dietary soybean oil concentration on growth, nutrient utilization and muscle fatty acid composition of gilthead sea bream (*Sparus aurata* L.). *Aquaculture Research*, 38(1): 76–81.
- Martinez-Llorens, S., Vidal, A.T., Monino, A.V., Ader, J.G., Torres, M.P. & Cerda, M.J. 2008. Blood and haemoglobin meal as protein sources in diets for gilthead sea bream (*Sparus aurata*): effects on growth, nutritive efficiency and fillet sensory differences. *Aquaculture Research*, 39(10): 1028–1037.
- Martinez-Llorens, S., Vidal, A.T., Garcia, I.J., Torres, M.P. & Cerda, M.J. 2009. Optimum dietary soybean meal level for maximizing growth and nutrient utilization of on-growing gilthead sea bream (*Sparus aurata*). *Aquaculture Nutrition*, 15: 320–328.
- Martinez-Palacios, C.A., Olvera-Novoa, M.A., Luz Vazquez, M.I., Parra, I.A., Chavez-Sanchez, M., Ortega-Nieblas, M. & Ross, L.G. 2003. The use of halophytic beach-bean meal *Canavalia maritima*, as partial replacement for fishmeal in diets for juvenile Nile tilapia *Oreochromis niloticus* (Linnaeus). *Journal of Aquaculture in the Tropics*, 18(2): 171–180.
- Martinez-Vega J.A., Cruz-Suárez L.E., Ricque-Marie D. 2000a. Evaluación de diferentes partes corporales del calamar gigante (*Dosidicus gigas*) en forma de harina en dietas balanceadas para camarón blanco (*Litopenaeus vannamei*). *Ciencia y Mar*, Vol IV(11): 11–18.
- Martinez-Vega J.A., Cruz-Suárez L.E., Ricque-Marie D. 2000b. Composición corporal y proceso de secado del calamar gigante (*Dosidicus gigas*). *Ciencia y Mar*, Vol IV(11): 35–38.
- Martino, R.C., Cyrino, J.E.P., Ports, L., Trugo, L.C. 2002. Performance and fatty acid composition of surubim (*Pseudoplatystoma coruscans*) fed diets with animal and plant lipids. *Aquaculture*, 209: 233–246.
- Martins, D.A., Gomes, E., Rema, P., Dias, J., Ozorio, R.O.A., Valente, L.M.P. 2006. Growth, digestibility and nutrient utilization of rainbow trout (*Oncorhynchus mykiss*) and European sea bass (*Dicentrarchus labrax*) juveniles fed different dietary soybean oil levels. *Aquaculture International*, 14: 285–295.
- Martins, D.A., Afonso, L.O.B., Hosoya, S., Lewis-McCrea, L.M., Valente, L.M.P. & Lall, S.P. 2007. Effects of moderately oxidized dietary lipid and the role of vitamin E on the stress response in Atlantic halibut (*Hippoglossus hippoglossus* L.). *Aquaculture*, 272(1–4): 573–580.
- Martins, D.A., Valente, L.M.P. & Lall, S.P. 2007b. Effects of dietary lipid level on growth and lipid utilization by juvenile Atlantic halibut (*Hippoglossus hippoglossus*, L.). *Aquaculture*, 263(1–4): 150–158.
- Martins, D.A., Valente, L.M.P. & Lall, S.P. 2009. Apparent digestibility of lipid and fatty acids in fish oil, poultry fat and vegetable oil diets by Atlantic halibut, *Hippoglossus hippoglossus*. *Aquaculture*, 294: 132–137.
- Masumoto, T., Ruchimat, T., Ito, Y., Hosokawa, H. & Shimeno, S. 1996. Amino acid availability values for several protein sources for yellowtail (*Seriola quinqueradiata*). *Aquaculture*, 146(1–2): 109–119.
- Masumoto, T., Tamura, B. & Shimeno, S. 2001. Effects of phytase on bioavailability of phosphorus in soybean meal-based diets for Japanese flounder *Paralichthys olivaceus*. *Fisheries Science*, 67(6): 1075–1080.
- Masumoto, T., Bista, J.D., Itoh, Y., Hosokawa, H. & Shimeno, S. 1999. Bioavailability of modified forms of methionine in yellowtail and rainbow trout. *Bulletin of Marine Sciences and Fisheries, Kochi University*, (19): 43–48.
- Mataka, L. & Kang'ombe, J. 2007. Effect of substitution of maize bran with chicken manure in semi-intensive pond culture of *Tilapia rendalli* (Boulenger). *Aquaculture Research*, 38(9): 940–946.
- Matsuoka, S., Yagi, H., Hirai, M., Amita, T., Masumoto, T. & Hosokawa, H. 2006. Utilization of some kinds of replacer as a protein source in the diet of Japanese flounder. *Bulletin of the Ehime Prefectural Fisheries Experimental Station*, no. 12, pp. 15–24.
- Maule, A.G., Gannam, A.L. & Davis, J.W. 2007. Chemical contaminants in fish feeds used in federal salmonid hatcheries in the USA. *Chemosphere*, 67: 1308–1315.
- Mazurkiewicz, J. & Rozek, W. 2006. Partial substitution of fish meal with soybean protein concentrate and extracted rapeseed meal in the diet of sterlet (*Acipenser ruthenus*). *Journal of Applied Ichthyology/Zeitschrift für angewandte Ichthyologie*, 22(Suppl.): 298–302.
- Mbahinzireki, G.B., Dabrowski, K., Lee, K.J., El-Saidy, D. & Wisner, E.R. 2001. Growth, feed utilization and body composition of tilapia (*Oreochromis* sp.) fed with cottonseed meal-based diets in a recirculating system. *Aquaculture Nutrition*, 7(3): 189–200.
- McGoogan, B.B. & Gatlin, D.M. 1997. Effects of replacing fish meal with soybean meal in diets for red drum *Sciaenops ocellatus* and potential for palatability enhancement. *Journal of the World Aquaculture Society*, 28(4): 374–385.
- McGoogan, B.B. & Reigh, R.C. 1996. Apparent digestibility of selected ingredients in red drum (*Sciaenops ocellatus*) diets. *Aquaculture*, 141(3–4): 233–244.
- McKenzie, D.J., Piraccini, G., Papini, N., Galli, C., Bronzi, P., Bolis, C.G. & Taylor, E.W. 1997. Oxygen consumption and ventilatory reflex responses are influenced by dietary lipids in sturgeon. *Fish Physiology and Biochemistry*, 16(5): 365–379.
- McKenzie, D.J., Higgs, D.A., Dosanjh, B.S., Deacon, G. & Randall, D.J. 1998. Dietary fatty acid composition influences swimming performance in Atlantic salmon (*Salmo salar*) in seawater. *Fish Physiology and Biochemistry*, 19(2): 111–122.
- McKenzie, D.J., Piraccini, G., Piccolella, M., Steffensen, J.F., Bolis, C.L. & Taylor, E.W. 2000. Effects of dietary fatty acid composition on metabolic rate and responses to hypoxia in the European eel (*Anguilla anguilla*). *Fish Physiology and Biochemistry*, 22(4): 281–296.

- Medale, F. & Kaushik, S. 2009. Protein sources in feed for farmed fish. *Cabiers Agricultures*, 18(2): 103–111.
- Medale, F., Boujard, T., Valee, F., Blanc, D., Mambrini, M., Roem, A. & Kaushik, S.J. 1998. Voluntary feed intake, nitrogen and phosphorus losses in rainbow trout (*Oncorhynchus mykiss*) fed increasing dietary levels of soy protein concentrate. *Aquat. Living Resour.*, 11(4): 239–246.
- Medina-Reyna, C.E., Chavez-Sanchez, M.C., Martinez-Palacios, C.A. & Pedroza-Islas, R. 2000. Evaluation of a microbound spray-dried feed for the rearing of penaeid shrimp larvae. *North American Journal of Aquaculture*, 62(1): 73–77.
- Meeker, D.L. & Hamilton, C.R. 2006. An overview of the rendering industry, pp.1–16. In: D.L. Meeker (ed.), *Essential Rendering – All about the animal by-products industry*. Arlington, Virginia, USA, National Renderers Association, Kirby Lithographic Company, Inc.
- Menasveta, P. & Yu, Y. 2002. Replacement of fish meal with meat and bone meal or poultry byproduct on growth performance of black tiger shrimp, *P. monodon*. *National Renderers Association Inc. Research Report No. 22*, Hong Kong.
- Menasveta, P., Somkiat, P. & Y. Yu. 2003. Respuesta de crecimiento del camarón *Penaeus monodon* cuando se le alimenta con dietas formuladas con proteínas animales recicladas o harina de pescado, pp.5–13. In: A. Tacon and R Hardy (eds), *Reciclaje*, 15. Alexandria, Virginia, USA, National Renderers Association.
- Mendoza, R., De-Dios, A., Vazquez, C., Cruz, E., Ricque, D., Aguilera, C. & Montemayor, J. 2001. Fishmeal replacement with feather-enzymatic hydrolyzates co-extruded with soya-bean meal in practical diets for the Pacific white shrimp (*Litopenaeus vannamei*). *Aquaculture Nutrition* 7: 143–151.
- Menoyo, D., Lopez-Bote, C.J., Bautista, J.M. & Obach, A. 2002. Herring vs. anchovy oils in salmon feeding. *Aquatic Living Resources*, 15(4): 217–223.
- Menoyo, D., Lopez-Bote, C.J., Bautista, J.M. & Obach, A. 2003. Growth, digestibility and fatty acid utilization in large Atlantic salmon (*Salmo salar*) fed varying levels of n-3 and saturated fatty acids. *Aquaculture*, 225(1): 295–307.
- Menoyo, D., Izquierdo, M.S., Robaina, L., Ginés, R., Lopez-Bote, C.J., Bautista, J.M. 2004. Adaptation of lipid metabolism, tissue composition and flesh quality in gilthead sea bream (*Sparus aurata*) to the replacement of dietary fish oil by linseed and soyabean oils. *British Journal of Nutrition*, 92: 41–52.
- Menoyo, D., Lopez-Bote, C.J., Obach, A. & Bautista, J.M. 2005. Effect of dietary fish oil substitution with linseed oil on the performance, tissue fatty acid profile, metabolism, and oxidative stability of Atlantic salmon. *Journal of Animal Science*, 83(12): 2853–2862.
- Mente, E., Deguara, S., Santos, M.B. & Houlihan, D. 2003. White muscle free amino acid concentrations following feeding a maize gluten dietary protein in Atlantic salmon (*Salmo salar* L.). *Aquaculture*, 225(1–4): 133–147.
- Meronuck, R. & Xie, W.Q. 2000. *Mycotoxins in feed*. 2000 Feedstuffs Reference Issue, 72(29): 95–102.
- Meunpol, O., Iam-Pai, S., Suthikrai, W. & Piyatiratitivorakul, S. 2007. Identification of progesterone and 17 alpha-hydroxyprogesterone in polychaetes (*Perinereis* sp.) and the effects of hormone extracts on penaeid oocyte development in vitro. *Aquaculture*, 270(1–4): 485–492.
- Middendorp, A. J. 1995a. Pond farming of Nile tilapia, *Oreochromis niloticus* (L.), in northern Cameroon. Mixed culture of large tilapia (greater than 200 g) with cattle manure and cottonseed cake as pond inputs, and African catfish, *Clarias gariepinus* (Burchell), as police-fish. *Aquaculture Research*, 26(10): 723–730.
- Middendorp, A. J. & Huisman, E.A. 1995b. Pond farming of Nile tilapia, *Oreochromis niloticus* (L.), in northern Cameroon. Comparing two different strategies for feeding cottonseed cake in tilapia male monosex culture. *Aquaculture Research*, 26(10): 731–738.
- Middleton, T.F., Ferket, P.R., Boyd, L.C., Daniels, H.V. & Gallagher, M.L. 2001. An evaluation of co-extruded poultry silage and culled jewel sweet potatoes as a feed ingredient for hybrid Tilapia (*Oreochromis niloticus* x *O-mossambicus*). *Aquaculture*, 198(3–4): 269–280.
- Millamena, O.M. 2002. Replacement of fish meal by animal by-product meals in a practical diet for grow-out culture of grouper *Epinephelus coioides*. *Aquaculture*, 204(1–2): 75–84.
- Millamena, O.M. & Golez, N.V. 2001. Evaluation of processed meat solubles as replacement for fish meal in diet for juvenile grouper *Epinephelus coioides* (Hamilton). *Aquaculture Research*, 32(s1): 281–287.
- Millamena, O.M. & Trino, A.T. 1997. Low-cost feed for *Penaeus monodon* reared in tanks and under semi-intensive and intensive conditions in brackishwater ponds. *Aquaculture*, 154(1): 69–78.
- Millamena, O.M., Coloso, R.M. & Pascual, F.P. (eds). 2002. *Nutrition in Tropical Aquaculture*. Tigbauan, Iloilo, Philippines, Aquaculture Department, Southeast Asian Fisheries Development Center. 221 pp.
- Millamena, O.M., Golez, N.V., Janssen, J.A.J. & Peschcke-Koedt, M. 2000. Processed meat solubles, protamino aqua, used as an ingredient in juvenile shrimp feeds. *Israeli Journal of Aquaculture – Bamidgeh*, 52(3):91–97.
- Miller, E.L., Bimbo, A.P., Barlow, S.M. & Sheridan, B. 2007. Repeatability and reproducibility of determination of the nitrogen content of fishmeal by the combustion (Dumas) method and comparison with the Kjeldahl method: Interlaboratory study. *Journal of AOAC International*, 90(1): 6–20.
- Miller, M.R., Nichols, P.D. & Carter, C.G. 2007a. Replacement of fish oil with *thraustochytrid* *Schizochytrium* sp L oil in Atlantic salmon parr (*Salmo salar* L) diets. *Comparative Biochemistry and Physiology – Part A*, 148(2): 382–392.
- Miller, M.R., Nichols, P.D. & Carter, C.G. 2007b. Replacement of dietary fish oil for Atlantic salmon parr (*Salmo salar* L.) with a stearidonic acid containing oil has no effect on omega-3 long-chain polyunsaturated fatty acid concentrations. *Comparative Biochemistry and Physiology, Part B – Biochemistry and Molecular Biology*, 146(2): 197–206.

- Miller, M.R., Nichols, P.D. & Carter, C.G. 2008. The digestibility and accumulation of dietary phytosterols in Atlantic salmon (*Salmo salar* L.) smolt fed diets with replacement plant oils. *Lipids*, 43(6): 549–557.
- Minh, N.H., Minh, T.B., Natsuko, K., Tatsuya, K., Hisato, I., Viet, P.H., Tu, N.P.C., Tuyen, B.C. & Shinsuke, T. 2006. Contamination by polybrominated diphenyl ethers and persistent organochlorines in catfish and feed from Mekong River Delta, Vietnam. *Environmental toxicology and chemistry*, 25 (10): 2700–2708.
- Mishra, K. & Samantaray, K. 2004. Interacting effects of dietary lipid level and temperature on growth, body composition and fatty acid profile of rohu, *Labeo rohita* (Hamilton). *Aquaculture Nutrition*, 10(6): 359–369.
- Mohammed-Suhaimee, A.M., Zainoha, Z. & Ng, W.K. 2006. The inclusion of urea-treated palm kernel meal as a feed ingredient in the diet of juvenile seabass (*Lates calcarifer*) affects growth performance. *Journal of Aquaculture in the Tropics*, 21(1–2): 51–68.
- Mohanta, K.N., Mohanty, S.N., Jena, J. & Sahu, N.P. 2007. Effect of different oil cake sources on growth, nutrient retention and digestibility, muscle nucleic acid content, gut enzyme activities and whole-body composition in silver barb, *Puntius gonionotus* fingerlings. *Aquaculture Research* 38(16):1702–1713.
- Mohanta, K.N., Mohanty, S.N., Jena, J. & Sahu, N.P. 2008. Effect of three different oil cake-based diets on pond production performance of silver barb, *Puntius gonionotus* (Bleeker). *Aquaculture Research*, 39(11): 1131–1140.
- Moksness, E., Rosenlund, G. & Lie, O. 1995. Effect of fish meal quality on growth of juvenile wolffish, *Anarhichas lupus* L. *Aquaculture Research*, 26(2): 109–115.
- Mokolensang, J.F., Yamasaki, S. & Onoue, Y. 2003. Utilization of sweet potato distillery by-products as a feedstuff for red carp *Cyprinus carpio* L. *Journal of the World Aquaculture Society*, 34(4): 512–517.
- Molina-Poveda, C. & Morales, M.E. 2004. Use of a mixture of barley-based fermented grains and wheat gluten as an alternative protein source in practical diets for *Litopenaeus vannamei* (Boone). *Aquaculture Research*, 35(12): 1158–1165.
- Molina-Poveda, C. & Lucas, M. 2007. Harina de lupino, pp. 156–165. In: T.G. Galano, H. Villarreal-Colmenares and J.L. Fenucci (eds), *Manual de ingredientes proteicos y aditivos empleados en la formulacion de alimentos balanceados para camarones peneidos*. Subprograma II “Acuicultura” Red Tematica II.C, Proyecto II-8 Ciencia y Tecnologia El Desarrollo (CYTED). Argentina, Universidad Nacional de Mar del Plata. 264 pp.
- Molnar, T., Szabo, A., Szabo, G., Szabo, C., Hancz, C. 2006. Effect of different dietary fat content and fat type on the growth and body composition of intensively reared pikeperch *Sander lucioperca* (L.). *Aquaculture Nutrition*, 12: 173–182.
- Mondal, K., Kaviraj, A. & Mukhopadhyay, P.K. 2008. Evaluation of fermented fish-offal in the formulated diet of the freshwater catfish *Heteropneustes fossilis*. *Aquaculture Research*, 39(13): 1443–1449.
- Montero, D., Kalinowski, T., Obach, A., Robaina, L., Tort, L., Caballero, M.J. & Izquierdo, M.S. 2003. Vegetable lipid sources for gilthead seabream (*Sparus aurata*): Effects on fish health. *Aquaculture*, 225: 353–370.
- Montero, D., Kalinowski, T., Caballero, M.J., Obach, A., Tort, L., Robaina, L.Y. & Izquierdo, M.S. 2005a. Effect of dietary vegetable lipid sources in gilthead seabream (*Sparus aurata*) immune status and stress resistance. *Cab. Options Mediterr.*, 103–112.
- Montero, D., Robaina, L., Caballero, M.J., Gines, R. & Izquierdo, M.S. 2005b. Growth, feed utilization and flesh quality of European sea bass (*Dicentrarchus labrax*) fed diets containing vegetable oils. A time-course study on the effect of a re-feeding period with a 100 percent fish oil. *Aquaculture*, 248: 121–134.
- Montero, D., Grasso, V., Izquierdo, M.S., Ganga, R., Real, F., Tort, L., Caballero, M.J. & Acosta, F. 2008. Total substitution of fish oil by vegetable oils in gilthead sea bream (*Sparus aurata*) diets: effects on hepatic Mx expression and some immune parameters. *Fish Shellfish Immunol.*, 24: 147–155.
- Morais, S., Caballero, M.J., Conceicao, L.E.C., Izquierdo, M.S. & Dinis, M.T. 2006. Dietary neutral lipid level and source in Senegalese sole (*Solea senegalensis*) larvae: Effect on growth, lipid metabolism and digestive capacity. *Comparative Biochemistry and Physiology, Part B – Biochemistry and Molecular Biology*, 144(1): 57–69.
- Morales, A.E., Cardenete, G., Sanz, A. & de la Higuera, M. 1999. Re-evaluation of crude fibre and acid-insoluble ash as inert markers, alternative to chromic oxide, in digestibility studies with rainbow trout (*Oncorhynchus mykiss*). *Aquaculture*, 179(1–4): 71–79.
- Moreau, M.F., Surico-Bennett, J., Vicario-Fisher, M., Crane, D., Gerads, R., Gersberg, R.M. & Hurlbert, S.H. 2007. Contaminants in tilapia (*Oreochromis mossambicus*) from the Salton Sea, California, in relation to human health, piscivorous birds and fish meal production. *Hydrobiologia*, 576: 127–165.
- Moreau, Y., Arredondo, J.L., Perraud-Gaime, I. & Roussos, S. 2003. Dietary utilisation of protein and energy from fresh and ensiled coffee pulp by the Nile tilapia, *Oreochromis niloticus*. *Brazilian Archives of Biology and Technology*, 46(2): 223–231.
- Moren, M., Malde, M.K., Olsen, R.E., Hemre, G.I., Dahl, L., Karlsen, O. & Julshamn, K. 2007. Fluorine accumulation in Atlantic salmon (*Salmo salar*), Atlantic cod (*Gadus morhua*), rainbow trout (*Oncorhynchus mykiss*) and Atlantic halibut (*Hippoglossus hippoglossus*) fed diets with krill or amphipod meals and fish meal based diets with sodium fluoride (NaF) inclusion. *Aquaculture*, 269(1–4): 525–531.
- Mørkøre, T. 2006. Relevance of dietary oil source for contraction and quality of pre-rigor filleted Atlantic cod, *Gadus morhua*. *Aquaculture*, 251(1): 56–65.
- Mørkøre, T., Netteberg, C., Johnsson, L. & Pickova, J. 2007. Impact of dietary oil source on product quality of farmed Atlantic cod, *Gadus morhua*. *Aquaculture* 267: 236–247.

- Mourente, G. & Dick, J.R. 2002. Influence of partial substitution of dietary fish oil by vegetable oils on the metabolism of [1-C-14] 18 : 3n-3 in isolated hepatocytes of European sea bass (*Dicentrarchus labrax* L.). *Fish Physiology and Biochemistry*, 26(3): 297–308.
- Mourente, G. & Bell, J.G. 2006. Partial replacement of dietary fish oil with blends of vegetable oils (rapeseed, linseed and palm oils) in diets for European sea bass (*Dicentrarchus labrax* L.) over a long term growth study: effects on muscle and liver fatty acid composition and effectiveness of a fish oil finishing diet. *Comp Biochem Physiol B Biochem Mol Biol.*, 145(3–4): 389–99.
- Mourente, G., Good, J.E. & Bell, J.G. 2005a. Partial substitution of fish oil with rapeseed, linseed and olive oils in diets for European sea bass (*Dicentrarchus labrax* L.): effects on flesh fatty acid composition, plasma prostaglandins E2 and F2, immune function and effectiveness of a fish oil finishing diet. *Aquaculture Nutrition*, 11: 25–40.
- Mourente, G., Dick, J.R., Bell, J.G. & Tocher, D.R. 2005b. Effect of partial substitution of dietary fish oil by vegetable oils on desaturation and beta -oxidation of [1- super(1) super(4)C]18:3n-3 (LNA) and [1- super(1) super(4)C]20:5n-3 (EPA) in hepatocytes and enterocytes of European sea bass (*Dicentrarchus labrax* L.). *Aquaculture*, 248(1–4): 173–186.
- Mourente, G., Diaz-Salvago, E., Tocher, D.R. & Bell, J.G. 2000. Effects of dietary polyunsaturated fatty acid/vitamin E (PUFA/tocopherol ratio on antioxidant defence mechanisms of juvenile gilthead sea bream (*Sparus aurata* L., Osteichthyes, Sparidae). *Fish Physiology and Biochemistry*, 23(4): 337–351.
- Mukhopadhyay, N. 2000. Improvement of quality of copra (dried kernel of *Cocos nucifera*) seed meal protein with supplemental amino acids in feeds for rohu, *Labeo rohita* (Hamilton) fingerlings. *Acta Ichthyologica et Piscatoria*, 30(2): 21–34.
- Mukhopadhyay, N. & Ray, A.K. 1996. The potential of deoiled sal (*Shorea robusta*) seed meal as a feedstuff in pelleted feed for Indian major carp, rohu, *Labeo rohita* (Hamilton), fingerlings. *Aquaculture Nutrition*, 2(4): 221–227.
- Mukhopadhyay, N. & Ray, A.K. 1997. The apparent total and nutrient digestibility of sal seed (*Shorea robusta*) meal in rohu, *Labeo rohita* (Hamilton), fingerlings. *Aquaculture Research*, 28(9): 683–689.
- Mukhopadhyay, N. & Ray, A.K. 1999a. Effect of fermentation on the nutritive value of sesame seed meal in the diets for rohu, *Labeo rohita* (Hamilton), fingerlings. *Aquaculture Nutrition*, 5(4): 229–236.
- Mukhopadhyay, N. & Ray, A.K. 1999b. Improvement of quality of sesame *Seasamum indicum* seed meal protein with supplemental amino acids in feeds for rohu *Labeo rohita* (Hamilton) fingerlings. *Aquaculture Research*, 30(8): 549–557.
- Mukhopadhyay, N. & Ray, A.K. 1999c. Utilization of copra meal in the formulation of compound diets for rohu, *Labeo rohita*, fingerlings. *Journal of Applied Ichthyology*, 15(3): 127–131.
- Mukhopadhyay, N. & Ray, A.K. 2001. Effects of amino acid supplementation on the nutritive quality of fermented linseed meal protein in the diets for rohu, *Labeo rohita*, fingerlings. *Journal of Applied Ichthyology*, 17(5): 220–226.
- Mukhopadhyay, P.K. & Rout, S.K. 1996. Effects of different dietary lipids on growth and tissue fatty acid changes in fry of the carp *Catla catla* (Hamilton). *Aquaculture Research* 27: 623–630.
- Mukhopadhyay, P.K. & Mishra, S. 1998. Effect of feeding different lipid sources on growth, feed efficiency and tissue fatty acid composition of *Clarias batrachus* fry and fingerling. *Journal of Applied Ichthyology*, 14: 105–107.
- Mundheim, H., Aksnes, A. & Hope, B. 2004. Growth, feed efficiency and digestibility in salmon (*Salmo salar* L.) fed different dietary proportions of vegetable protein sources in combination with two fish meal qualities. *Aquaculture*, 237(1–4): 315–331.
- Murray, A. L., Pascho, R.J., Alcorn, S.W., Fairgrieve, W.T., Shearer, K.D. & Roley, D. 2003. Effects of various feed supplements containing fish protein hydrolysate or fish processing by-products on the innate immune functions of juvenile coho salmon (*Oncorhynchus kisutch*). *Aquaculture*, 220(1–4): 643–653.
- Mustafa, M.G. & Nakagawa, H. 1995. A review: Dietary benefits of algae as an additive in fish feed. *Israeli Journal of Aquaculture – Bamidgeh*, 47(3–4): 155–162.
- Mustafa, M.G., Wakamatsu, S., Takeda, T.A., Umino, T. & Nakagawa, H. 1995. Effects of algae meal as feed additive on growth, feed efficiency, and body composition in red sea bream. *Fisheries Science*, 61(1): 25–28.
- Muzinic, L.A., Thompson, K.R., Morris, A., Webster, C.D., Rouse, D.B. Rouse & Manomaitis, L. 2004. Partial and total replacement of fish meal with soybean meal and brewer's grains with yeast in practical diets for Australian red claw crayfish *Cherax quadricarinatus*. *Aquaculture*, 230(1–4): 359–376.
- Muzinic, L.A., Thompson, K.R., Metts, L.S., Dasgupta, S. & Webster, C.D. 2006. Use of turkey meal as partial and total replacement of fish meal in practical diets for sunshine bass (*Morone chrysops* x *Morone saxatilis*) grown in tanks. *Aquaculture Nutrition*, 12(1): 71–81.
- Mwachireya, S.A., Beames, R.M., Higgs, D.A. & Dosanjh, B.S. 1999. Digestibility of canola protein products derived from the physical, enzymatic and chemical processing of commercial canola meal in rainbow trout *Oncorhynchus mykiss* (Walbaum) held in fresh water. *Aquaculture Nutrition*, 5(2): 73–82.
- Naegel, L.C.A. & Rodriguez-Astudillo, S. 2004. Comparison of growth and survival of white shrimp postlarvae (*Litopenaeus vannamei*) fed dried *Artemia* biomass versus four commercial feeds and three crustacean meals. *Aquaculture International*, 12: 573–581.
- Naik, S.D., Sahu, N.P. & Jain, K.K. 2001. Use of squilla (*Orato squilla nepa*), squid (*Sepia pharonis*) and clam (*Katelysia opima*) meal alone or in combination as a substitute for fish meal in the postlarval diet of *Macrobrachium rosenbergii*. *Asian-Australasian Journal of Animal Sciences*, 14(9): 1272–1275.
- Nakagawa, H., Umino, T. & Tasaka, Y. 1997. Usefulness of *Ascophyllum* meal as a feed additive for red sea bream, *Pagrus major*. *Aquaculture*, 151(1–4): 275–281.

- Nakano, T., Tosa, M. & Takeuchi, M. 1995. Improvement of biochemical features in fish health by red yeast and synthetic astaxanthin. *J. Agric. Food Chem.*, 43(6): 1570–1573.
- Nakano, T., Miura, Y., Wazawa, M., Sato, M. & Takeuchi, M. 1999. Red yeast *Phaffia rhodozyma* reduces susceptibility of liver homogenate to lipid peroxidation in rainbow trout. *Fisheries Science*, 65(6): 961–962.
- Nandeeshha, M.C., Gangadhar, B., Varghese, T.J. & Keshavanath, P. 1998. Effect of feeding *Spirulina platensis* on the growth, proximate composition and organoleptic quality of common carp, *Cyprinus carpio* L. *Aquaculture Research*, 29(5): 305–312.
- Nandeeshha, M.C., Gangadhara B., Maniserry, J.K. & Venkataraman, L.V. 2001. Growth performance of two Indian major carps, catla (*Catla catla*) and rohu (*Labeo rohita*) fed diets containing different levels of *Spirulina platensis*. *Bioresource Technology*, 80(2): 117–120.
- Nandeeshha, M.C., Gangadhara, B. & Maniserry, J.K. 2002. Further studies on the use of mixed feeding schedules with plant- and animal-based diets for common carp *Cyprinus carpio* (Linnaeus). *Aquaculture Research*, 33(14): 1157–1162.
- Nang Thu, T.T., Parkouda, C., Saeger, S.D., Larondelle, Y. & Rollin, X. 2007. Comparison of the lysine utilization efficiency in different plant protein sources supplemented with l-lysine.HCl in rainbow trout (*Oncorhynchus mykiss*) fry. *Aquaculture*, 272(1–4): 477–488.
- Nanton, D.A., Vegusdal, A., Benze-Røraa, A.M., Ruyter, B., Baeverfjord, G., Torstensen, B.E. 2007. Muscle lipid storage pattern, composition, and adipocyte distribution in different parts of Atlantic salmon (*Salmo salar*) fed fish oil and vegetable oil. *Aquaculture*, 265: 230–243.
- Nargis, A., Ahmed, K.N., Ahmed, G.M., Hossain, M.A. & Rahman, M. 2006. Nutritional value and use of shrimp head waste as fish meal. *Bangladesh J. Sci. Ind. Res.*, 41(1–2): 63–66.
- Nates, S.F. & Bureau, D.P. 2007. Opportunities for rendered animal proteins in aquaculture feeds. *Global Aquaculture Advocate*, 10(6): 66–68.
- Nava Guerrero, R., Vásquez-Peláez, C. & Viana, M.T. 2004. Replacing kelp meal (*Macrocystis pyrifera*) with a winery by-product in a balanced diet for green abalone (*Haliotis fulgens*). *Ciencias Marinas*, 30(1B): 227–234.
- Navarro, N. & Sarasquete, C. 1998. Use of freeze-dried microalgae for rearing gilthead seabream, *Sparus aurata*, larvae – I. Growth, histology and water quality. *Aquaculture*, 167(3–4): 179–193.
- Navas, J. M., Mananos, E., Thrush, M., Ramos, J., Zanuy, S., Carrillo, M., Zohar, Y. & Bromage, N. 1998. Effect of dietary lipid composition on vitellogenin, 17 beta-estradiol and gonadotropin plasma levels and spawning performance in captive sea bass (*Dicentrarchus labrax* L.). *Aquaculture*, 165(1–2): 65–79.
- Nayak, S.K., Swain, P. & Mukherjee, S.C. 2007. Effect of dietary supplementation of probiotic and vitamin C on the immune response of Indian major carp, *Labeo rohita* (Ham.). *Fish & Shellfish Immunology*, 23(4): 892–896.
- Nematipour, G.R. & Gatlin, D.M. 1993. Effects of different kinds of dietary lipid on growth and fatty acid composition of juvenile sunshine bass, *Morone chrysops* female x *M. saxatilis* male. *Aquaculture*, 114: 141–154.
- Nengas, I., Alexis, M.N. & Davies, S.J. 1996. Partial substitution of fishmeal with soybean meal products and derivatives in diets for the gilthead sea bream *Sparus aurata* (L.). *Aquaculture Research*, 27(3): 147–156.
- Nengas, I., Alexis, M.N. & Davies, S.J. 1999. High inclusion levels of poultry meals and related byproducts in diets for gilthead seabream *Sparus aurata* L. *Aquaculture*, 179(1–4): 13–23.
- Nesse, L.L., Nordby, K., Heir, E., Bergsjoe, B., Vardund, T., Nygaard, H. & Holstad, G. 2003. Molecular analyses of *Salmonella enteric* isolates from fish feed factories and fish feed ingredients. *Appl. Environ. Microbiol.* 69, 1075–1081.
- New, M.B., Tacon, A.G.J. & Csavas, I. (eds). 1995. *Farm-made aquafeeds*. FAO Fisheries Technical Paper No. 343. Rome. 434 pp.
- Ng, W.K. 2007. Replacing marine fish oil in aquafeeds with tropical palm oil products. *Aquaculture Asia Magazine*, 12:38–41.
- Ng, W.K. & Chen, M.L. 2002a. Replacement of soybean meal with palm kernel meal in practical diets for hybrid Asian-African catfish, *Clarias macrocephalus* x *C. gariepinus*. *Journal of Applied Aquaculture*, 12(4): 67–76.
- Ng, W.K. & Chong, K.K. 2002b. The nutritive value of palm kernel meal and the effect of enzyme supplementation in practical diets for red hybrid tilapia (*Oreochromis* sp.). *Asian Fisheries Science*, 15(2): 167–176.
- Ng, W.K., Lim, P.K. & Sidek, H. 2001. The influence of a dietary lipid source on growth, muscle fatty acid composition and erythrocyte osmotic fragility of hybrid tilapia. *Fish Physiology and Biochemistry*, 25: 301–310.
- Ng, W.K., Liew, F.L., Ang, L.P. & Wong, K.W. 2001. Potential of mealworm (*Tenebrio molitor*) as an alternative protein source in practical diets for African, *Clarias gariepinus*. *Aquaculture Research*, 32: 273–280.
- Ng, W. K., Lim, H.A., Lim, S.L. & Ibrahim, C.O. 2002. Nutritive value of palm kernel meal pretreated with enzyme or fermented with *Trichoderma koningii* (Oudemans) as a dietary ingredient for red hybrid tilapia (*Oreochromis* sp.). *Aquaculture Research*, 33(15): 1199–1207.
- Ng, W.K., Lim, P.K. & Boey, P.L. 2003. Dietary lipid and palm oil source affects growth, fatty acid composition and muscle a-tocopherol concentration of African catfish, *Clarias gariepinus*. *Aquaculture*, 215: 229–243.
- Ng, W.K., Campbell, P.J., Dick, J.R. & Bell, J.G. 2003b. Interactive effects of dietary palm oil concentration and water temperature on lipid digestibility in rainbow trout, *Oncorhynchus mykiss*. *Lipids*, 38(10): 1031–1038.

- Ng, W.K., Sigholt, T. & Bell, J.G. 2004a. The influence of environmental temperature on the apparent nutrient and fatty acid digestibility in Atlantic salmon (*Salmo salar* L.) fed finishing diets containing different blends of fish oil, rapeseed oil and palm oil. *Aquaculture Research*, 35: 1228–1237.
- Ng, W.K., Wang, Y., Ketchimenin, P. & Yuen, K.H. 2004b. Replacement of dietary fish oil with palm fatty acid distillate elevates tocopherol and tocotrienol concentrations and increases oxidative stability in the muscle of African catfish, *Clarias gariepinus*. *Aquaculture*, 233: 423–437.
- Ng, W.K., Koh, C.B. & Zubir, B.D. 2006. Palm oil-laden spent bleaching clay as a substitute for marine fish oil in the diets of Nile tilapia, *Oreochromis niloticus*. *Aquaculture Nutrition*, 12: 459–468.
- Ng, W.K., Tee, M.C. & Boey, P.L. 2000. Evaluation of crude palm oil and refined palm olein as dietary lipids in pelleted feeds for a tropical bagrid catfish *Mystus nemurus* (Cuvier & Valenciennes). *Aquaculture Research*, 31(4): 337–347.
- Ng, W.K., Tocher, D.R. & Bell, J.G. 2007. The use of palm oil in aquaculture feeds for salmonid species. *European Journal of Lipid Science and Technology*, 109: 394–399.
- Nguyen, T.N., Davis, D.A. & Saoud, I.P. 2009. Evaluation of alternative protein sources to replace fish meal in practical diets for juvenile Tilapia, *Oreochromis* spp. *Journal of the World Aquaculture Society*, 40(1): 113.
- Nguyen, T.N.A., Tran, T.T.H., Mathieu, W., Nguyen, V.H. & Sorgeloos, P. 2009. Effect of fishmeal replacement with Artemia biomass as a protein source in practical diets for the giant freshwater prawn *Macrobrachium rosenbergii*. *Aquaculture Research*, 40(6): 669–680.
- Nickell, D.C. & Bromage, N.R. 1998. The effect of timing and duration of feeding astaxanthin on the development and variation of fillet colour and efficiency of pigmentation in rainbow trout (*Oncorhynchus mykiss*). *Aquaculture*, 169(3–4): 233–246.
- Nielsen, N.S., Gottsche, J.R., Holm, J., Xu, X., Mu, H. & Jacobsen, C. 2005. Effect of structured lipids based on fish oil on the growth and fatty acid composition in rainbow trout (*Oncorhynchus mykiss*). *Aquaculture*, 250(1–2): 411–423.
- Niu, J., Liu, Y.J., Tian, L.X., Mai, K.S., Yang H.J., Ye, C.X. & Zhu, Y. 2008. The effect of different levels of dietary phospholipid on growth, survival and nutrient composition of early juvenile cobia (*Rachycentron canadum*). *Aquaculture Nutrition*, 14(3): 249–256.
- Nordrum, S., Asgard, T., Shearer, K.D. & Arnesen, P. 1997. Availability of phosphorus in fish bone meal and inorganic salts to Atlantic salmon (*Salmo salar*) as determined by retention. *Aquaculture*, 157(1–2): 51–61.
- Nordrum, S., Bakke-McKellep, A.M., Krogdahl, A. & Buddington, R.K. 2000. Effects of soybean meal and salinity on intestinal transport of nutrients in Atlantic salmon (*Salmo salar* L.) and rainbow trout (*Oncorhynchus mykiss*). *Comparative Biochemistry and Physiology B – Biochemistry and Molecular Biology*, 125(3): 317–335.
- NRC (National Research Council). 1982. *United States-Canadian tables of feed composition*. Committee on Animal Nutrition, Washington, D.C., National Academy Press. 148 pp.
- NRC (National Research Council). 1983. *Nutrient requirements of warmwater fishes and shellfishes*. Washington, D.C., National Academy Press. 102 pp.
- NRC (National Research Council). 1993. *Nutrient requirements of fish*. Washington, D.C., National Academy Press. 114 pp.
- Nunes, A.J.P., Sa, M.V.C., Andriola-Neto, F.F. & Lemos, D. 2006. Behavioral response to selected feed attractants and stimulants in Pacific white shrimp, *Litopenaeus vannamei*. *Aquaculture*, 260(1–4): 244–254.
- Nur, A. 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in Indonesia, pp. 245–267. In: M.R. Hasan, T. Hecht, S.S. De Silva and A.G.J. Tacon (eds), Study and analysis of feeds and fertilizers for sustainable aquaculture development. *FAO Fisheries Technical Paper*, No. 497. Rome. 510 pp.
- Nwadu, F.O., Marioghae, I.E. & Opara, J.Y. 1997. Early growth performance of *Clarias gariepinus* (B), *Heterobranchus longifilis* (val.) and their F sub(1) hybrid fry fed on *Moina* spp. mixed plankton, and shrimp meal/cow pea diets. *Journal of Aquaculture in the Tropics*, 12 (3): 219–226.
- Nwanna, L.C. 2003. Nutritional value and digestibility of fermented shrimp head waste meal by African catfish *Clarias gariepinus*. *Pakistan Journal of Nutrition*, 2(6): 339–345.
- Nwanna, L.C., Balogun, A.M., Ajenifuja, Y.F. & Enujiugha, V.N. 2004. Replacement of fish meal with chemically preserved shrimp head in the diets of African catfish, *Clarias gariepinus*. *Journal of Food Agriculture and Environment*, 2(1): 79–83.
- Nyirenda, J., Mwabumba, M., Kaunda, E. & Sales, J. 2000. Effect of substituting animal protein sources with soybean meal in diets of *Oreochromis karongae* (Trewavas 1941). *NAGA*, 23(4):13–15.
- Obradovic, S., Vukasinovic, M. & Levic, J. 2007. Effect of dietary phytase supplementation on Rainbow trout *Oncorhynchus mykiss* (Walbaum) productivity and nutritional properties of feed. *Romanian Biotechnological Letters*, 12(4): 3361–3370.
- Ochoa-Solano, J.L. & Olmos-Soto, J. 2006. The functional property of Bacillus for shrimp feeds. *Food Microbiology*, 23(6): 519–525.
- Ofojekwu, P.C., Onuoha, P.C. & Ayuba, V.O. 2003. Substitution of cottonseed cake with palm kernel meal in diets for Nile tilapia, *Oreochromis niloticus* (L.). *Journal of Aquatic Sciences*, 18(1): 59–64.
- Ogino, C. 1980. Requirements of carp and rainbow trout for essential amino acids. *Bulletin of the Japanese Society for Scientific Fisheries*, 46: 171–174.
- Ogunji, J.O. & Wirth, M. 2000. Effect of dietary protein content on growth, food conversion and body composition of tilapia *Oreochromis niloticus* fingerlings fed fish meal diet. *Journal of Aquaculture in the Tropics*, 15(4): 381–389.

- Ogunji, J.O., Nimptsch, J., Wiegand, C. & Schulz, C. 2007. Evaluation of the influence of housefly maggot meal (magmaeal) diets on catalase, glutathione S-transferase and glycogen concentration in the liver of *Oreochromis niloticus* fingerling. *Comparative Biochemistry and Physiology, Part A: Molecular and Integrative Physiology*, 147(4): 942–947.
- Ogunji, J., Toor, S., Schulz, C. & Kloas, W. 2008a. Growth performance, nutrient utilization of Nile tilapia *Oreochromis niloticus* fed housefly maggot meal (Magmaeal) diets. *Turkish Journal of Fisheries and Aquatic Sciences*, 8(1): 141–147.
- Ogunji, J., Kloas, W., Wirth, M., Neumann, N. & Pietsch, C. 2008b. Effect of housefly maggot meal (magmaeal) diets on the performance, concentration of plasma glucose, cortisol and blood characteristics of *Oreochromis niloticus* fingerlings. *Journal of Animal Physiology and Animal Nutrition*, 92(4): 511–518.
- Ogunji, J., Kloas, W., Wirth, M., Schultz, C. & Rennert, B. 2008c. Housefly maggot meal (magmaeal) as a protein source for *Oreochromis niloticus* (Linn.). *Asian Fisheries Science*, 21(3): 319–331.
- Ogunkoya, A.E., Page, G. I., Adewolu, M.A. & Bureau, D.P. 2006. Dietary incorporation of soybean meal and exogenous enzyme cocktail can affect physical characteristics of faecal material egested by rainbow trout (*Oncorhynchus mykiss*). *Aquaculture*, 254(1–4): 466–475.
- Oliva-Teles A. & Goncalves, P. 2001. Partial replacement of fishmeal by brewers yeast (*Saccharomyces cerevisiae*) in diets for sea bass (*Dicentrarchus labrax*) juveniles. *Aquaculture*, 202(3): 269–278.
- Oliva-Teles, A., Guedes, M.J., Vachot, C. & Kaushik, S.J. 2006. The effect of nucleic acids on growth, ureagenesis and nitrogen excretion of gilthead sea bream *Sparus aurata* juveniles. *Aquaculture*, 253(1–4): 608–617.
- Olli, J.J. & Krogdahl, A. 1995. Alcohol soluble components of soybeans seem to reduce fat digestibility in fish-meal-based diets for Atlantic salmon, *Salmo salar* L. *Aquaculture Research*, 26(11): 831–835.
- Olli, J.J., Krogdahl, A. & Vaabenoe, A. 1995. Dehulled solvent-extracted soybean meal as a protein source in diets for Atlantic salmon, *Salmo salar* L. *Aquaculture Research*, 26(3): 167–174.
- Ölmez, M. & Tiryakioglu, F.O. 2006. The effects of virginiamycin added feeding on the growth performance and feed utilization of the tilapia (*O. niloticus* L.). fry. *Journal of Animal and Veterinary Advances*, 5(1): 10–15.
- Olsen, R.E., Myklebust, R., Kaino, T. & Ringo, E. 1999. Lipid digestibility and ultrastructural changes in the enterocytes of Arctic char (*Salvelinus alpinus* L.) fed linseed oil and soybean lecithin. *Fish Physiology and Biochemistry*, 21(1): 35–44.
- Olsen, R.E., Myklebust, R., Ringo, E. & Mayhew, T.M. 2000. The influences of dietary linseed oil and saturated fatty acids on caecal enterocytes in Arctic char (*Salvelinus alpinus* L.): a quantitative ultrastructural study. *Fish Physiology and Biochemistry*, 22(3): 207–216.
- Olsen, R.E., Dragnes, B.T., Myklebust, R. & Ringo, E. 2003. Effect of soybean oil and soybean lecithin on intestinal lipid composition and lipid droplet accumulation of rainbow trout, *Oncorhynchus mykiss* Walbaum. *Fish Physiology and Biochemistry*, 29(3): 181–192.
- Olsen, R.E., Henderson, R.J., Sountama, J., Hemre, G-I., Ringo, E., Melle, W. & Tocher, D.R. 2004. Atlantic salmon, *Salmo salar*, utilizes wax ester-rich oil from *Calanus finmarchicus* effectively. *Aquaculture*, 240: 433–449.
- Olsen, R.E., Kiessling, A., Milley, J.E., Ross, N.W. & Lall, S.P. 2005. Effect of lipid source and bile salts in diet of Atlantic salmon, *Salmo salar* L., on astaxanthin blood levels. *Aquaculture*, 250(3–4): 804–812.
- Olsen, R.E., Suontama, J., Langmyhr, E., Mundheim, H., Ringo, E., Melle, W., Malde, M.K. & Hemre, G.I. 2006. The replacement of fish meal with Antarctic krill, *Euphausia superba* in diets for Atlantic salmon, *Salmo salar*. *Aquaculture Nutrition*, 12(4): 280–290.
- Olsvik, P.A., Torstensen, B.E. & Berntssen, M.H.G. 2007. Effects of complete replacement of fish oil with plant oil on gastrointestinal cell death, proliferation and transcription of eight genes' encoding proteins responding to cellular stress in Atlantic salmon *Salmo salar* L. *Journal of Fish Biology*, 71(2): 550–568.
- Olude, O.O., Alegbeleye, W.O.A. & Obasa, S.O. 2008. The use of soaked copra meal as a partial substitute for soybean meal in the diet of Nile tilapia (*Oreochromis niloticus*) fingerlings. *Livestock Research for Rural Development*, 20, Article #169 (available at www.lrrd.org/lrrd20/10/olud20169.htm).
- Olurin, K.B., Akinyemi, Y., Obe, O.Y. & Olojo, E.A.A. 2004. Use of palm oil in the diet of the African mudfish, *Clarias gariepinus*. *African Journal of Biotechnology*, 3(8): 418–420.
- Olvera-Novoa, M.A., Martínez-Palacios, C.A. & de Leon, E.R. 1994. *Nutrition of fish and crustaceans: a laboratory manual*. FAO Field Document, Project GCP/RLA/102/ITA, Field Document No. 19, Mexico City, Mexico. 104 pp.
- Olvera-Novoa, M.A., Pereira-Pacheco, F., Olivera-Castillo, L., Perez-Flores, V., Navarro, L. & Samano, J.C. 1997. Cowpea (*Vigna unguiculata*) protein concentrate as replacement for fish meal in diets for tilapia (*Oreochromis niloticus*) fry. *Aquaculture*, 158(1–2): 107–116.
- Olvera-Novoa, M.A., Domínguez-Cen, L.J., Olivera-Castillo, L., Martínez-Palacios, C.A. 1998. Effect of the use of the microalga *Spirulina maxima* as fish meal replacement in diets for tilapia, *Oreochromis mossambicus* (Peters), fry. *Aquaculture Research*, 29(10): 709–715.
- Olvera-Novoa, M.A., Olivera-Castillo, L. & Martínez-Palacios, C.A. 2002. Sunflower seed meal as a protein source in diets for *Tilapia rendalli* (Boulanger, 1896) fingerlings. *Aquaculture Research*, 33(3): 223–229.
- Olvera-Novoa, M., Martínez-Palacios, C. & Olivera-Castillo, L. 2002b. Utilization of torula yeast (*Candida utilis*) as a protein source in diets for tilapia (*Oreochromis mossambicus* Peters) fry. *Aquaculture Nutrition*, 8(4): 257–264.

- Omorieg, E. 2001. Utilization and nutrient digestibility of mango seeds and palm kernel meal by juvenile *Labeo senegalensis* (Antheriniformes : Cyprinidae). *Aquaculture Research*, 32(9): 681–687.
- O'Neal, C.C. & Kohler, C.C. 2008. Effect of replacing menhaden oil with catfish oil on the fatty acid composition of juvenile channel catfish, *Ictalurus punctatus*. *Journal of the World Aquaculture Society*, 39(1): 62–71.
- Opsahl-Ferstad, H.-G., Rudi, H., Ruyter, B. & Refstie, S. 2003. Biotechnological approaches to modify rapeseed oil composition for applications in aquaculture. *Plant Science*, 165: 349–357.
- Opstvedt, J., Mundheim, H., Nygard, E., Asse, H. & Pike, I.H. 2000. Reduced growth and feed consumption of Atlantic salmon (*Salmo salar* L.) fed fish meal made from stale fish is not due to increased content of biogenic amines. *Aquaculture*, 188(3–4): 323–337.
- Opstvedt, J., Nygard, E., Samuelsen, T.A., Venturini, G., Luzzana, U. & Mundheim, H. 2003a. Effect on protein digestibility of different processing conditions in the production of fish meal and fish feed. *Journal of the Science of Food and Agriculture*, 83(8): 775–782.
- Opstvedt, J., Aksnes, A., Hope, B. & Pike, I.H. 2003b. Efficiency of feed utilization in Atlantic salmon (*Salmo salar* L.) fed diets with increasing substitution of fish meal with vegetable proteins. *Aquaculture*, 221(1–4): 365–379.
- Oresegun, A., Aleggeye, W.O. & Oguntade, O.R. 2004. Growth response of Tilapia (*Oreochromis niloticus*) fed varying levels of cassava peel-based ration supplemented with DL-methionine. *Journal of Sustainable Tropical Agricultural Research*, 10: 26–30.
- Osako, K., Hossain, M.A., Ruttanapornvaessakul, Y., Fujii, A., Kuwahara, K., Okamoto, A. & Nagano, N. 2006. The aptitude of the green alga *Ulva pertusa* as a diet for purple sea urchin *Anthocidaris crassispina*. *Suisan Zoshoku (Aquaculture Science)*, 54(1): 15–23.
- Osman, M.F., Omar, A.E. & Nour, A.M. 1996. The use of leucaena leaf meal in feeding Nile tilapia. *Aquaculture International*, 4(1): 9–18.
- Ostaszewska, T., Dabrowski, K., Palacios, M.E., Olejniczak, M. & Wieczorek, M. 2005. Growth and morphological changes in the digestive tract of rainbow trout (*Oncorhynchus mykiss*) and pacu (*Piaractus mesopotamicus*) due to casein replacement with soybean proteins. *Aquaculture*, 245(1–4): 273–286.
- Ostrowski-Meissner, H., LeaMaster, B., Duerr, E. & Walsh, W. 1995. Sensitivity of the Pacific white shrimp, *Penaeus vannamei*, to aflatoxin B1. *Aquaculture*, 131: 155–164.
- Osuigwe, D.I., Obiekezie A.I. & Onuoha, G.C. 2005. Some haematological changes in hybrid catfish (*Heterobranchus longifilis* x *Clarias gariepinus*) fed different dietary levels of raw and boiled jackbean (*Canavalia ensiformis*) seed meal. *African Journal of Biotechnology*, 4(9): 1017–1021.
- Osuigwe, D.I., Obiekezie A.I. & Onuoha, G.C. 2006. Effects of jackbean seed meal on the intestinal mucosa of juvenile *Heterobranchus longifilis*. *African Journal of Biotechnology*, 5(13): 1294–1298.
- Otleş, S. & Pire, R. 2001. Fatty acid composition of *Chlorella* and *Spirulina* microalgae species. *Journal of the American Organization of Analytical Chemists*, 84(6): 1708–1714.
- Ouraji, H., Shabanpour, B., Kenari, A.A., Shabanio, A., Nezami, S., Sudagar, M. & Faghani, S. 2009. Total lipid, fatty acid composition and lipid oxidation of Indian white shrimp (*Fenneropenaeus indicus*) fed diets containing different lipid sources. *Journal of the Science of Food and Agriculture*, 89(6): 993–997.
- Øverland, M., Romarheim, O.H., Hovin, M., Storebakken, T. & Skrede, A. 2006. Apparent total tract digestibility of unprocessed and extruded diets containing basic and autolyzed bacterial protein meal grown on natural gas in mink and rainbow trout. *Animal Feed Science and Technology*, 129(3–4): 237–251.
- Øverland, M., Romarheim, O.H., Ahlstrom, O., Storebakken, T. & Skrede, A. 2007. Technical quality of dog food and salmon feed containing different bacterial protein sources and processed by different extrusion conditions. *Animal Feed Science and Technology*, 134(1–2): 124–139.
- Overland, M., Sorensen, M., Storebakken, T., Penn, M., Krogdahl, A. & Skrede, A. 2009. Pea protein concentrate substituting fish meal or soybean meal in diets for Atlantic salmon (*Salmo salar*) – Effect on growth performance, nutrient digestibility, carcass composition, gut health, and physical feed quality. *Aquaculture*, 288(3–4): 305–311.
- Overturf, K., Raboy, V., Cheng, Z. & Hardy, R. 2003. Mineral availability from barley low phytic acid grains in rainbow trout (*Oncorhynchus mykiss*) diets. *Aquaculture Nutrition*, 9(4): 239–246.
- Oxley, A., Tocher, D.R., Torstensen, B.E. & Olsen, R.E. 2005. Fatty acid utilisation and metabolism in caecal enterocytes of rainbow trout (*Oncorhynchus mykiss*) fed dietary fish or copepod oil. *Biochimica et Biophysica Acta*, 1737: 119–129.
- Ozorio, R.O.A., Cyrino, J.E.P., Turini, B.G.S., Moro, G.V., de Oliveira, L.S.T. & Nascimento, A. 2005. Feeding dried yeast to Pacu (*Piaractus mesopotamicus*) as dietary fish meal replacement. *World Aquaculture*, 36(2): 29–35.
- Padilla-Perez, P., Pereira-Filho, M., Mori-Pinedo, L.A. & de Oliveira-Pereira, M.I. 2001. Influence of biological fish silage and cooked fish by-product on growth and body composition of tambaqui (*Colossoma macropomum*) fingerlings. *Acta Amazonica*, 31(3): 501–507.
- Padula, D.J., Daughtry, B.J. & Nowak, B.F. 2008. Dioxins, PCBs, metals, metallaloides, pesticides and antimicrobial residues in wild and farmed Australian southern bluefin tuna (*Thunnus maccoyii*). *Chemosphere*, 72: 34–44.
- Page, G.I., Russell, P.M. & Davies, S.J. 2005. Dietary carotenoid pigment supplementation influences hepatic lipid and mucopolysaccharide levels in rainbow trout (*Oncorhynchus mykiss*). *Comparative Biochemistry and Physiology B – Biochemistry and Molecular Biology*, 142(4): 398–402.

- Paibulkichakul, C., Piyatiratitivorakul, S., Kittakoop, P., Viyakarn, V., Fast, A.W. & Menasveta, P. 1998. Optimal dietary levels of lecithin and cholesterol for black tiger prawn *Penaeus monodon* larvae and postlarvae. *Aquaculture*, 167(3–4): 273–281.
- Palma, J., Bureau, D.P. & Andrade, J.P. 2008. Effects of binder type and binder addition on the growth of juvenile *Palaemonetes varians* and *Palaemon elegans* (Crustacea : Palaemonidae). *Aquaculture International*, 16(5): 427–436.
- Palmelegiano, G.B., Agradi, E., Forneris, G., Gai, F., Gasco, L., Rigamonti, E., Sicuro, B. & Zoccarato, I. 2005. Spirulina as a nutrient source in diets for growing sturgeon (*Acipenser baeri*). *Aquaculture Research*, 36(2): 188–195.
- Palmelegiano, G.B., Dapra, F., Forneris, G., Gai, F., Gasco, L., Guo, K., Peiretti, P.G., Sicuro, B. & Zoccarato, I. 2006. Rice protein concentrate meal as a potential ingredient in practical diets for rainbow trout (*Oncorhynchus mykiss*). *Aquaculture*, 258(1–4): 357–367.
- Palmelegiano, G.B., Costanzo, M.T., Dapra, F., Gai, F., Galletta, M.G., Maricchiolo, G., Micale, V., Peiretti, P.G. & Genovese, L. 2007. Rice protein concentrate meal as potential dietary ingredient in practical diets for blackspot seabream (*Pagellus bogaraveo*). *Journal of Animal Physiology and Animal Nutrition*, 91(5–6): 235–239.
- Palmelegiano, G.B., Gai, F., Daprà, F., Gasco, L., Pazzaglia, M. & Peiretti, P.G. 2008. Effects of Spirulina and plant oil on the growth and lipid traits of white sturgeon (*Acipenser transmontanus*) fingerlings. *Aquaculture Research*, 39(6): 587–595.
- Palti, Y., Silverstein, J.T., Wieman, H., Phillips, J.G., Barrows, F.T. & Parsons, J.E. 2006. Evaluation of family growth response to fishmeal and gluten-based diets in rainbow trout (*Oncorhynchus mykiss*). *Aquaculture*, 255(1–4): 548–556.
- Pan, C-H. & Chien, Y-H. 2009. Effects of dietary supplementation of alga *Haematococcus pluvialis* (Flotow), synthetic astaxanthin and Beta carotene on survival, growth, and pigment distribution of red devil, *Cichlasoma citrinellum* (Gunther). *Aquaculture Research*, 40: 871–879.
- Pan, Y., Wang, F. & Liu, H. 2000. Optimal proportion of fish meal and soybean cake in formulated diets of juvenile sea perch *Lateolabrax japonicus*. *Journal of Dalian Fisheries College/Dalian Shuichan Xueyuan Xuebao*, 15(3): 157–163.
- Pandey A. & Satoh S. 2008. Effects of organic acids on growth and phosphorus utilization in rainbow trout *Oncorhynchus mykiss*. *Fisheries Science*, 74: 867–874.
- Panserat, S., Perrin, A. & Kaushik, S. 2002. High dietary lipids induce liver glucose-6-phosphatase expression in rainbow trout (*Oncorhynchus mykiss*). *Journal of Nutrition*, 132(2): 137–141.
- Panserat, S., Kolditz, C., Richard, N., Plagnes-Juan, E., Piumi, F., Esquerre, D., Medale, F., Corraze, G. & Kaushik, S. 2008. Hepatic gene expression profiles in juvenile rainbow trout (*Oncorhynchus mykiss*) fed fishmeal or fish oil-free diets. *British Journal of Nutrition*, 100(5): 953–967.
- Pantazis, P.A., Kelly, M.S., Connolly, J.G. & Black, K.D. 2000. Effect of artificial diets on growth, lipid utilization, and gonad biochemistry in the adult sea urchin *Psammechinus miliaris*. *Journal of Shellfish Research*, 19(2): 995–1001.
- Papanikos, N., Phelps, R.P., Davis, D.A., Ferry, A. & Maus, D. 2008. Spontaneous spawning of captive red snapper, *Lutjanus campechanus*, and dietary lipid effect on reproductive performance. *Journal of the World Aquaculture Society*, 39(3): 324–338.
- Papatryphon, S. 2001. The effect of phytase on apparent digestibility of four practical plant feedstuffs fed to striped bass, *Morone saxatilis*. *Aquaculture Nutrition*, 7(3): 161–167.
- Papoutsoglou, S.E., Karakatsouli, N. & Chiras, G.L. 2005. Dietary L-tryptophan and tank colour effects on growth performance of rainbow trout (*Oncorhynchus mykiss*) juveniles reared in a recirculating water system. *Aquacultural Engineering*, 32(2): 277–284.
- Paripatananont, T., Boonyaratpalin, M., Pengseng, P. & Chotipuntu, P. 2001. Substitution of soy protein concentrate for fishmeal in diets of tiger shrimp *Penaeus monodon*. *Aquaculture Research*, 32(1): 369–374.
- Park, G.S., Takeuchi, T., Seikai, T. & Yoshinaga, T. 2000. The effects of residual salts and free amino acids in mysid meal on growth of juvenile Japanese flounder *Paralichthys olivaceus*. *Nippon Suisan Gakkaishi*, 66(4): 697–704.
- Park, H., Flores, R.A. & Johnson, L.A. 1997. Preparation of fish feed ingredients: reduction of carotenoids in corn gluten meal. *J. Agric. Food Chem.*, 45(6): 2088–2092.
- Park, H.G., Puvanendran, V., Kellett, A., Parrish, C.C. & Brown, J.A. 2006. Effect of enriched rotifers on growth, survival, and composition of larval Atlantic cod (*Gadus morhua*). *ICES Journal of Marine Science*, 63(2): 285–295.
- Parova, J. & Rehulka, J. 1997. The effect of dietary fat in market rainbow trout on growth dynamics, specific growth rate and trout health. *Zivocisna Vyroba*, 42(12): 547–551.
- Parpoura, A.C.R. & Alexis, M.N. 2001. Effects of different dietary oils in sea bass (*Dicentrarchus labrax*) nutrition. *Aquaculture International*, 9(6): 463–476.
- Parthiban, F., Christopher, I.M.M., Selvaraj, S., Surendraraj, A. & Venkataramani, V.K. 2006. Enhancement of ovulation in goldfish (*Carassius auratus*) by a supplementary feed incorporated with polychaete worm (*Marphysa gravelyi*). *Indian Journal of Fisheries*, 53(3): 307–312.
- Parra, J.E.G., Neto, J.R., Veiverberg, C.A., Lazzari, R., Bergamin, G.T., Pedron, F.D., Rossato, S. & Sutilli, F.J. 2008. Use of lipid sources on feeding jundia (*Rhamdia quelen*) and its relation with embryo and larval development. *Ciencia Rural*, 38(7): 2011–2017.

- Partridge, G.J. & Southgate, P.C. 1999. The effect of binder composition on ingestion and assimilation of microbound diets (MBD) by barramundi *Lates calcarifer* Bloch larvae. *Aquaculture Research*, 30(11–12): 879–886.
- Patnaik, D., Sahu, N.P. & Chaudhari, A. 2005. Effects of feeding raw soybean meal to fry of Indian major carp, *Catla catla*, on growth, survival, and protein digestibility. *Israeli Journal of Aquaculture – Bamidgeh*, 57(3): 164–174.
- Patnaik, S., Samocha, T.M., Davis, D.A., Bullis, R.A. & Browdy, C.L. 2006. The use of HUFA-rich algal meals in diets for *Litopenaeus vannamei*. *Aquaculture Nutrition*, 12(5): 395–401.
- Patra, B., Maity, J., Debnath, J. & Patra, S. 2002. Making aquatic weeds useful II: *Nymphoides cristatum* (Roxb.) O. Kuntze as feed for an Indian major carp *Labeo rohita* (Hamilton). *Aquaculture Nutrition*, 8(1): 33–42.
- Paul, B.N., Nandi, S., Sarkar, S. & Mukhopadhyay, P.K. 1997. Effects of feeding unconventional animal protein sources on the nitrogen metabolism in Rohu *Labeo rohita* (Hamilton). *Israeli Journal of Aquaculture – Bamidgeh*, 49(4): 183–192.
- Pavasovic, A., Anderson, A.J., Mather, P.B. & Richardson, N.A. 2007. Effect of a variety of animal, plant and single cell-based feed ingredients on diet digestibility and digestive enzyme activity in redclaw crayfish, *Cherax quadricarinatus* (Von Martens 1868). *Aquaculture*, 272(1–4): 564–572.
- Pearce, C.M., Daggett, T.L. & Robinson, S.M.C. 2002. Effect of binder type and concentration on prepared feed stability and gonad yield and quality of the green sea urchin, *Strongylocentrotus droebachiensis*. *Aquaculture*, 205(3–4): 301–323.
- Penafiorida, V. 1995. Growth and survival of juvenile tiger shrimp fed diet where fish meal is partially replaced with papaya (*Carica papaya* L.) or camote (*Ipomea batatas* Lam.) leaf meal. *Israeli Journal of Aquaculture – Bamidgeh* 47(1): 25–33.
- Penafiorida, V. & Golez, N.V. 1996. Use of seaweed meals from *Kappaphycus alvarezii* and *Gracilaria heteroclada* as binders in diets for juvenile shrimp *Penaeus monodon*. *Aquaculture*, 143(3–4): 393–401.
- Penafiorida, V. & Virtanen, E. 1996. Growth, survival and feed conversion of juvenile shrimp (*Penaeus monodon*) fed a betaine/amino acid additive. *Israeli Journal of Aquaculture – Bamidgeh*, 48(1): 3–9.
- Peng, S.M., Chen, L.Q., Qin, J.G., Hou, J.L., Yu, N., Long, Z.Q., Ye, J.Y. & Sun, X.J. 2008. Effects of replacement of dietary fish oil by soybean oil on growth performance and liver biochemical composition in juvenile black seabream, *Acanthopagrus schlegeli*. *Aquaculture*, 276(1–4): 154–161.
- Pepeljnjak, S., Petrinc, Z., Kovacic, S. & Segvic, M. 2002. Screening toxicity study in young carp (*Cyprinus carpio*) on feed amended with fumonisin B1. *Mycopathologia*, 156: 139–145.
- Pereira, J.O. & Gomes, E.F. 1995. Growth of rainbow trout fed a diet supplemented with earthworms, after chemical treatment. *Aquaculture International*, 3(1): 36–42.
- Pereira, T.G. & Oliva-Teles, A. 2002. Preliminary evaluation of pea seed meal in diets for gilthead sea bream (*Sparus aurata*) juveniles. *Aquaculture Research*, 33(14): 1183–1189.
- Pereira, T.G. & Oliva-Teles, A. 2003. Evaluation of corn gluten meal as a protein source in diets for gilthead sea bream (*Sparus aurata* L.) juveniles. *Aquaculture Research*, 34(13): 1111–1117.
- Pereira, T.G. & Oliva-Teles, A. 2004. Evaluation of micronized lupin seed meal as an alternative protein source in diets for gilthead sea bream *Sparus aurata* L. juveniles. *Aquaculture Research*, 35(9): 828–835.
- Peres, H. & Oliva-Teles, A. 2003. The effect of dietary ribonucleic acid incorporation in performance of European sea bass (*Dicentrarchus labrax*) juveniles. *Aquaculture*, 215(1–4): 245–253.
- Peres, H. & Oliva-Teles, A. 2005. The effect of dietary protein replacement by crystalline amino acid on growth and nitrogen utilization of turbot *Scophthalmus maximus* juveniles. *Aquaculture*, 250(3–4): 755–764.
- Peres, H., Lim, C. & Klesius, P.H. 2003. Nutritional value of heat-treated soybean meal for channel catfish (*Ictalurus punctatus*). *Aquaculture*, 225(1–4): 67–82.
- Perez-Velazquez, M., Lawrence A.L., Gatlin III D.M., Gonzalez-Félix M.L. & Bray, W.A. 2002. Replacement of fresh dietary components by a dry feed for successful maturation of male *Litopenaeus vannamei* (Boone) broodstock. *Aquaculture Research*, 33: 1091–1095.
- Perez-Velazquez, M., Gonzalez-Felix, M.L., Navarro-Garcia, G. & Valenzuela-Escalante, E. 2008. Nutritional value of various ray fish liver oils to the Pacific white shrimp *Litopenaeus vannamei*. *Lipids*, 43(11): 1009–1016.
- Peterson, B.C., Small, B.C. & Bosworth, B.G. 2004. Effects of bovine growth hormone (Posilac®) on growth performance, body composition, and IGFbPs in two strains of channel catfish. *Aquaculture*, 232: 651–663.
- Petri, D., Glover, C.N., Ylving, S., Kolas, K., Fremmersvik, G., Waagbo, R. & Berntssen, M.H.G. 2006. Sensitivity of Atlantic salmon (*Salmo salar*) to dietary endosulfan as assessed by haematology, blood biochemistry, and growth parameters. *Aquatic Toxicology*, 80(3): 207–216.
- Petri, D., Hamre, K. & Lundebye, A.K. 2008. Retention of the synthetic antioxidant butylated hydroxyanisole in Atlantic salmon (*Salmo salar*) filets. *Aquaculture Nutrition*, 14(5): 453–458.
- Petrinc, Z., Pepeljnjak, S., Kovacic, S. & Krznic, A. 2004. Fumonisin B1 causes multiple lesions in common carp (*Cyprinus carpio*). *Deutsche Tierärztliche Wochenschrift*, 111(9): 358–363.
- Pfeffer, E., Kinzinger, S. & Rodehutsord, M. 1995. Influence of the proportion of poultry slaughter by-products and of untreated or hydrothermally treated legume seeds in diets for rainbow trout, *Oncorhynchus mykiss* (Walbaum), on apparent digestibilities of their energy and organic compounds. *Aquaculture Nutrition*, 1(2): 111–117.

- Pham, M.A., Lee, K.-J., Lim, S.-J. Lim & Park, K.-H. 2007. Evaluation of cottonseed and soybean meal as partial replacement for fishmeal in diets for juvenile Japanese flounder *Paralichthys olivaceus*. *Fisheries Science*, 73(4):760–769.
- Pickova, J. & Mørkøre, T. 2007. Alternative oils in fish feeds. *Eur. J. Lipid Sci. Technol.*, 109: 256–263.
- Piedecausa, M.A., Mazon, M.J., Garcia Garcia, B. & Hernandez, M.D. 2007. Effects of total replacement of fish oil by vegetable oils in the diets of sharpnose seabream (*Diplodus puntazzo*). *Aquaculture*, 263: 211–219.
- Pillay, T.V.R. & Kutty, M.N. 2005. *Aquaculture: Principles and Practices*. 2nd Edition, Wiley-Blackwell Publishers, 624 pp.
- Pine, H.J., Daniels, W.H., Davis, D.A., Jiang, M.K. & Webster, C.D. 2008. Replacement of fish meal with poultry by-product meal as a protein source in pond-raised sunshine bass, *Morone chrysops* female X *M. saxatilis* male, diets. *Journal of the World Aquaculture Society*, 39(5): 586–597.
- Pipalova, I. 2003. Grass carp (*Ctenopharyngodon idella*) grazing on duckweed (*Spirodela polyrrhiza*). *Aquaculture International*, 11(4): 325–336.
- Plank, L.R., Lawrence, J.M., Lawrence, A.L. & Olvera, R.M. 2002. The effect of dietary carotenoids on gonad production and carotenoid profiles in the sea urchin *Lytechinus variegatus*. *Journal of the World Aquaculture Society*, 33(2): 127–137.
- Plascencia-Jatomea, M., Olvera-Novoa, M.A., Arredondo-Figueroa, J.L., Hall, G.M. & Shirai, K. 2002. Feasibility of fishmeal replacement by shrimp head silage protein hydrolysate in Nile tilapia (*Oreochromis niloticus* L.) diets. *Journal of the Science of Food and Agriculture*. 82(7): 753–759.
- Podoskina, T.A., Podoskin, A.G. & Bekina, E.N. 1997. Efficiency of utilization of some potato starch modifications by rainbow trout (*Oncorhynchus mykiss*). *Aquaculture*, 152(1–4): 235–248.
- Pongmaneerat, J., Kasornchandra, J., Boonyaratpalin, S. & Boonyaratpalin, M. 2001. Effect of dietary shrimp head meal contaminated with white spot syndrome virus (WSSV) on detection of WSSV in black tiger shrimp (*Penaeus monodon* Fabricius). *Aquaculture Research*, 32(1): 383–387.
- Pouomogne, V. 1995. Nile tilapia feeding in earthen ponds: evaluation of the nutritional value of some agro-industrial by-products and feeding practices. *Naga*, ICLARM, 18(1): 33–34.
- Pouomogne, V. 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in Cameroon, pp. 381–399. In: M.R. Hasan, T. Hecht, S.S. De Silva and A.G.J Tacon (eds), Study and analysis of feeds and fertilizers for sustainable aquaculture development. *FAO Fisheries Technical Paper*, No. 497. Rome. 510 pp.
- Pouomogne, V., Takam, G. & Pouemegne, J.B. 1997. A preliminary evaluation of cacao husks in practical diets for juvenile Nile tilapia (*Oreochromis niloticus*). *Aquaculture*, 156(3–4): 211–219.
- Pratoomyot, J., Bendiksen, E.A., Bell, J.G. & Tocher, D.R. 2008. Comparison of effects of vegetable oils blended with southern hemisphere fish oil and decontaminated northern hemisphere fish oil on growth performance, composition and gene expression in Atlantic salmon (*Salmo salar* L.). *Aquaculture*, 280: 170–178.
- Quartararo, N., Alan, G.L. & Bell, J.D. 1998. Replacement of fish meal in diets for Australian snapper, *Pagrus auratus*. *Aquaculture*, 166 (3–4): 279–295.
- Rab, A., Khan, S.U., Afzal, M., Ali, M.R. & Qayyum, M. 2008. Replacement of fishmeal with soybean meal in diets for channel catfish, *Ictalurus punctatus* fry introduced in Pakistan. *Pakistan Journal of Zoology*, 40(5): 341–346.
- Rahman, M.A., Zaher, M., Mazid, M.A., Haque, M.Z. & Mahata, S.C. 1996. Replacement of costly fish meal by silkworm pupae in diet of mirror carp (*Cyprinus carpio* L.). *Pakistan Journal of Scientific and Industrial Research*, 39(1–4): 64–67.
- Rahnema, S. & Borton, R. 2007. Determination of the effects of fish vs plant and feather meal-based diets on the growth and health of rainbow trout. *Journal of Applied Animal Research*, 32(2): 113–117.
- Ramachandran, S. & Ray, A.K. 2007. Nutritional evaluation of fermented black gram (*Phaseolus mungo*) seed meal in compound diets for rohu, *Labeo rohita* (Hamilton), fingerlings. *Journal of Applied Ichthyology*, 23(1): 74–79.
- Ramachandran, S., Bairagi, A. & Ray, A.K. 2005. Improvement of nutritive value of grass pea (*Lathyrus sativus*) seed meal in the formulated diets for rohu, *Labeo rohita* (Hamilton) fingerlings after fermentation with a fish gut bacterium. *Bioresource Technology*, 96(13): 1465–1472.
- Ramsay, J.M., Castell, J.D., Anderson, D.M & Hebb, C.D. 2000. Effects of fecal collection methods on estimation of digestibility of protein feedstuffs by Winter Flounder. *North American Journal of Aquaculture*, 62(3): 168–173.
- Ramseyer, L., Garling, D., Hill, G. & Link, J. 1999. Effect of dietary zinc supplementation and phytase pre-treatment of soybean meal or corn gluten meal on growth, zinc status and zinc-related metabolism in rainbow trout, *Oncorhynchus mykiss*. *Fish Physiology and Biochemistry*, 20(3): 251–261.
- Rao, D., Rao, K.V., Reddy, T.P. & Reddy, V.D. 2009. Molecular characterization, physicochemical properties, known and potential applications of phytases: An overview. *Critical Reviews in Biotechnology*, 29(2): 182–198.
- Raso, S. & Anderson, T.A. 2003. Effects of dietary fish oil replacement on growth and carcass proximate composition of juvenile barramundi (*Lates calcarifer*). *Aquaculture Research*, 34: 813–819.
- Rathbone, C.K., Babbitt, J.K., Dong, F.M. & Hardy, R.W. 2001. Performance of juvenile coho salmon *Oncorhynchus kisutch* fed diets containing meals from fish wastes, deboned fish wastes, or skin-and-bone by-product as the protein ingredient. *Journal of the World Aquaculture Society*, 32(1): 21–29.

- Rawles, S.D., Gaylord, T.G. & Gatlin, D.M. 2006. Digestibility of gross nutrients by sunshine bass in animal by products and commercially blended products used as fish meal replacements. *North American Journal of Aquaculture*, 68(1): 74–80.
- Rawles, S.D., Riche, M., Gaylord, T.G., Webb, J., Freeman, D.W. & Davis, M. 2006. Evaluation of poultry by-product meal in commercial diets for hybrid striped bass (*Morone chrysops* female x *M. saxatilis* male) in recirculated tank production. *Aquaculture*, 259(1–4):377–389.
- Rawles, S.D., Gaylord, T.G., McEntire, M.E. & Freeman, D.W. 2009. Evaluation of poultry by-product meal in commercial diets for hybrid striped bass, *Morone chrysops* x *Morone saxatilis*, in pond production. *Journal of the World Aquaculture Society*, 40(2): 141–156.
- Ray, A.K. 2007. Nutritional evaluation of fermented black gram (*Phaseolus mungo*) seed meal in compound diets for rohu, *Labeo rohita* (Hamilton), fingerlings. *Journal of Applied Ichthyology/Zeitschrift für angewandte Ichthyologie*, 23(1): 74–79.
- Ray, A.K. & Das, I. 1996. Evaluation of dried aquatic weed, *Pistia stratiotes*, meal as a feedstuff in pelleted feed for Rohu, *Labeo rohita*, fingerlings. *Journal of Applied Aquaculture*, 5(4): 35–44.
- Re-Araujo, A.D. & Ruiz, M.D. 2003. Lecithin essay in the diet of young *Penaeus vannamei* (Crustacea: Decapoda). *Revista De Biología Tropical*, 51(3–4): 743–747.
- Refstie, S. & Tiekstra, H.A.J. 2003. Potato protein concentrate with low content of solanidine glycoalkaloids in diets for Atlantic salmon (*Salmo salar*). *Aquaculture*, 216(1–4): 283–298.
- Refstie, S., Helland, S.J. & Storebakken, T. 1997. Adaptation to soybean meal in diets for rainbow trout, *Oncorhynchus mykiss*. *Aquaculture*, 153(3–4): 263–272.
- Refstie, S., Storebakken, T. & Roem, A.J. 1998. Feed consumption and conversion in Atlantic salmon (*Salmo salar*) fed diets with fish meal, extracted soybean meal or soybean meal with reduced content of oligosaccharides, trypsin inhibitors, lectins and soya antigens. *Aquaculture*, 162(3–4): 301–312.
- Refstie, S., Korsoeen, O.J., Storebakken, T., Baeverfjord, G., Lein, I. & Roem, A.J. 2000. Differing nutritional responses to dietary soybean meal in rainbow trout (*Oncorhynchus mykiss*) and Atlantic salmon (*Salmo salar*). *Aquaculture*, 190(1–2): 49–63.
- Refstie, S., Storebakken, T., Baeverfjord, G. & Roem, A.J. 2001. Long-term protein and lipid growth of Atlantic salmon (*Salmo salar*) fed diets with partial replacement of fish meal by soy protein products at medium or high lipid level. *Aquaculture*, 193(1–2): 91–106.
- Refstie, S., Sahlstrom, S., Brathen, E., Baeverfjord, G. & Krogedal, P. 2005. Lactic acid fermentation eliminates indigestible carbohydrates and antinutritional factors in soybean meal for Atlantic salmon (*Salmo salar*). *Aquaculture*, 246(1–4): 331–345.
- Refstie, S., Bakke-McKellep, A.M., Penn, M.H., Sundby, A., Shearer, K.D. & Krogdahl, A. 2006a. Capacity for digestive hydrolysis and amino acid absorption in Atlantic salmon (*Salmo salar*) fed diets with soybean meal or inulin with or without addition of antibiotics. *Aquaculture*, 261(1): 392–406.
- Refstie, S., Forde-Skjaervik, O., Rosenlund, G. & Rorvik, K.A. 2006b. Feed intake, growth, and utilisation of macronutrients and amino acids by 1- and 2-year old Atlantic cod (*Gadus morhua*) fed standard or bioprocessed soybean meal. *Aquaculture*, 255(1–4): 279–291.
- Refstie, S., Glencross, B., Landsverk, T., Sorensen, M., Lilleeng, E., Hawkins, W. & Krogdahl, A. 2006c. Digestive function and intestinal integrity in Atlantic salmon (*Salmo salar*) fed kernel meals and protein concentrates made from yellow or narrow-leaved lupins. *Aquaculture*, 261(4): 1382–1395.
- Regost, C., Arzel, J. & Kaushik, S.J. 1999. Partial or total replacement of fish meal by corn gluten meal in diet for turbot (*Psetta maxima*). *Aquaculture*, 180(1–2): 99–117.
- Regost, C., Arzel, J., Robin, J.H., Rosenlund, G. & Kaushik, S.J. 2003a. Total replacement of fish oil by soybean or linseed oil with a return to fish oil in turbot (*Psetta maxima*). 1. Growth performance, flesh fatty acid profile and lipid metabolism. *Aquaculture*, 217: 465–482.
- Regost, C., Arzel, J., Cardinal, M., Rosenlund, G. & Kaushik, S.J. 2003b. Total replacement of fish oil by soybean or linseed oil with a return to fish oil in Turbot (*Psetta maxima*). 2. Flesh quality properties. *Aquaculture*, 220: 737–747.
- Regost, C., Jakobsen, J.V. & Røra, A.M.B.F. 2004. Flesh quality of raw and smoked fillets of Atlantic salmon as influenced by dietary oil sources and frozen storage. *Food Research International*, 37: 259–271.
- Rehulka, J. & Parova, J. 2000. Influence of three types of oil in diet upon some blood and condition indices of rainbow trout, *Oncorhynchus mykiss* (Walbaum). *Czech Journal of Animal Science*, 45(3): 127–132.
- Rehulka, J. & Minarik, B. 2003. Effect of lecithin on the haematological and condition indices of the rainbow trout *Oncorhynchus mykiss* (Walbaum). *Aquaculture Research*, 34(8): 617–627.
- Reig, L., Ginovart, M. & Flos, R. 2003. Modification of the feeding behaviour of sole (*Solea solea*) through the addition of a commercial flavour as an alternative to betaine. *Aquatic Living Resources*, 16(4): 370–379.
- Rennie, S., Huntingford, F.A., Loeland, A.L. & Rimbach, M. 2005. Long term partial replacement of dietary fish oil with rapeseed oil; effects on egg quality of Atlantic salmon *Salmo salar*. *Aquaculture*, 248(1–4): 135–146.
- Reyes, O.S. & Fermin, C. 2003. Terrestrial leaf meals or freshwater aquatic fern as potential feed ingredients for farmed abalone *Haliotis asinina* (Linnaeus 1758). *Aquaculture Research*, 34(8): 593–599.
- Reyes-Becerril, M., Tovar-Ramirez, D., Ascencio-Valle, F., Civera-Cerecedo, R., Gracia-Lopez, V. & Barbosa-Solomieu, V. 2008a. Effects of dietary live yeast *Debaryomyces hansenii* on the immune and antioxidant system in juvenile leopard grouper *Mycteroperca rosacea* exposed to stress. *Aquaculture*, 280(1–4): 39–44.

- Reyes-Becerril, M., Salinas, I., Cuesta, A., Meseguer, J., Tovar-Ramirez, D., Ascencio-Valle, F. & Esteban, M.A. 2008b. Oral delivery of live yeast *Debaryomyces hansenii* modulates the main innate immune parameters and the expression of immune-relevant genes in the gilthead seabream (*Sparus aurata* L.). *Fish and Shellfish Immunology*, 25(6): 731–739.
- Reyes-Sosa, C.F. & Castellanos-Molina, R. 1995. Nutritional evaluation of gizzard erosion positive brown fish meal in starter diets for Nile tilapia, *Oreochromis niloticus*. *Aquaculture*, 138(1–4): 323–329.
- Ribeiro, P.A.P., Logato, P.V.R., Paula, D.A.D., Costa, A.C., Murgas, L.D.S. & de Freitas, R.T.F. 2008. Effect of different oils in the diet on lipogenesis and the lipid profile of Nile tilapia. *Revista Brasileira De Zootecnia-Brazilian Journal of Animal Science*, 37(8): 1331–1337.
- Richard, N., Mourente, G., Kaushik, S. & Corraze, G. 2006a. Replacement of a large portion of fish oil by vegetable oils does not affect lipogenesis, lipid transport and tissue lipid uptake in European seabass (*Dicentrarchus labrax* L.). *Aquaculture*, 261: 1077–1087.
- Richard, N., Kaushik, S., Larroquet, L., Panserat, S. & Corraze, G. 2006b. Replacing dietary fish oil by vegetable oils has little effect on lipogenesis, lipid transport and tissue lipid uptake in rainbow trout (*Oncorhynchus mykiss*). *British Journal of Nutrition*, 96: 299–309.
- Riche, M., Trottier, N.L., Ku, P.K. & Garling, D.L. 2001. Apparent digestibility of crude protein and apparent availability of individual amino acids in tilapia (*Oreochromis niloticus*) fed phytase pretreated soybean meal diets. *Fish Physiology and Biochemistry*, 25(3): 181–194.
- Ricque-Marie, D., Abdo-de La Parra, M.I., Cruz-Suarez, L.E., Cuzon, G., Cousin, M., Aquacop & Pike, I.H. 1998. Raw material freshness, a quality criterion for fish meal fed to shrimp. *Aquaculture*, 165: 95–109.
- Rinchar, J., Mbahinzireki, G., Dabrowski, K., Lee, K.J., Garcia-Abiado, M.A. & Ottobre, J. 2002. Effects of dietary cottonseed meal protein level on growth, gonad development and plasma sex steroid hormones of tropical fish tilapia *Oreochromis* sp. *Aquaculture International*, 10(1): 11–28.
- Rinchar, J., Lee, K.J., Czesny, S., Ciereszko, A. & Dabrowski, K. 2003a. Effect of feeding cottonseed meal-containing diets to broodstock rainbow trout and their impact on the growth of their progenies. *Aquaculture*, 227(1–4): 77–87.
- Rinchar, J., Lee, K.J., Dabrowski, K., Ciereszko, A., Blom, J.H. & Ottobre, J.S. 2003b. Influence of gossypol from dietary cottonseed meal on haematology, reproductive steroids and tissue gossypol enantiomer concentrations in male rainbow trout (*Oncorhynchus mykiss*). *Aquaculture Nutrition*, 9(4): 275–282.
- Ringo, E., Lodemel, J.B., Myklebust, R., Jensen, L., Lund, V., Mayhew, T.M. & Olsen, R.E. 2002. The effects of soybean, linseed and marine oils on aerobic gut microbiota of Arctic charr *Salvelinus alpinus* L. before and after challenge with *Aeromonas salmonicida* ssp *salmonicida*. *Aquaculture Research*, 33(8): 591–606.
- Ringo, E., Sperstad, S., Myklebust, R., Refstie, S. & Krogdahl, A. 2006. Characterisation of the microbiota associated with intestine of Atlantic cod (*Gadus morhua* L.) – The effect of fish meal, standard soybean meal and a bioprocessed soybean meal. *Aquaculture*, 261(3): 829–841.
- Robaina, L., Izquierdo, M.S., Moyano, F.J., Socorro, J., Vergara, J.M., Montero, D. & Fernandezpalacios, H. 1995. Soybean and lupin seed meals as protein sources in diets for Gilthead seabream (*Sparus aurata*): nutritional and histological implications. *Aquaculture*, 130(2–3): 219–233.
- Robaina, L., Moyano, F.J., Izquierdo, M.S., Socorro, J., Vergara, J.M. & Montero, D. 1997. Corn gluten and meat and bone meals as protein sources in diets for gilthead seabream (*Sparus aurata*): Nutritional and histological implications. *Aquaculture*, 157(3–4): 347–359.
- Robaina, L., Izquierdo, M.S., Moyano, F.J., Socorro, J., Vergara, J.M. & Montero, D. 1998. Increase of the dietary n-3/n-6 fatty acid ratio and addition of phosphorus improves liver histological alterations induced by feeding diets containing soybean meal to gilthead seabream, *Sparus aurata*. *Aquaculture*, 161(1–4): 281–293.
- Robaina, L., Corraze, G., Aguirre, P., Blanc, D., Melcion, J.P. & Kaushik, S. 1999. Digestibility, postprandial ammonia excretion and selected plasma metabolites in European sea bass (*Dicentrarchus labrax*) fed pelleted or extruded diets with or without wheat gluten. *Aquaculture*, 179(1–4): 45–56.
- Robin, J.H., Regost, C., Arzel, J. & Kaushik, S.J. 2003. Fatty acid profile of fish following a change in dietary fatty acid source: model of fatty acid composition with a dilution hypothesis. *Aquaculture* 225: 283–293.
- Robinette, H.R., Taylor, J.B., Gatlin, D.M. & Craig, S. 1997. Effects of dietary catfish and menhaden oils on hybrid striped bass production. *Progressive Fish Culturist*, 59(4): 261–265.
- Robinson, E.H. & Tiersch, T.R. 1995. Effects of long-term feeding of cottonseed meal on growth, testis development, and sperm motility of male channel catfish *Ictalurus punctatus* broodfish. *Journal of the World Aquaculture Society*, 26(4): 426–431.
- Robinson, E.H. & Li, M.H. 2008. Replacement of soybean meal in channel catfish, *Ictalurus punctatus*, diets with cottonseed meal and distiller's dried grains with solubles. *Journal of the World Aquaculture Society*, 39(4): 521–527.
- Robinson, E.H., Li, M.H. & Manning, B.B. 2001. Evaluation of corn gluten feed as a dietary ingredient for pond-raised Channel ratfish *Ictalurus punctatus*. *Journal of the World Aquaculture Society*, 32(1): 68–71.
- Rodehutsord, M., Borchert, F., Gregus, Z., Pack, M. & Pfeffer, E. 2000a. Availability and utilisation of free lysine in rainbow trout (*Oncorhynchus mykiss*) – 1. Effect of dietary crude protein level. *Aquaculture*, 187(1–2): 163–176.

- Rodehutsord, M., Borchert, F., Gregus, Z. & Pfeffer, E. 2000b. Availability and utilisation of free lysine in rainbow trout (*Oncorhynchus mykiss*) – 2. Comparison of L-lysine HCl and L-lysine sulphate. *Aquaculture*, 187(1–2): 177–183.
- Rodriguez, C., Henderson, R.J., Porter, A.E.A. & Dick, J.R. 1997. Modification of odd-chain length unsaturated fatty acids by hepatocytes of rainbow trout (*Oncorhynchus mykiss*) fed diets containing fish oil or olive oil. *Lipids*, 32(6): 611–619.
- Rojas, J.B.U. & Verreth, J.A.J. 2003. Growth of *Oreochromis aureus* fed with diets containing graded levels of coffee pulp and reared in two culture systems. *Aquaculture*, 217(1–4): 275–283.
- Rollin, X., Peng, J., Pham, D., Ackman, R.G. & Larondelle, Y. 2003. The effects of dietary lipid and strain difference on polyunsaturated fatty acid composition and conversion in anadromous and landlocked salmon (*Salmo salar* L.) parr. *Comparative Biochemistry and Physiology, B* 134: 349–366.
- Romarheim, O.H., Skrede, A., Gao, Y.L., Krogdahl, A., Denstadli, V., Lilleeng, E. & Storebakken, T. 2006. Comparison of white flakes and toasted soybean meal partly replacing fish meal as protein source in extruded feed for rainbow trout (*Oncorhynchus mykiss*). *Aquaculture*, 256(1–4): 354–364.
- Romarheim, O.H., Skrede, A., Penn, M., Mydland, L.T., Krogdahl, A. & Storebakken, T. 2008a. Lipid digestibility, bile drainage and development of morphological intestinal changes in rainbow trout (*Oncorhynchus mykiss*) fed diets containing defatted soybean meal. *Aquaculture*, 274(2–4): 329–338.
- Romarheim, O.H., Zhang, C., Penn, M., Liu, Y.J., Tian, L.X., Skrede, A., Krogdahl, A. & Storebakken, T. 2008b. Growth and intestinal morphology in cobia (*Rachycentron canadum*) fed extruded diets with two types of soybean meal partly replacing fish meal. *Aquaculture Nutrition*, 14(2): 174–180.
- Rondan, M., Hernandez, M.D., Egea, M.A., Garcia, B., Jover, M., Rueda, F.M. & Martinez, F.J. 2004. Effects of fishmeal replacement with soybean meal as protein source, and protein replacement with carbohydrates as an alternative energy source on sharpnose sea bream, *Diplodus puntazzo*, fatty acid profile. *Aquaculture Research*, 35(13): 1220–1227.
- Røra, A.M.B., Regost, C. & Lampe, J. 2003. Liquid holding capacity, texture and fatty acid profile of smoked fillets of Atlantic salmon fed diets containing fish oil or soybean oil. *Food Research International*, 36: 231–239.
- Rosas, C., Tut, J., Baeza, J., Sanchez, A., Sosa, V., Pascual, C., Arena, L., Domingues, P & Cuzon, G. 2008. Effect of type of binder on growth, digestibility, and energetic balance of *Octopus maya*. *Aquaculture*, 275(1–4): 291–297.
- Rosenlund, G., Obach, A., Sandberg, M.G., Standal, H. & Tveit, K. 2001. Effect of alternative lipid sources on long-term growth performance and quality of Atlantic salmon (*Salmo salar* L.). *Aquaculture Research*, 32: 323–328.
- Rout, R.K. & Bandyopadhyay, S. 1999. A comparative study of shrimp feed pellets processed through cooking extruder and meat mincer. *Aquacultural Engineering*, 19(2): 71–79.
- Rowland, S.J., Allan, G.L., Mifsud, C., Read, P.A., Glendenning, D. & Ingram, B.A. 2007. Effects of diets with different plant proteins on the performance of silver perch (*Bidyanus bidyanus* Mitchell) and on water quality in earthen ponds. *Aquaculture Research*, 38(7): 748–756.
- Roy, L.A., Bordinhon, A., Sookying, D., Davis, D.A., Brown, T.W. & White, G.N. 2009. Demonstration of alternative feeds for the Pacific white shrimp, *Litopenaeus vannamei*, reared in low salinity waters of west Alabama. *Aquaculture Research*, 40: 496–503.
- Ruchimat, T., Masumoto, T., Hosokawa, H. & Shimeno, S. 1997. Nutritional evaluation of several protein sources for yellowtail (*Seriola quinqueradiata*). *Bull. Mar. Sci. Fish. Kochi Univ.* no. 17, pp. 69–78.
- Rumsey, G.L., Hughes, S.G., Smith, R.R., Kinsella, J.E. & Shetty, K.J. 1991a. Digestibility and energy values of intact, disrupted and extracts from brewer's dried yeast fed to rainbow trout (*Oncorhynchus mykiss*). *Anim. Feed Sci. Technol.* 33: 185–193.
- Rumsey, G.L., Kinsella, J.E., Shetty, K.J. & Hughes, S.G. 1991b. Effect of high dietary concentrations of brewer's dried yeast on growth performance and liver uricase in rainbow trout (*Oncorhynchus mykiss*). *Anim. Feed Sci. Technol.* 33: 177–183.
- Rumsey, G.L., Winfree, R.A. & Hughes, S.G. 1992. Nutritional value of dietary nucleic acids and purine bases to rainbow trout (*Oncorhynchus mykiss*). *Aquaculture*, 108: 97–110.
- Rungruangsak-Torrissen, K. 2007. Digestive efficiency, growth and qualities of muscle and oocyte in Atlantic salmon (*Salmo salar* L.) fed on diets with krill meal as an alternative protein source. *Journal of Food Biochemistry*, 31(4): 509–540.
- Ruscoe, I.M., Jones, C.M., Jones, P.L. & Caley, P. 2005. The effects of various binders and moisture content on pellet stability of research diets for freshwater crayfish. *Aquaculture Nutrition*, 11(2): 87–93.
- Sa, R., Pousao-Ferreira, P. & Oliva-Teles, A. 2008. Dietary lipid utilization by white sea bream (*Diplodus sargus*) juveniles. *Journal of the World Aquaculture Society*, 39(3): 423–428.
- Sadiku, S.O.E. & Jauncey, K. 1995. Digestibility, apparent amino acid availability and waste generation potential of soybean flour: Poultry meat meal blend based diets for tilapia, *Oreochromis niloticus* (L.), fingerlings. *Aquaculture Research*, 26(9): 651–657.
- Sadiku, S.O.E. & Jauncey, K. 1998. Digestibility, apparent amino acid availability and waste generation potential of soybean flour-poultry meat meal blend diets for the sharp-toothed catfish, *Clarias gariepinus*, fingerlings. *Journal of Applied Aquaculture*, 8(1): 69–75.
- Sagstad, A., Sanden, M., Haugland, O., Hansen, A.C., Olsvik, P.A. & Hemre, G.I. 2007. Evaluation of stress- and immune-response biomarkers in Atlantic salmon, *Salmo salar* L., fed different levels of genetically modified maize (Bt maize), compared with its near-isogenic parental line and a commercial supplex maize. *Journal of Fish Diseases*, 30(4): 201–212.

- Saha, A.K. & Ray, A.K. 1998. Incorporation of animal by-products in carp diets: Evaluation of poultry litter and goat blood meal as dietary protein sources for rohu (*Labeo rohita*), fingerlings. *Journal of Aquaculture in the Tropics*, 13(4): 277–284.
- Sahoo, P. & Mukherjee, S.C. 2001. Immunosuppressive effects of aflatoxin B1 in Indian major carp (*Labeo rohita*). *Comparative Immunology, Microbiology & Infectious Diseases*, 24: 143–149.
- Sahu, P.K., Jena, J.K., Das, P.C., Mondal, S. & Das, R. 2007. Production performance of *Labeo calbasu* in polyculture with three Indian major carps *Catla catla* (Hamilton), *Labeo rohita* (Hamilton) and *Cirrhinus mrigala* (Hamilton) with provision of fertilizers, feed and periphytic substrate as varied inputs. *Aquaculture*, 262: 333–339.
- Sajjadi, M. & Carter, C.G. 2004. Dietary phytase supplementation and the utilisation of phosphorus by Atlantic salmon (*Salmo salar* L.) fed a canola-meal-based diet. *Aquaculture*, 240(1–4): 417–431.
- Salaro, A. L., L. E. Pezzato, M. M. Barros & C. A. Vicentini. 1999a. Performance and spermatogenesis of Nile tilapia fingerlings fed with cottonseed meal or cottonseed flour. *Pesquisa Agropecuaria Brasileira*, 34(3): 449–457.
- Salaro, A. L., Pezzato, L.E., Vicentini, C.A. & Barros, M.M. 1999b. Effect of adding cottonseed meal or cottonseed flour to rations for Nile tilapia (*Oreochromis niloticus*) broodstock. *Revista Brasileira De Zootecnia – Brazilian Journal of Animal Science*, 28(6): 1169–1176.
- Sales, J. & Britz, P.J. 2002. Evaluation of the reference diet substitution method for determination of apparent nutrient digestibility coefficients of feed ingredients for South African abalone (*Haliotis midae* L.). *Aquaculture*, 207(1–2): 113–123.
- Sales, J. & Britz, P. 2003. Apparent and true availability of amino acids from common feed ingredients for South African abalone (*Haliotis midae* L.). *Aquaculture Nutrition*, 9(1): 55–64.
- Salo, M.L. 1977. The carbohydrate composition and solubility of pekilo protein and two yeasts. *Acta Agric. Scand.*, 27: 77–80.
- Salvador, A.M., Alonso-Damian, A., Choubert, G. & Milicua, J.C.G. 2007. Effect of soybean phospholipids on Canthaxanthin lipoproteins transport, digestibility, and deposition in rainbow trout (*Oncorhynchus mykiss*) muscle. *Journal of Agricultural and Food Chemistry*, 55(22): 9202–9207.
- Sambhu, C. & Jayaprakas, V. 2003. Effect of synthetic feed additive Stafac-20 on growth characteristics of juveniles of white prawn *Penaeus indicus* (Crustacea/Penaeidea). *Indian Journal of Marine Sciences*, 32(1): 76–80.
- Samocha, T.M., Davis, D.A., Saoude, I.P. & DeBault, K. 2004. Substitution of fish meal by co-extruded soybean poultry by-product meal in practical diets for the Pacific white shrimp, *Litopenaeus vannamei*. *Aquaculture*, 231: 197–203.
- Samocha, T.M., Patnaik, S., Speed, M., Ali, A.M., Burger, J.M., Almeida, R.V., Ayub, Z., Harisanto, M., Horowitz, A. & Brock, D.L. 2007. Use of molasses as carbon source in limited discharge nursery and grow-out systems for *Litopenaeus vannamei*. *Aquacultural Engineering*, 36(2): 184–191.
- Sampaio, F.G., Hisano, H., Yamaki, R.A., Kleemann, G.K., Pezzato, L.E. & Barros, M.M. 2001. Apparent digestibility by Nile tilapia *Oreochromis niloticus* (L.) of Brazilian-made meal, imported fish meal and toasted and spray-dried blood meals. *Acta Scientiarum Universidade Estadual de Maringa*, 23(4): 891–896.
- Sanchez, D.R., Fox, J.M., Lawrence, A.L., Castille, F.L. & Dunsford, B. 2005. A methodology for evaluation of dietary feeding stimulants for the Pacific white shrimp, *Litopenaeus vannamei*. *Journal of the World Aquaculture Society*, 36(1): 14–23.
- Sanchez Lozano, N.B., Tomas Vidal, A., Martinez-Llorens, S., Nogales Merida, S., Blanco, J.E., Monino Lopez, A., Pla Torres, M. & Cerda, M. J. 2007. Growth and economic profit of gilthead sea bream (*Sparus aurata*, L.) fed sunflower meal. *Aquaculture*, 272(1–4): 528–534.
- Sanchez-Muros, M.J., Corchete, V., Suarez, M.D., Cardenete, G., Gomez-Milan, E. & de la Higuera, M. 2003. Effect of feeding method and protein source on *Sparus aurata* feeding patterns. *Aquaculture*, 224(1–4): 89–103.
- Sandholm, R.R., Shih, J.C.H. & Scott, M.L. 1976. Determination of antitrypsin activity on agar plates: relationship between antitrypsin and biological value of soybean for trout. *Journal of Nutrition*, 106: 761–766.
- Santacroce, M.P., Conversano, M.C., Casalino, E., Lai, O., Zizzadoro, C., Centoducati, G. & Crescenzo, G. 2008. Aflatoxins in aquatic species: metabolism, toxicity and perspectives. *Rev. Fish Biol. Fish.* 18: 99–130.
- Santigosa, E., Sanchez, J., Medale, F., Kaushik, S., Perez-Sanchez, J. & Gallardo, M.A. 2008. Modifications of digestive enzymes in trout (*Oncorhynchus mykiss*) and sea bream (*Sparus aurata*) in response to dietary fish meal replacement by plant protein sources. *Aquaculture*, 282(1–4): 68–74.
- Saoud, I.P., Rodgers, L.J., Davis, D.A. & Rouse, D.B. 2008. Replacement of fish meal with poultry by-product meal in practical diets for redclaw crayfish (*Cherax quadricarinatus*). *Aquaculture Nutrition*, 14(2): 139–142.
- Sato, T. & Kikuchi, K. 1997. Meat meal as a protein source in the diet of juvenile Japanese flounder. *Fisheries Science*, 63(6): 877–880.
- Sato, N., Fujioka, T. & Nobuta, S. 2006. Availability of commercial squid liver meal as diets of fingerling rockfish. *Nippon Suisan Gakkaishi*, 72(3): 401–407.
- Satoh, S., Apines, M.J., Tsukioka, T., Kiron, V., Watanabe, T. & Fujita, S. 2001. Bioavailability of amino acid-chelated and glass-embedded manganese to rainbow trout, *Oncorhynchus mykiss* (Walbaum), fingerlings. *Aquaculture Research*, 32(s1): 18–25.

- Satoh, S., Takanezawa, M., Akimoto, A., Kiron, V. & Watanabe, T. 2002. Changes of phosphorus absorption from several feed ingredients in rainbow trout during growing stages and effect of extrusion of soybean meal. *Fisheries Science*, 68(2): 325–331.
- Sawant, G.P., Singh, H., Sawant, N.H. & Shirdhankar, M.M. 2005. Effects of different oil cakes on the growth and survival of *Liza parsia* (Hamilton-Buchanan, 1822). *Fishery Technology. Society of Fisheries Technologists (India)*, 42(1): 37–40.
- Schlechtriem, C., Bron, J.E. & Tocher, D.R. 2007. Inter-individual variation in total fatty acid compositions of flesh of Atlantic salmon smolts-fed diets containing fish oil or vegetable oil. *Aquaculture Research*, 38(10): 1045–1055.
- Schneider, O., Amirkolaie, A.K., Vera-Cartas, J., Eding, E.H., Schrama, J.W. & Verreth, J.A.J. 2004. Digestibility, faeces recovery, and related carbon, nitrogen and phosphorus balances of five feed ingredients evaluated as fishmeal alternatives in Nile tilapia, *Oreochromis niloticus* L. *Aquaculture Research*, 35(14): 1370–1379.
- Scholz, U., Diaz, G.G., Ricque, D., Suarez, L.E.C., Albores, F.V. & Latchford, J. 1999. Enhancement of vibriosis resistance in juvenile *Penaeus vannamei* by supplementation of diets with different yeast products. *Aquaculture*, 176(3–4): 271–283.
- Schuchardt, D., Vergara, J.M., Fernández-Palacios, H., Kalinowski, T., Hernández Cruz, C.M., Izquierdo, M.S. & Robaina, L. 2008. Effects of different dietary protein and lipid levels on growth, feed utilization and body composition of red porgy (*Pagrus pagrus*) fingerlings. *Aquaculture Nutrition*, 14: 1–9.
- Schulz, C., Wickert, M., Kijora, C., Ogunji, J. & Rennert, B. 2007. Evaluation of pea protein isolate as alternative protein source in diets for juvenile tilapia (*Oreochromis niloticus*). *Aquaculture Research*, 38(5): 537–545.
- Sclabos Katevas, D. 2008. The South Antarctic krill industry. How far can derivatives become a real feed ingredient substitute? Brief industry overview. Santiago, Chile, Tharos Ltd. 210 pp. (www.tharos.biz).
- Sealey, W.M., Barrows, F.T., Johansen, K.A., Overturf, K., LaPatra, S.E. & Hardy, R.W. 2007. Evaluation of the ability of partially autolyzed yeast and Grobionic-A to improve disease resistance in rainbow trout. *North American Journal of Aquaculture*, 69(4): 400–406.
- Sebahattin, E., Soyuturk, M., Guroy, B., Guroy, D. & Merrifield, D. 2009. Influence of Ulva meal on growth, feed utilization, and body composition of juvenile Nile tilapia (*Oreochromis niloticus*) at two levels of dietary lipid. *Aquaculture International*, 17: 355–361.
- Segovia-Quintero, M.A. & Reight, R.C. 2004. Coating crystalline methionine with tripalmitin-polyvinyl alcohol slows its absorption in the intestine of Nile tilapia, *Oreochromis niloticus*. *Aquaculture*, 238(1–4): 355–367.
- Seierstad, S.L., Poppe, T.T., Koppang, E.O., Svindland, A., Rosenlund, G., Froeyland, L. & Larsen, S. 2005. Influence of dietary lipid composition on cardiac pathology in farmed Atlantic salmon, *Salmo salar* L. *Journal of Fish Diseases*, 28(11): 677–690.
- Seierstad, S.L., Svindland, A., Larsen, S., Rosenlund, G., Torstensen, B.E. & Evensen, O. 2008. Development of intimal thickening of coronary arteries over the lifetime of Atlantic salmon, *Salmo salar* L., fed different lipid sources. *Journal of Fish Diseases*, 31(6): 401–413.
- Seierstad, S.L., Haugland, O., Larsen, S., Waagbo, R. & Evensen, O. 2009. Pro-inflammatory cytokine expression and respiratory burst activity following replacement of fish oil with rapeseed oil in the feed for Atlantic salmon (*Salmo salar* L.). *Aquaculture*, 289(3–4): 212–218.
- Selden, G.L., Brown, P.B., Ostrowski, A.C., Flores, R.A. & Johnson, L.A. 2001. Evaluation of soybean meal-red blood cell coextruded feed ingredient in diets fed to rainbow trout *Oncorhynchus mykiss*. *Journal of the World Aquaculture Society*, 32(4): 409–415.
- Senaratna, M., Evans, L.H., Southam, L. & Tsvetnenko, E. 2005. Effect of different feed formulations on feed efficiency, gonad yield and gonad quality in the purple sea urchin *Heliocidaris erythrogramma*. *Aquaculture Nutrition*, 11(3): 199–207.
- Sener, E. & Yildiz, M. 2003. Effect of the different oil on growth performance and body composition of rainbow trout (*Oncorhynchus mykiss* W., 1792) juveniles. *Turkish Journal of Fisheries and Aquatic Sciences*, 3(2): 111–116.
- Sener, E., Yildiz, M. & Savas, E. 2005. Effects of dietary lipids on growth and fatty acid composition in Russian sturgeon (*Acipenser gueldenstaedtii*) juveniles. *Turkish Journal of Veterinary and Animal Sciences*, 29: 1101–1107.
- Sener, E., M. Yildiz & E. Savas. 2006. Effect of vegetable protein and oil supplementation on growth performance and body composition of Russian sturgeon juveniles (*Acipenser gueldenstaedtii* Brandt, 1833) at low temperatures. *Turkish Journal of Fisheries and Aquatic Sciences*, 6(1): 23–27.
- Seno, O.A., Takakuwa, F., Hashiguchi, T., Morioka, K., Masumoto, T. & Fukada, H. 2008. Replacement of dietary fish oil with olive oil in young yellowtail *Seriola quinqueradiata*: effects on growth, muscular fatty acid composition and prevention of dark muscle discoloration during refrigerated storage. *Fisheries Science*, 74(6): 1297–1306.
- Serot, T., Regost, C., Prost, C., Robin, J.H. & Arzel, J. 2001. Effect of dietary lipid sources on odour-active compounds in muscle of turbot (*Psetta maxima*). *Journal of the Science of Food and Agriculture*, 81: 1339–1346.
- Serot, T., Regost, C. & Arzel, J. 2002. Identification of odour-active compounds in muscle of brown trout (*Salmo trutta*) as affected by dietary lipid sources. *Journal of the Science of Food and Agriculture*, 82: 636–643.

- Shafaipour, A., Yavari, V., Falahatkar, B., Maremmazi, J.G. & Gorjipour, E. 2008. Effects of canola meal on physiological and biochemical parameters in rainbow trout (*Oncorhynchus mykiss*). *Aquaculture Nutrition*, 14(2): 110–119.
- Shah, A.K.M., Hossain, M.A. & Afsana, K. 1998. Effect of different rice bran on the growth of Thai silver barb (*Puntius gonionotus* Bleekeri) in seasonal ponds. *Bangladesh J. Fish Res.*, 2: 159–169.
- Shahzad, K., Salim, M. & Asad, F. 2006. Evaluation of apparent digestibility coefficient of corn, wheat and feather meal for *Labeo rohita*. *Pakistan Journal of Zoology*, 38(2): 125–130.
- Shamushaki, V.A.J., Kasumyan, A.O., Abedian, A. & Abtahi, B. 2007. Behavioural responses of the Persian sturgeon (*Acipenser persicus*) juveniles to free amino acid solutions. *Marine and Freshwater Behaviour and Physiology*, 40(3): 219–224.
- Shankar, R., Murthy, H.S., Pavadi, P. & Thanuja, K. 2008. Effect of betaine as a feed attractant on growth, survival, and feed utilization in fingerlings of the Indian major carp, *Labeo rohita*. *Israeli Journal of Aquaculture – Bamidgeh*, 60(2): 95–99.
- Shapawi, R., Ng, W.K. & Mustafa, S. 2007. Replacement of fish meal with poultry by-product meal in diets formulated for the humpback grouper, *Cromileptes altivelis*. *Aquaculture*, 273(1): 118–126.
- Shapawi, R., Mustafa, S. & Ng, W.K. 2008. Effects of dietary fish oil replacement with vegetable oils on growth and tissue fatty acid composition of humpback grouper, *Cromileptes altivelis* (Valenciennes). *Aquaculture Research*, 39: 315–323.
- Sharshar, K.M. & Haroon, A.M. 2009. Comparative investigations on some biological and biochemical aspects in freshwater crayfish (*Procambarus clarkii*) fed on *Echhornia crassipes*, *Echinocloa stagnina* L. and *Polygonum timentosum* L. *American-Eurasian Journal of Agriculture and Environmental Science*, 5(4): 579–589.
- Sheen, S.S. & Fall, J. 2005. Replacement of soybean meal by shell shrimp meal in the diet for hybrid tilapia fry (*Oreochromis niloticus* x *O. aureus*) reared under brackish water. Abstract of the Fisheries Society of Taiwan 2004 Annual Conference, Taipei (Taiwan), 25–26 December 2004, 32(1): 29.
- Shimeno, S., Kanetaka, Y., Ruchimat, T. & Ukawa, M. 1995. Nutritional evaluation of several soy proteins for fingerling yellowtail. *Nippon Suisan Gakkaishi*, 61(6): 919–926.
- Shimeno, S., Hosokawa, H., Masumoto, T., Ruchimat, T. & Kishi, S. 1996. Addition of combined defatted soybean meal, malt protein flour, and meat meal to yellowtail diet. *Nippon Suisan Gakkaishi*, 62(2): 243–247.
- Shimeno, S., Matsumoto, M. & Ukawa, M. 1997a. Effect of dietary types on nutritive values of fish meal-based diet for yellowtail. *Nippon Suisan Gakkaishi*, 63(6): 971–976.
- Shimeno, S., Ruchimat, T., Matsumoto, M. & Ukawa, M. 1997b. Inclusion of full-fat soybean meal in diet for fingerling yellowtail. *Nippon Suisan Gakkaishi*, 63(1): 70–76.
- Shipton, T.A. & Britz, P.J. 2000. *Partial and total substitution of fishmeal with plant protein concentrates in formulated diets for the South African abalone, Haliotis midae*. 4. International Abalone Symposium, Cape Town, South Africa, February 2000 19(1): 534.
- Shipton, T.A. & Britz, P.J. 2001. *The partial and total replacement of fishmeal with selected plant protein sources in diets for the South African abalone, Haliotis midae* L. 4. International Symposium on Abalone Biology, Fisheries, and Culture, Cape Town, Western Cape, South Africa, 6–11 February 2000, 20(2): 637–645.
- Shyla, G., Nair, C.M., Salin, K.R., Sherief, P.M. & Mukundan, M.K. 2009. Liver oil of pharaoh cuttlefish *Sepia pharaonis* Ehrenberg, 1831 as a lipid source in the feed of giant freshwater prawn, *Macrobrachium rosenbergii* (De Man, 1879). *Aquaculture Nutrition*, 15: 273–281.
- Siddhuraju, P. & Becker, K. 2001. Preliminary nutritional evaluation of Mucuna seed meal (*Mucuna pruriens* var. *utilis*) in common carp (*Cyprinus carpio* L.): an assessment by growth performance and feed utilisation. *Aquaculture*, 196(1–2): 105–123.
- Signor, A.A., Boscolo, W.R., Bittencourt, F., Feiden, A. & Reidel, A. 2008. Poultry by-product meal in lambari fingerlings diet. *Ciencia Rural*, 38(8): 2339–2344.
- Silva, T.C.S., Furuya, W.M., Santos, V.G., Botaro, D., Silva, L.C.R., Sales, P.J.P., Hayashi, C., Santos, L.D. & Furuya, V.R.B. 2005. Apparent digestibility coefficients of energy and nutrients of fullfat soybean meal with and without phytase for Nile tilapia (*Oreochromis niloticus*). *Acta scientiarum*, 27(3): 371–376.
- Sinha, A. & Asimi, O.A. 2007. China rose (*Hibiscus rosasinensis*) petals: a potent natural carotenoid source for goldfish (*Carassius auratus* L.). *Aquaculture Research*, 38(11): 1123–1128.
- Singh, S.D., Nayak, S.K., Sekar, M. & Behera, B.K. 2008. Applications of nutritional biotechnology in aquaculture. *Aquaculture Asia Magazine*, Oct–Dec 2008, pp.17–23.
- Sink, T.D. & Lochmann, R.T. 2008. Effects of dietary lipid source and concentration on channel catfish (*Ictalurus punctatus*) egg biochemical composition, egg and fry production, and egg and fry quality. *Aquaculture*, 283(1–4): 68–76.
- Sintayehu, A., Mathies, E., Meyer-Burgdorff, K.H., Rosenow, H. & Guenther, K.D. 1996. Apparent digestibilities and growth experiments with tilapia (*Oreochromis niloticus*) fed soybean meal, cottonseed meal and sunflower seed meal. *Journal of Applied Ichthyology/Zeitschrift fur angewandte Ichthyologie*, 12(2): 125–130.
- Sissener, N.H., Sanden, M., Bakke, A.M., Krogdahl, A. & Hemre, G.I. 2009. A long term trial with Atlantic salmon (*Salmo salar* L.) fed genetically modified soy; focusing general health and performance before, during and after the parr–smolt transformation. *Aquaculture*, 294: 108–117.
- Sitja-Bobadilla, A., Pena-Llopis, S., Gomez-Requeni, P., Medale, F., Kaushik, S. & Perez-Sanchez, J. 2005. Effect of fish meal replacement by plant protein sources on non-specific defence mechanisms and oxidative stress in gilthead sea bream (*Sparus aurata*). *Aquaculture*, 249(1–4):387–400.

- Skrede, A., Berge, G.M., Storebakken, T., Herstad, O., Aarstad, K.G. & Sundstøl, F. 1998. Digestibility of bacterial protein grown on natural gas in mink, pigs, chicken and Atlantic salmon. *Anim. Feed Sci. Technol.* 76: 103–116.
- Skrede, G., Storebakken, T., Skrede, A., Sahlstrom, S., Sorensen, M., Shearer, K.D. & Slinde, E. 2002. Lactic acid fermentation of wheat and barley whole meal flours improves digestibility of nutrients and energy in Atlantic salmon (*Salmo salar* L.) diets. *Aquaculture*, 210(1–4): 305–321.
- Slawski, H., Schulz, C. & Ogunji, J.O. 2008. Evaluation of housefly maggot meal as an alternative protein source in the diet of *Oreochromis niloticus*. *World Aquaculture*, 39(2): 16–18.
- Sloth, J.J., Julshamn, K. & Lundebye, A.K. 2005. Total arsenic and inorganic arsenic content in Norwegian fish feed products. *Aquaculture Nutrition*, 11(1): 61–66.
- Small, B.C., Austic, R. & Soares, J.H. 1999. Amino acid availability of four practical feed ingredients fed to Striped bass *Morone saxatilis*. *Journal of the World Aquaculture Society*, 30(1): 58–64.
- Smiley, S., Babbitt, J., Divakaran, S., Forster, I. & De Oliveira, A. 2003. *Analysis of groundfish meals made in Alaska*, pp. 431–454. In: P.J. Bechtel (ed.), *Advances in Seafood Byproducts: 2002 Conference Proceedings*. Alaska Sea Grant College Program, University of Alaska Fairbanks, Fairbanks, USA. 566 pp.
- Smith, D.M., Williams, K.C. & Irvin, S.J. 2005a. Response of the tropical spiny lobster *Panulirus ornatus* to protein content of pelleted feed and to a diet of mussel flesh. *Aquaculture Nutrition*, 11(3): 209–217.
- Smith, D.M., Tabrett, S.J., Barclay, M.C. & Irvin, S.J. 2005b. The efficacy of ingredients included in shrimp feeds to stimulate intake. *Aquaculture Nutrition*, 11(4): 263–272.
- Smith, D.M., Tabrett, S.J. & Glencross, B.D. 2007a. Growth response of the black tiger shrimp, *Penaeus monodon* fed diets containing different lupin cultivars. *Aquaculture*, 269: 436–446.
- Smith, D.M., Tabrett, S.J., Glencross, B.D., Irvin, S.J. & Barclay, M.C. 2007b. Digestibility of lupin kernel meals in feeds for the black tiger shrimp, *Penaeus monodon*. *Aquaculture*, 264(1–4): 353–362.
- Smith, M.A., Hubert, W.A. & Barrows, F.T. 2004. Failure of a plant-and-krill-based diet to affect the performance of Yellowstone Cutthroat trout broodfish. *North American Journal of Aquaculture*, 66(1): 61–69.
- Smith, T.K. 2008. The significance of feed-borne mycotoxins in *Aquaculture*, 13–19 pp. In: L.E. Cruz-Suarez, D. Ricque-Mari, M. Tapia-Salazar, M.G. Nieto López, D.A. Villarreal Cavazos, J.P. Lazo Corvea y M.T. Viana (eds), *Avances en Nutrición Acuicola IX*. Memorias del Noveno Simposium Internacional de Nutrición Acuicola. 24–26 November 2008. Ensenada, Baja California, México. ISBN-978-607-433-021-2. Universidad Autónoma de Nuevo León. Monterrey, N.L. México.
- Soares, C.M., Hayashi, C., de Faria, A. & Furuya, W.M. 2001. Replacement of soybean meal protein by canola meal protein in diets for Nile tilapia (*Oreochromis niloticus*) in the growing phase. *Revista Brasileira de Zootecnia-Brazilian Journal of Animal Science*, 30 (4): 1172–1177.
- Sogbesan, A.O. & Ugwumba, A.A.A. 2008. Nutritive values of some non-conventional animal protein feedstuffs used as fishmeal supplement in aquaculture in Nigeria. *Turkish Journal of Fisheries and Aquatic Science*, 8: 159–164.
- Sogbesan, A.O. & Madu, C.T. 2008. Evaluation of earthworm (*Hyperiodrilus euryalos*, Clausen, 1914; Oligochaeta: Eudrilidae) meal as protein feedstuff in diet for *Heterobranchus longifilis* Valenciennes, 1840 (Teleostei, Clariidae) fingerlings under laboratory condition. *Research Journal of Environmental Sciences*, 2(1): 23–31.
- Sogbesan, A.O. & Ugwumba, A.A.A. 2008. Nutritional evaluation of termite (*Macrotermes subhyalinus*) meal as animal protein supplements in the diets of *Heterobranchus longifilis* (Valenciennes, 1840) fingerlings. *Turkish Journal of Fisheries and Aquatic Sciences*, 8(1): 149–157.
- Sogbesan, O.A., Ugwumba, A.A.A. & Madu, C.T. 2006. Nutritive potentials and utilization of garden snail (*Limicolaria aurora*) meat meal in the diet of *Clarias gariepinus* fingerlings. *African Journal of Biotechnology*, 5(20): 1999–2003.
- Sogbesan, A.O., Ugwumba, A.A.A. & Madu, C.T. 2007. Productivity potentials and nutritional values of semi-arid zone earthworm (*Hyperiodrilus euryalos*; Clausen, 1967) cultured in organic wastes as fish meal supplement. *Pakistan Journal of Biological Sciences*, 10(2): 409–414.
- Sola, C. & Tongiorgi, P. 1998. Behavioural responses of glass eels of *Anguilla anguilla* to non-protein amino acids. *Journal of Fish Biology*, 53(6): 1253–1262.
- Solberg, C. 2004. Influence of dietary oil content on the growth and chemical composition of Atlantic salmon (*Salmo salar*). *Aquaculture Nutrition*, 10(1): 31–37.
- Soliman, A.K. 2000. Water hyacinth protein concentrate meal as a partial fish meal replacer in red tilapia diets, pp. 221–226. In: K. Fitzsimmons and J.C. Filho (eds), *Tilapia Aquaculture in the 21st Century*.
- Soltan, M.A. 2002. Using of tomato and potato by-products as non-conventional ingredients in Nile tilapia, *Oreochromis niloticus* diets. *Annals of Agricultural Science, Moshtohor*, 40(4): 2081–2096.
- Song, X.J., Zhang, X.C., Guo, N., Zhu, L.Y. & Kuang, C.H. 2007. Assessment of marine thraustochytrid *Schizochytrium limacinum* OUC88 for mariculture by enriched feeds. *Fisheries Science*, 73(3): 565–573.
- Sorensen, A. & Denstadli, V. 2008. Alkaline preserved herring by-products in feed for Atlantic salmon (*Salmo salar* L.). *Animal Feed Science and Technology*, 144(3–4): 327–334.
- Sorensen, M., Stjepanovic, N., Romarheim, O.H., Krekling, T. & Storebakken, T. 2009. Soybean meal improves the physical quality of extruded fish feed. *Animal Feed Science and Technology*, 149(1–2): 149–161.
- Stafford, E.A. & Tacon, A.G.J. 1988. The use of earthworms as a food for rainbow trout *Salmo gairdneri*, pp. 193–208. In: C.A. Edwards and E.F. Neuhauser (eds), *Earthworms in Waste and Environmental Management*. The Hague, Netherlands, SPB Academic Publishing.

- Steffens, W., Wirth, M. & Rennert, B. 1995. Effects of adding various oils to the diet on growth, feed conversion and chemical composition of carp (*Cyprinus carpio*). *Archives of Animal Nutrition*, 47: 381–389.
- St-Hilaire, S., Sheppard, C., Tomberlin, J.K., Irving, S., Newton, L., McGuire, M.A., Mosley, E.E., Hardy, R.W. & Sealey, W. 2007. Fly prepupae as a feedstuff for rainbow trout, *Oncorhynchus mykiss*. *Journal of the World Aquaculture Society*, 38(1): 59–67.
- Stickney, R.R., Hardy, R.W., Koch, K., Harrold, R., Seawright, D. & Masee, K.C. 1996. The effects of substituting selected oilseed protein concentrates for fish meal in rainbow trout *Oncorhynchus mykiss* diets. *Journal of the World Aquaculture Society*, 27(1): 57–63.
- Stolker, A.A.M., Zuidema, T. & Mielen, M.W.F. 2007. Residue analysis of veterinary drugs and growth-promoting agents. *Trends in Analytical Chemistry*, 26(10): 967–979.
- Stone, D.A.J., Allan, G.L., Parkinson, S. & Rowland, S.J. 2000. Replacement of fish meal in diets for Australian silver perch, *Bidyanus bidyanus* III. Digestibility and growth using meat meal products. *Aquaculture*, 186(3–4): 311–326.
- Stone, D.A.J., Hardy, R.W., Barrows, F.T. & Cheng, Z.J. 2005. Effects of extrusion on nutritional value of diets containing corn gluten meal and corn distiller's dried grain for Rainbow trout, *Oncorhynchus mykiss*. *Journal of Applied Aquaculture*, 17(3): 1–20.
- Storebakken, T., Kvien, I.S., Shearer, K.D., Grisdale-Helland, B., Helland, S.J. & Berge, G.M. 1998a. The apparent digestibility of diets containing fish meal, soybean meal or bacterial meal fed to Atlantic salmon (*Salmo salar*): evaluation of different faecal collection methods. *Aquaculture*, 169(3–4): 195–210.
- Storebakken, T., Shearer, K.D. & Roem, A.J. 1998b. Availability of protein, phosphorus and other elements in fish meal, soy-protein concentrate and phytase-treated soy-protein-concentrate-based diets to Atlantic salmon, *Salmo salar*. *Aquaculture*, 161(1–4): 363–377.
- Storebakken, T., Shearer, D. & Roem, A.J. 2000. Growth, uptake and retention of nitrogen and phosphorus, and absorption of other minerals in Atlantic salmon *Salmo salar* fed diets with fish meal and soy-protein concentrate as the main sources of protein. *Aquaculture Nutrition*, 6(2): 103–108.
- Storebakken, T., Shearer, K.D., Baevefjord, G., Nielsen, B.G., Asgard, T., Scott, T. & De Laporte, A. 2000b. Digestibility of macronutrients, energy and amino acids, absorption of elements and absence of intestinal enteritis in Atlantic salmon, *Salmo salar*, fed diets with wheat gluten. *Aquaculture*, 184(1–2): 115–132.
- Storebakken, T., Baevefjord, G., Skrede, A., Olli, J.J. & Berge, G.M. 2004. Bacterial protein grown on natural gas in diets for Atlantic salmon, *Salmo salar*, in freshwater. *Aquaculture*, 241: 413–425.
- Storebakken, T., Sørensen, M., Bjerkeng, B., Harris, J., Monahan, P. & Hiu, S. 2004b. Stability of astaxanthin from red yeast, *Xanthophyllomyces dendrorhous*, during feed processing: effects of enzymatic cell wall disruption and extrusion temperature. *Aquaculture*, 231: 489–500.
- Stubhaug, I., Frøyland, L. & Torstensen, B.E. 2005. Beta-oxidation capacity of red and white muscle and liver in Atlantic salmon (*Salmo salar* L.) – effects of increasing dietary rapeseed oil and olive oil to replace capelin oil. *Lipids*, 40: 39–47.
- Stubhaug, I., Lie, Ø. & Torstensen, B.E. 2006. Beta-oxidation capacity in liver increases during parr-smolt transformation of Atlantic salmon (*Salmo salar* L.) fed vegetable and fish oil. *Journal of Fish Biology*, 69: 504–517.
- Stubhaug, I., Lie, Ø. & Torstensen, B.E. 2007. Fatty acid productive value and beta-oxidation capacity in Atlantic salmon tissues (*Salmo salar* L.) fed on different lipid sources along the whole growth period. *Aquaculture Nutrition*, 13: 145–155.
- Subasinghe, R.P., Barg, U. & Tacon, A.G.J. 2000. Chemicals in Asian aquaculture: need, usage, issues and challenges. In: J.R. Arthur, C.R. Lavilla-Pitog and R.P. Subasinghe (eds), *Use of Chemicals in Aquaculture in Asia. Proceedings of the Meeting on the Use of Chemicals in Aquaculture in Asia*, 20–22 May 1996, Tigbauan, Iloilo, Philippines. Tigbauan, Iloilo, Philippines, Southeast Asian Fisheries Development Center (SEAFDEC).
- Subhadra, B., Lochmann, R., Rawles, S. & Chen, R.G. 2006. Effect of fish-meal replacement with poultry by-product meal on the growth, tissue composition and hematological parameters of largemouth bass (*Micropterus salmoides*) fed diets containing different lipids. *Aquaculture*, 260(1–4): 221–231.
- Subhadra, B., Lochmann, R., Rawles, S. & Chen, R. 2006b. Effect of dietary lipid source on the growth, tissue composition and hematological parameters of largemouth bass (*Micropterus salmoides*). *Aquaculture*, 255: 210–220.
- Sudagar, M., Azari Takami, G., Panomarev, C.A., Mahmoudzadeh, H., Abedian, A. & Hosseini, S.A. 2005. The effects of different dietary levels of betaine and methionine as attractants on the growth factors and survival rate of juvenile beluga (*Huso huso*). *Iranian Journal of Fisheries Sciences*, 14(2): 41–50. (in Farsi)
- Sudaryono, A., Hoxey, M.J., Kailis, S.G. & Evans, L.H. 1995. Investigation of alternative protein sources in practical diets for juvenile shrimp, *Penaeus monodon*. *Aquaculture*, 134(3–4): 313–323.
- Sudaryono, A., Tsvetnenko, E. & Evans, L.H. 1996. Digestibility studies on fisheries by-product based diets for *Penaeus monodon*. *Aquaculture*, 143(3–4): 331–340.
- Sudaryono, A., Tsvetnenko, E. & Evans, L.H. 1999a. Replacement of soybean meal by lupin meal in practical diets for juvenile *Penaeus monodon*. *Journal of the World Aquaculture Society*, 30(1): 46–57.
- Sudaryono A., Tsvetnenko E. & Evans L.H. 1999b. Evaluation of potential of lupin meal as an alternative to fish meal in juvenile *Penaeus monodon* diets. *Aquaculture Nutrition*, 5(4): 277 – 285

- Sudaryono A., Tsvetnenko E., Hutabarat J., Supriharyono & L. H. Evans. 1999c. Lupin ingredients in shrimp *Penaeus monodon* diets: influence of lupin species and types of meals. *Aquaculture*, 171:121–133
- Sughra, F., Ahmed, I., Kanwal, S. & Ateeq, U. 2003. Effect of different levels of cow dung on growth performance of major carps. *International Journal of Agriculture & Biology*, 5:194–195.
- Sugiura, S.H., Dong, F.M., Rathbone, C.K. & Hardy, R.W. 1998. Apparent protein digestibility and mineral availabilities in various feed ingredients for salmonid feeds. *Aquaculture*, 159(3–4): 177–202.
- Sugiura, S.H., Babbitt, J.K., Dong, F.M. & Hardy, R.W. 2000. Utilization of fish and animal by-product meals in low-pollution feeds for rainbow trout *Oncorhynchus mykiss* (Walbaum). *Aquaculture Research*, 31(7): 585–593.
- Sugiura S.H., Gabaudan J., Dong F.M. & Hardy R.W. 2001. Dietary microbial phytase supplementation and the utilization of phosphorus, trace minerals and protein by rainbow trout [*Oncorhynchus mykiss* (Walbaum)] fed soybean meal-based diets. *Aquaculture Research*, 32: 583–592.
- Sui, L.Y., Wu, X.G., Wille, M., Cheng, Y.X. & Sorgeloos, P. 2009. Effect of dietary soybean lecithin on reproductive performance of Chinese mitten crab *Eriocheir sinensis* (H. Milne-Edwards) broodstock. *Aquaculture International*, 17(1): 45–56.
- Sullivan, J.A. & Reigh, R.C. 1995. Apparent digestibility of selected feedstuffs in diets for hybrid striped bass (*Morone saxatilis* female X *Morone chrysops* male). *Aquaculture*, 138(1–4): 313–322.
- Sumagaysay-Chavoso, N.S. 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in the Philippines, pp. 269–308. In: M.R. Hasan, T. Hecht, S.S. De Silva and A.G.J. Tacon (eds), Study and analysis of feeds and fertilizers for sustainable aquaculture development. *FAO Fisheries Technical Paper* No. 497. Rome. 510 pp.
- Sun, M., Kim, Y.C., Okorie, O.E., Devnath, S., Yoo, G., Lee, S., Jo, Y.K. & Bai, S.C. 2007. Use of fermented fisheries by-products and soybean curd residues mixture as a fish meal replacer in diets of juvenile olive flounder, *Paralichthys olivaceus*. *Journal of the World Aquaculture Society*, 38(4): 543–549.
- Suontama, J., Kiessling, A., Melle, W., Waagbo, R. & Olsen, R.E. 2007. Protein from Northern krill (*Thysanoessa inermis*), Antarctic krill (*Euphausia superba*) and the Arctic amphipod (*Themisto libellula*) can partially replace fish meal in diets to Atlantic salmon (*Salmo salar*) without affecting product quality. *Aquaculture Nutrition*, 13(1): 50–58.
- Suontama, J., Karlsen, O., Moren, M., Hemre, G. I., Melle, W., Langmyhr, E., Mundheim, H., Ringo, E. & Olsen, R. E. 2007b. Growth, feed conversion and chemical composition of Atlantic salmon (*Salmo salar* L.) and Atlantic halibut (*Hippoglossus hippoglossus* L.) fed diets supplemented with krill or amphipods. *Aquaculture Nutrition*, 13(4): 241–255.
- Supamattaya, K., Kiriratnikom, S. Boonyaratpalin M. & Borowitzka, L. 2005. Effect of a *Dunaliella* extract on growth performance, health condition, immune response and disease resistance in black tiger shrimp (*Penaeus monodon*). *Aquaculture*, 248(1–4): 207–216
- Suppadit, T., Jaturasitha, S. & Pripwai, N. 2006. Utilization of hydrated sodium calcium aluminosilicate and vermiculite for aflatoxin B-1 adsorption in pacific white shrimp (*Litopenaeus vannamei*) diets. *Journal of Applied Animal Research*, 29(2): 129–132.
- Suprayudi, M.A., Takeuchi, T., Mokoginta, I. & Kartikasari, A.T. 2000. The effect of additional arginine in the high defatted soybean meal diet on the growth of giant gouramy *Osphronemus gouramy* Lac. *Fisheries Science*, 66(5): 807–811.
- Suresh, V.A. 2007. Development of the aquafeed industry in India, pp. 221–243. In: M.R. Hasan, T. Hecht, S.S. De Silva and A.G.J. Tacon (eds), Study and analysis of feeds and fertilizers for sustainable aquaculture development. *FAO Fisheries Technical Paper* No. 497. Rome. 510 pp.
- Sveier, H., Wathne, E. & Lied, E. 1999. Growth, feed and nutrient utilisation and gastrointestinal evacuation time in Atlantic salmon (*Salmo salar* L.): the effect of dietary fish meal particle size and protein concentration. *Aquaculture*, 180(3–4): 265–282.
- Sveier, H., Nordas, H., Berge, G. E. & Lied, E. 2001. Dietary inclusion of crystalline D- and L-methionine: effects on growth, feed and protein utilization, and digestibility in small and large Atlantic salmon (*Salmon salar* L.). *Aquaculture Nutrition*, 7(3): 169–181.
- Swick, R.A. 2002. Soybean meal quality: assessing the characteristics of a major aquatic feed ingredient. *The Global Aquaculture Advocate*, April 2002, pp.46–49.
- 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, Project GCP/RLA/075/ITA Field Document No. 5, Brasilia, Brazil. 129 pp.
- Tacon, A.G.J. 1992. *Nutritional fish pathology: morphological signs of nutrient deficiency and toxicity in farmed fish*. FAO Fisheries Technical Paper No.330. Rome. 75 pp.
- Tacon, A.G.J. 1993a. *Feed ingredients for warmwater fish: Fish meal and other processed feedstuffs*. FAO Fisheries Circular No. 856. Rome. 64 pp.
- Tacon, A.G.J. 1993b. *Feed ingredients for crustaceans: Natural foods and processed feedstuffs*. FAO Fisheries Circular No. 866. Rome. 67 pp.
- Tacon, A.G.J. 1994. *Feed ingredients for carnivorous fish species : alternatives to fishmeal and other fishery resources*. FAO Fisheries Circular No. 881. Rome. 35 pp.
- Tacon, A.G.J. 1995. Application of nutrient requirement data under practical conditions: special problems of intensive and semi-intensive fish farming systems. *Journal of Applied Ichthyology*, 11: 205–214.
- Tacon, A.G.J. 1996. Nutritional studies in crustaceans and the problems of applying research findings to practical farming systems. *Aquaculture Nutrition*, 1: 165–174.

- Tacon, A.G.J. 1997. Fishmeal replacers: Review of antinutrients within oilseeds and pulses – A limiting factor for the aquafeed Green Revolution?, pp.1022–1379. In: A.G.J. Tacon and T.B. Basurco (eds), *Feeding tomorrow's fish*. Proceedings of the Workshop of the CIHEAM Network on Technology of Aquaculture in the Mediterranean (TECAM), Mazarron (Spain), 24–26 June 1996. Zaragoza, Spain, Cahiers Options Mediterraneeennes.
- Tacon, A.G.J. & Metian, M. 2008a. Global overview on the use of fish meal and fish oil in industrially compounded aquafeeds: Trends and future prospects. *Aquaculture*, 285(1–4): 146–158.
- Tacon, A.G.J. & Metian, M. 2008b. Aquaculture feed and food safety: the role of FAO and Codex Alimentarius. *New York Academy of Sciences*, 1140: 50–59.
- Tacon, A.G.J., Hasan, M.R. & Subasinghe, R.P. 2006. *Use of fishery resources as feed inputs for aquaculture development: trends and policy implications*. FAO Fisheries Circular No. 1018. Rome. 99 pp.
- Tacon, A.G.J., Cody, J.J., Conquest, L.D., Divakaran, S., Forster, I.P. & Decamp, O.E. 2002. Effect of culture system on the nutrition and growth performance of Pacific white shrimp *Litopenaeus vannamei* (Boone) fed different diets. *Aquaculture Nutrition*, 8(2): 121–139.
- Takagi, S. 2003. Development of diets for red sea bream *Pagrus major* employing lesser amounts of fish meal. *Bulletin of the Ehime Prefectural Fisheries Experimental Station*, 11: 1–125.
- Takagi, S., Hosokawa, H., Shimeno, S. & Ukawa, M. 2000a. Utilization of poultry by-product meal in a diet for red sea bream *Pagrus major*. *Nippon Suisan Gakkaishi*, 66(3): 428–438.
- Takagi, S., Hosokawa, H., Shimeno, S. & Ukawa, M. 2000b. Utilization of corn gluten meal in a diet for red sea bream *Pagrus major*. *Nippon Suisan Gakkaishi*, 66(3): 417–427.
- Takagi, S., Shimeno, S., Hosokawa, H. & Ukawa, M. 2001. Effect of lysine and methionine supplementation to a soy protein concentrate diet for red sea bream *Pagrus major*. *Fisheries Science*, 67(6): 1088–1096.
- Takagi, S., Murata, H., Goto, T., Hayashi, M., Hatate, H., Endo, M., Yamashita, H. & Ukawa, M. 2006. Hemolytic suppression roles of taurine in yellowtail *Seriola quinqueradiata* fed non-fishmeal diet based on soybean protein. *Fisheries Science*, 72(3): 546–555.
- Takeuchi, T., Lu, J., Yoshizaki, G. & Satoh, S. 2002. Effect on the growth and body composition of juvenile tilapia *Oreochromis niloticus* fed raw Spirulina. *Fisheries Science*, 68(1): 34–40.
- Takii, K., Ukawa, M., Nakamura, M. & Kumai, H. 1995. Suitable lipid-level in brown fish-meal diet for Tiger puffer. *Fisheries Science*, 61(5): 841–844.
- Takii, K., Kita, E., Nakamura, M., Kumai, H. & Yagi, T. 1999. Evaluation of rapeseed protein concentration as protein source of diet for red sea bream. *Fisheries Science*, 65(1): 150–154.
- Tan, B. & Mai, K. 2001. Zinc methionine and zinc sulfate as sources of dietary zinc for juvenile abalone, *Haliotis discus hannai* Ino. *Aquaculture*, 192(1): 67–84.
- Tan, B. & Yu, Y. 2003. *Digestibility of fishmeal, meat and bone meal, and poultry byproduct meal (pet food grade) by Whiteleg shrimp Litopenaeus vannamei*. Research Report No. 13, Asia Region. Virginia, USA, National Renderers Association Inc.
- Tan, B., Mai, K., Zheng, S., Zhou, Q., Liu, L. & Yu, Y. 2005. Replacement of fish meal by meat and bone meal in practical diets for the white shrimp *Litopenaeus vannamei* (Boone) *Aquaculture Research*. 36, 5: 439–444.
- Tantikitti, C., Sangpong, W. & Chiavareesajja, S. 2005. Effects of defatted soybean protein levels on growth performance and nitrogen and phosphorus excretion in Asian seabass (*Lates calcarifer*). *Aquaculture*, 248(1–4): 41–50.
- Tapia-Salazar, M., Cruz-Suarez, L. E., Ricque-Marie, D., Pike, I.H., Smith, T.K., Harris, A., Nygard, E. & Opstvedt, J. 2004. Effect of fishmeal made from stale versus fresh herring and of added crystalline biogenic amines on growth and survival of blue shrimp *Litopenaeus stylirostris* fed practical diets. *Aquaculture*, 242(1–4): 437–453.
- Taylor, M.H. & Tsvetnenko, E. 2004. Growth assessment of juvenile abalone *Haliotis laevigata* fed enriched macroalgae *Ulva rigida*. *Aquaculture International*, 12(4–5): 467–480.
- Tejera, N., Cejas, J.R., Rodriguez, C., Bjerkgeng, B., Jerez, S., Bolanos, A. & Lorenzo, A. 2007. Pigmentation, carotenoids, lipid peroxides and lipid composition of skin of red porgy (*Pagrus pagrus*) fed diets supplemented with different astaxanthin sources. *Aquaculture*, 270(1–4): 218–230.
- Terrazas, W.D.M., Pereira-Filho, M. & de Oliveira-Pereira, M.I. 2002. Effect of different levels of fish meal and chicken by-product meal in the weight gain and body composition of tambaqui (*Colossoma macropomum*). *Acta Amazonica*, 32(1): 155–162.
- Teruel, M.B. 2002. Evaluation of feedstuffs and aquafeeds, pp.149–168. In: O.M. Millamena, R.M. Coloso and F.P. Pascual (eds), *Nutrition in Tropical Aquaculture*. Tigbauan, Iloilo, Philippines, Aquaculture Department, Southeast Asian Fisheries Development Center. 221 pp.
- Teskeredzic, Z., Higgs, D.A., Dosanjh, B.S., McBride, J.R., Hardy, R.W., Beames, R.M., Jones, J.D., Simell, M., Vaara, T. & Bridges, R.B. 1995. Assessment of undehydrated and dehydrated rapeseed protein concentrate as sources of dietary protein for juvenile rainbow trout (*Oncorhynchus mykiss*). *Aquaculture*, 131(3–4): 261–277.
- Thiessen, D.L. 2004. Optimization of feed peas, canola and flaxseed for aquafeeds: the Canadian Prairie perspective, pp. 259–277. In: L.E. Cruz-Suarez, D. Ricque-Mari, M.G. Nieto Lopez, D. Villarreal, U. Scholz and M. y Gonzalez (eds), *Avances en Nutricion Acuicola VII*. Memorias de VII Simposium Internacional de Nutricion Acuicola. 16–19 November 2004. Hermosillo, Sonora, Mexico.
- Thiessen, D.L., Campbell, G.L. & Tyler, R.T. 2003a. Utilization of thin distillers' solubles as a palatability enhancer in rainbow trout (*Oncorhynchus mykiss*) diets containing canola meal or air-classified pea protein. *Aquaculture Nutrition*, 9(1):1–10.

- Thiessen, D., Campbell, G. & Adelizi, P. 2003b. Digestibility and growth performance of juvenile rainbow trout (*Oncorhynchus mykiss*) fed with pea and canola products. *Aquaculture Nutrition*, 9(2): 67–75.
- Thiessen, D.L., Maenz, D.D., Newkirk, R.W., Classen, H.L. & Drew, M.D. 2004. Replacement of fishmeal by canola protein concentrate in diets fed to rainbow trout (*Oncorhynchus mykiss*). *Aquaculture Nutrition*, 10(6): 379–388.
- Thodesen, J. & Storebakken, T. 1998. Digestibility of diets with precooked rye or wheat by Atlantic salmon, *Salmo salar* L. *Aquaculture Nutrition*, 4(2): 123–126.
- Thompson, K.R., Muzinic, L.A., Christian, T.D., Webster, C.D., Manomaitis, L. & Rouse, D.B. 2003a. Lecithin requirements of juvenile Australian red claw crayfish *Cherax quadricarinatus*. *Aquaculture Nutrition*, 9(4): 223–230.
- Thompson, K.R., Muzinic, L.A., Christian, T.D., Webster, L. Manomaitis, L. & Rouse, D.B. 2003b. Effect on growth, survival, and fatty acid composition of Australian red claw crayfish *Cherax quadricarinatus* fed practical diets with and without supplemental lecithin and/or cholesterol. *Journal of the World Aquaculture Society*, 34(1): 1–10.
- Thompson, K.R., Muzinic, L.A., Engler, L.S. & Webster, C.D. 2005. Evaluation of practical diets containing different protein levels, with or without fish meal, for juvenile Australian red claw crayfish (*Cherax quadricarinatus*). *Aquaculture*, 244(1–4): 241–249.
- Thompson, K.R., Metts, L.S., Muzinic, L.A., Dasgupta, S. & Webster, C.D. 2006. Effects of feeding practical diets containing different protein levels, with or without fish meal, on growth, survival, body composition and processing traits of male and female Australian red claw crayfish (*Cherax quadricarinatus*) grown in ponds. *Aquaculture Nutrition*, 12(3): 227–238.
- Thompson, K.R., Metts, L.S., Muzinic, L.A., Dasgupta, S., Webster, C.D. & Brady, Y.J. 2007. Use of turkey meal as a replacement for menhaden fish meal in practical diets for sunshine bass grown in cages. *North American Journal of Aquaculture*, 69(4): 351–359.
- Thompson, K.R., Rawles, S.D., Metts, L.S., Smith, R., Wimsatt, A., Gannam, A.L., Twibell, R.G., Johnson, R.B., Brady, Y.J. & Webster, C.D. 2008. Digestibility of dry matter, protein, lipid, and organic matter of two fish meals, two poultry by-product meals, soybean meal, and distiller's dried grains with solubles in practical diets for sunshine bass, *Morone chrysops* x *M. saxatilis*. *Journal of the World Aquaculture Society*, 39(3): 352–363.
- Thongrod, S. & Boonyaratpulin, M. 1998. Cholesterol and lecithin requirement of juvenile banana shrimp, *Penaeus merguensis*. *Aquaculture*, 161: 315–321.
- Thongrod, S. 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in Thailand, pp. 309–330. In: M.R. Hasan, T. Hecht, S.S. De Silva and A.G.J. Tacon (eds), Study and analysis of feeds and fertilizers for sustainable aquaculture development. *FAO Fisheries Technical Paper No. 497*. Rome. 510 pp.
- Tiamiyu, L.O., Solomon, G.S., Sham, A.R., Enin, U.I., Chukwu, E.I., Ajah, P.O., Ama-Abasi, D.A. & Nwosu, F.M. 2007. Growth performance of *Clarias gariepinus* fingerlings fed cooked breadfruit (*Artocarpus altilis*) seed meal as replacement for maize in outdoor hapas. *Proceedings of the annual conference of Fisheries Society of Nigeria*. pp. 292–296. 2007.
- Tibaldi, E., Hakim, Y. Uni, Z., Tulli, F., de Francesco, M., Luzzana, U. & Harpaz, S. 2006. Effects of the partial substitution of dietary fish meal by differently processed soybean meals on growth performance, nutrient digestibility and activity of intestinal brush border enzymes in the European sea bass (*Dicentrarchus labrax*). *Aquaculture*, 261(1): 182–193.
- Tibbetts, S.M., Lall, S.P. & Milley, J.E. 2004. Apparent digestibility of common feed ingredients by juvenile haddock, *Melanogrammus aeglefinus* L. *Aquaculture Research*, 35(7): 643–651.
- Tibbetts, S.M., Milley, J.E. & Lall, S.P. 2006. Apparent protein and energy digestibility of common and alternative feed ingredients by Atlantic cod, *Gadus morhua* (Linnaeus, 1758). *Aquaculture* 261(4): 1314–1327.
- Tiril, S.U., Alagil, F., Yagci, F.B. & Aral, O. 2008. Effects of betaine supplementation in plant protein based diets on feed intake and growth performance in rainbow trout (*Oncorhynchus mykiss*). *Israeli Journal of Aquaculture – Bamidgeh*, 60(1): 57–64.
- Tocher, D.R., Bell, J.G., Dick, J.R., Henderson, R.J., McGhee, F., Michell, D. & Morris, C. 2000. Polyunsaturated fatty acid metabolism in Atlantic salmon (*Salmo salar*) undergoing parr–smolt transformation and the effects of dietary linseed and rapeseed oils. *Fish Physiology and Biochemistry*, 23: 59–73.
- Tocher, D.R., Bell, J.G., MacGlaughlin, P., McGhee, F. & Dick, J.R. 2001. Hepatocyte fatty acid desaturation and polyunsaturated fatty acid composition of liver in salmonids: effects of dietary vegetable oil. *Comparative Biochemistry and Physiology B-Biochemistry and Molecular Biology*, 130(2): 257–270.
- Tocher, D.R., Fonseca-Madrigal, J., Bell, J.G., Dick, J.R., Henderson, R.J. & Sargent, J.R. 2002. Effects of diets containing linseed oil on fatty acid desaturation and oxidation in hepatocytes and intestinal enterocytes in Atlantic salmon (*Salmo salar*). *Fish Physiology and Biochemistry*, 26: 157–170.
- Tocher, D.R., Bell, J.G., Dick, J.R. & Crampton, V.O. 2003a. Effects of dietary vegetable oil in Atlantic salmon hepatocyte fatty acid desaturation and liver fatty acid composition. *Lipids* 38:723–732.
- Tocher, D.R., Bell, J.G., McGhee, F., Dick, J.R., & Fonseca-Madrigal, J. 2003b. Effects of dietary lipid level and vegetable oil on fatty acid metabolism in Atlantic salmon (*Salmo salar* L.) over the whole production cycle. *Fish Physiology and Biochemistry*, 29(3): 193–209.

- Tocher, D.R., Fonseca-Madrigal, J., Dick, J.R., Ng, W.K., Bell, J.G. & Campbell, P.J. 2004. Effects of water temperature and diets containing palm oil on fatty acid desaturation and oxidation in hepatocytes and intestinal enterocytes of rainbow trout (*Oncorhynchus mykiss*). *Comparative Biochemistry and Physiology B-Biochemistry and Molecular Biology*, 137(1): 49–63.
- Todorovic, M., Kjaer, M.A., Djakovic, N., Vegusdal, A., Torstensen, B.E. & Ruyter, B. 2009. N-3 HUFAs affect fat deposition, susceptibility to oxidative stress, and apoptosis in Atlantic salmon visceral adipose tissue. *Comparative Biochemistry and Physiology B-Biochemistry and Molecular Biology*, 152(2): 135–143.
- Toko, I.I., Fiogbe, E.D. & Kestemont, P. 2008a. Growth, feed efficiency and body mineral composition of juvenile vundu catfish (*Heterobranchus longifilis*, Valenciennes 1840) in relation to various dietary levels of soybean or cottonseed meals. *Aquaculture Nutrition*, 14(3): 193–203.
- Toko, I.I., Fiogbe, E.D. & Kestemont, P. 2008b. Mineral status of African catfish (*Clarias gariepinus*) fed diets containing graded levels of soybean or cottonseed meals. *Aquaculture*, 275(1–4): 298–305.
- Toledo-Aguero, P. & Viana, M.T. 2009. Fatty acid composition of juvenile abalone (*Haliotis tuberculata coccinea*) fed formulated diets containing various n3 HUFA levels. *Ciencias Marinas*, 35(1): 101–112.
- Tomas, A., de la Gandara, F., Garcia-Gomez, A., Perez, L. & Jover, M. 2005. Utilization of soybean meal as an alternative protein source in the Mediterranean yellowtail, *Seriola dumerili*. *Aquaculture Nutrition*, 11(5): 333–340.
- Torstensen, B.E., Lie, Ø. & Frøyland, L. 2000. Lipid metabolism and tissue composition in Atlantic salmon (*Salmo salar* L.) – effects of capelin oil, palm oil, and oleic acid-enriched sunflower oil as dietary lipid sources. *Lipids*, 35: 653–664.
- Torstensen, B.E., Frøyland, L. & Lie, Ø. 2004a. Replacing dietary fish oil with increasing levels of rapeseed oil and olive oil – effects on Atlantic salmon (*Salmo salar* L.) tissue and lipoprotein composition and lipogenic enzyme activities. *Aquaculture Nutrition*, 10: 175–192.
- Torstensen, B.E., Frøyland, L., Ørnsrud, R. & Lie, Ø. 2004b. Tailoring of a cardioprotective muscle fatty acid composition of Atlantic salmon (*Salmo salar*) fed vegetable oils. *Food Chemistry*, 87: 567–580.
- Torstensen, B.E., Bell, J.G., Rosenlund, G., Henderson, R.J., Graff, I.E., Tocher, D.R., Lie, Ø. & Sargent, J.R. 2005. Tailoring of Atlantic salmon (*Salmo salar* L.) flesh lipid composition and sensory quality by replacing fish oil with a vegetable oil blend. *Journal of Agricultural Food Chemistry*, 53: 10 166–10 178.
- Torstensen, B.E., Espe, M., Sanden, M., Stubhaug, I., Waagbo, R., Hemre, G.I., Fontanillas, R., Nordgarden, U., Hevroy, E.M., Olsvik, P. & Berntssen, M.H.G. 2008. Novel production of Atlantic salmon (*Salmo salar*) protein based on combined replacement of fish meal and fish oil with plant meal and vegetable oil blends. *Aquaculture*, 285(1–4): 193–200.
- Tou, J.C., Jaczynski, J. and Chen, Y-C. 2007. Krill for human consumption: nutritional value and potential health benefits. *Nutrition Reviews*, 65(2): 63–77.
- Tovar, D., Zambonino, J., Cahu, C., Gatesoupe, F.J., Vazquez-Juarez, R. & Lesel, R. 2002. Effect of live yeast incorporation in compound diet on digestive enzyme activity in sea bass (*Dicentrarchus labrax*) larvae. *Aquaculture*, 204(1–2): 113–123.
- Trigo-Stockli, D.M., Obaldo, L.G., Gominy, W.G. & Behnke, K.C. 2000. Utilization of deoxynivalenol contaminated hard red winter wheat for shrimp feeds. *Journal of the World Aquaculture Society*. 31:247–254.
- Truong, P.H., Anderson, A.J., Mather, P.B., Peterson, B.D. & Richardson, N.A. 2009. Apparent digestibility of selected feed ingredients in diets formulated for the sub-adult mud crab, *Scylla paramamosain*, in Vietnam. *Aquaculture Research*, 40:322–328.
- Tuan, N.A., Grizzle, J.M., Lovell, R.T., Manning, B.B. & Rottinghaus, G.E. 2002. Growth and hepatic lesions of Nile tilapia (*Oreochromis niloticus*) fed diets containing aflatoxin B1. *Aquaculture*, 212: 311–319.
- Tuan, N.A., Manning, B.B., Lovell, R.T. & Rottinghaus, G.E. 2003. Responses of Nile tilapia (*Oreochromis niloticus*) fed diets containing different concentrations of moniliformin of fumonisin B1. *Aquaculture*, 217: 515–528.
- Tucker, J.W.J., Lellis, W.A., Vermeer, G.K., Roberts, D.E. & Woodward, P.N. 1997. The effects of experimental starter diets with different levels of soybean or menhaden oil on red drum (*Sciaenops ocellatus*). *Aquaculture*, 149: 323–339.
- Tudor, K.W., Rosati, R.R., O'Rourke, P.D., Wu, Y.V., Sessa, D. & Brown, P. 1996. Technical and economical feasibility of on-farm fish feed production using fishmeal analogs. *Aquacultural Engineering*, 15(1): 53–65.
- Turchini, G.M., Gunasekera, R.M. & De Silva, S.S. 2003a. Effect of crude oil extracts from trout offal as a replacement for fish oil in the diets of the Australian native fish Murray cod (*Maccullochella peelii peelii*). *Aquaculture Research*, 34: 697–708.
- Turchini, G.M., Mentasti, T., Frøyland, L., Orban, E., Caprino, F., Moretti, V.M. & Valfre, F. 2003b. Effects of alternative dietary lipid sources on performance, tissue chemical composition, mitochondrial fatty acid oxidation capabilities and sensory characteristics in brown trout (*Salmo trutta* L.). *Aquaculture*, 225: 251–267.
- Turchini, G.M., Gunasekera, R. & De Silva, S.S. 2003. Effect of crude oil extracts from trout offal as a replacement for fish oil in the diets of the Australian native fish Murray cod, *Maccullochella peelii peelii*. *Aquaculture Research*, 34: 697–708.
- Turchini, G.M., Mentasti, T., Caprino, F., Panseri, S., Moretti, V.M. & Valfre, F. 2004. Effects of dietary lipid sources on flavor volatile compounds of brown trout (*Salmo trutta* L.) fillet. *Journal of Applied Ichthyology*, 20: 71–75.

- Turchini, G.M., Mentasti, T., Caprino, F., Giani, I., Panseri, S., Bellagamba, F., Moretti, V.M. & Valfre, F. 2005. The relative absorption of fatty acids in brown trout (*Salmo trutta*) fed a commercial extruded pellet coated with different lipid sources. *Italian Journal of Animal Science*, 4(3): 241–252.
- Turchini, G.M., Francis, D.S. & De Silva, S.S. 2006. Modification of tissue fatty acid composition in Murray cod (*Maccullochella peelii peelii*, Mitchell) resulting from a shift from vegetable oil diets to a fish oil diet. *Aquaculture Research*, 37: 570–585.
- Turchini, G.M., Moretti, V.M., Mentasti, T., Orban, E. & Valfre, F. 2007. Effects of dietary lipid source on fillet chemical composition, flavour volatile compounds and sensory characteristics in the freshwater fish tench (*Tinca tinca* L.). *Food Chemistry*, 102: 1144–1155.
- Turchini, G.M., Torstensen, B.E. & Ng, W-K. 2009. Fish oil replacement in finfish nutrition. *Reviews in Aquaculture*, 1: 10–57.
- Turker, A., Yigit, M., Ergun, S., Karaali, B. & Erteken, A. 2005. Potential of poultry by-product meal as a substitute for fishmeal in diets for Black Sea turbot *Scophthalmus maeoticus*: Growth and nutrient utilization in winter. *Israeli Journal of Aquaculture – Bamidgeh*, 57(1): 49–61.
- Twibell, R.G., Watkins, B.A. & Brown, P.B. 2001. Dietary conjugated linoleic acids and lipid source alter fatty acid composition of juvenile yellow perch, *Perca flavescens*. *Journal of Nutrition*, 131(9): 2 322–2 328.
- Twibell, R.G. & Wilson, R.P. 2004. Preliminary evidence that cholesterol improves growth and feed intake of soybean meal-based diets in aquaria studies with juvenile channel catfish, *Ictalurus punctatus*. *Aquaculture*, 236(1–4): 539–546.
- Ulloa, J.B. & Verreth, J.A.J. 2002. Growth, feed utilization and nutrient digestibility in tilapia fingerlings (*Oreochromis aureus* Steindachner) fed diets containing bacteria-treated coffee pulp. *Aquaculture Research*, 33(3): 189–195.
- Uran, P.A., Aydin, R., Schrama, J.W., Verreth, J.A.J. & Rombout, J.H.W.M. 2008a. Soybean meal-induced uptake block in Atlantic salmon *Salmo salar* distal enterocytes. *Journal of Fish Biology*, 73(Suppl. 10): 2571–2579.
- Uran, P.A., Goncalves, A.A., Taverne-Thiele, J.J., Schrama, J.W., Verreth, J.A.J. & Rombout, J.H. W.M. 2008b. Soybean meal induces intestinal inflammation in common carp (*Cyprinus carpio* L.). *Fish and Shellfish Immunology*, 25(6): 751–760.
- Uran, P.A., Schrama, J.W., Rombout, J.H.W.M., Obach, A., Jensen, L., Koppe, W. & Verreth, J.A.J. 2008c. Soybean meal-induced enteritis in Atlantic salmon (*Salmo salar* L.) at different temperatures. *Aquaculture Nutrition*, 14(4): 324–330.
- Usmani, N., Jafri, A.K. & Alvi, A.S. 1997. Effect of feeding glanded cottonseed meal on the growth, conversion efficiency and carcass composition of *Labeo rohita* (Hamilton) fry. *Journal of Aquaculture in the Tropics*, 12(1): 73–78.
- Ustaoglu, S. & Rennert, B. 2002. The apparent nutrient digestibility of diets containing fish meal or isolated soy protein in sterlet (*Acipenser ruthenus*). *International Review of Hydrobiology, Special Issue*, 87(5–6): 577–584.
- Ustaoglu, S. & Rennert, B. 2006. Effects of partial replacement of fishmeal with isolated soy protein on digestibility and growth performance in sterlet (*Acipenser ruthenus*). *Israeli Journal of Aquaculture – Bamidgeh*, 58(3): 170–177.
- Uyan, O., Koshio, S., Teshima, S., Ishikawa, M., Thu, M., Alam, M.S. & Michael, F.R. 2006. Growth and phosphorus loading by partially replacing fishmeal with tuna muscle by-product powder in the diet of juvenile Japanese flounder, *Paralichthys olivaceus*. *Aquaculture*, 257(1–4): 437–445.
- Vacha, F., Vejsada, P., Huda, J. & Hartvich, P. 2007. Influence of supplemental cereal feeding on the content and structure of fatty acids during long-lasting storage of common carp (*Cyprinus carpio* L.). *Aquaculture International*, 15(3–4): 321–329.
- Vadstein, O. 1997. The use of immunostimulation in marine larviculture: possibilities and challenges. *Aquaculture*, 155(1): 401–417.
- Vail, T., Jones, P.R. & Sparkman, O.D.D. 2007. Rapid and unambiguous identification of melamine in contaminated pet food based on mass spectrometry with four degrees of confirmation. *Journal of Analytical Toxicology*, 31(6): 304–312.
- Valdenebro-Ruiz, J.O. & Munoz-Medina, J.J. 2003. Evaluation of shrimp (*Penaeus vannamei*) growing diets with different soybean meal protein levels. *Journal of Aquaculture in the Tropics*, 18(1): 91–96.
- Valentea, L.M.P., Gouveia, A., Remaa, P., Matosa, J., Gomesa, E.F. & Pintoa, I.S. 2006. Evaluation of three seaweeds *Gracilaria bursa-pastoris*, *Ulva rigida* and *Gracilaria cornea* as dietary ingredients in European sea bass (*Dicentrarchus labrax*) juveniles. *Aquaculture*, 252: 85–91.
- Van Barneveld, R.J., Fleming, A.E., Vendepeer, M.E., Kruk, J.A. & Hone, P.W. 1998. Influence of dietary oil type and oil inclusion level in manufactured feeds on the digestibility of nutrients by juvenile greenlip abalone (*Haliotis laevigata*). *Journal of Shellfish Research*, 17(3): 649–655.
- Van der Meer, M.B., Huisman, E. A. & Verdegem, M.C.J. 1996. Feed consumption, growth and protein utilization of *Colossoma macropomum* (Cuvier) at different dietary fish meal/soya meal ratios. *Aquaculture Research*, 27(7): 531–538.
- Van der Meer, M.B., Faber, R., Zamora, J.E. & Verdegem, M.C.J. 1997. Effect of feeding level on feed losses and feed utilization of soya and fish meal diets in *Colossoma macropomum* (Cuvier). *Aquaculture Research*, 28(6): 391–403.
- Van Weerd, J.H., Khalaf, K.A., Aartsen, F.J. & Tijssen, P.A.T. 1999. Balance trials with African catfish *Clarias gariepinus* fed phytase-treated soybean meal-based diets. *Aquaculture Nutrition*, 5(2): 135–142.

- Vargas, R.J., de Souza, S.M.G., Kessler, A.M. & Baggio, S.R. 2008. Replacement of fish oil with vegetable oils in diets for jundia (*Rhamdia quelen* Quoy and Gaimard 1824): effects on performance and whole body fatty acid composition. *Aquaculture Research*, 39(6): 657–665.
- Vassallo-Agius, R., Imaizumi, H., Watanabe T., Yamazaki T., Satoh S. & Kiron V. 2001a. Effect of squid meal in dry pellets on the spawning performance of striped jack *Pseudocaranx dentex*. *Fisheries Science*, 67(2): 271–280.
- Vassallo-Agius, R., Watanabe, T., Imaizumi, H., Yamazaki T., Satoh S. & Kiron V. 2001b. Effects of dry pellets containing astaxanthin and squid meal on the spawning performance of striped jack *Pseudocaranx dentex*. *Fisheries Science*, 67(4): 667–674.
- Vassallo-Agius, R., Watanabe, T., Imaizumi, H. & Yamazaki, T. 2002. Spawning performance of yellowtail *Seriola quinqueradiata* fed dry pellets containing paprika and squid meal. *Fisheries Science*, 68(1): 230–232.
- Vendruscolo, F., Ribeiro, C.D., Esposito, E. & Ninow, J.L. 2009. Protein enrichment of apple pomace and use in feed for Nile Tilapia. *Applied Biochemistry and Biotechnology*, 152(1): 74–87.
- Venou, B., Alexis, M.N., Fountoulaki, E. & Haralabous, J. 2006. Effects of extrusion and inclusion level of soybean meal on diet digestibility, performance and nutrient utilization of gilthead sea bream (*Sparus aurata*). *Aquaculture*, 261(1): 343–356.
- Verakunpiriya, V., Watanabe, K., Mushiaki, K., Kawano, K., Kobayashi, T., Hasegawa, I., Kiron, V., Satoh, S. & Watanabe, T. 1997. Effect of krill meal supplementation in soft-dry pellets on spawning and quality of egg of yellowtail. *Fisheries Science*, 63(3): 433–439.
- Verleyen, T. & Adams, C.A. 2005. Antioxidants, multifunctional nutraceuticals, influence aquafeed quality, fish health and food quality. *International Aquafeed*, 8(5): 14–19.
- Viana, M.T., Lopez, L.M., GarciaEsquivel, Z. & Mendez, E. 1996. The use of silage made from fish and abalone viscera as an ingredient in abalone feed. *Aquaculture*, 140(1–2): 87–98.
- Viana, M.T., Guzman, J.M. & Escobar, R. 1999. Effect of heated and unheated fish silage as a protein source in diets for abalone *Haliotis fulgens*. *Journal of the World Aquaculture Society*, 30(4): 481–489.
- Vidotti, R.M., Carneiro, D.J. & Viegas, E.M.M. 2002. Growth rate of Pacu, *Piaractus mesopotamicus*, fingerlings fed diets containing co-dried fish silage as replacement of fish meal. *Journal of Applied Aquaculture*, 12(4): 77–88.
- Viegas, E.M.M., Carneiro, D.J., Urbinati, E.C. & Malheiros, E.B. 2008. Canola meal in the diets of pacu *Piaractus mesopotamicus* (Holmberg 1887): effects on growth and body composition. *Arquivo Brasileiro de Medicina Veterinaria e Zootecnia*, 60(6): 1502–1510.
- Vielma, J. & Lall, S.P. 1997. Dietary formic acid enhances apparent digestibility of minerals in rainbow trout, *Oncorhynchus mykiss* (Walbaum). *Aquaculture Nutrition*, 3: 265–268.
- Vielma, J., Lall, S.P., Koskela, J., Schoner, F.J. & Mattila, P. 1998. Effects of dietary phytase and cholecalciferol on phosphorus bioavailability in rainbow trout (*Oncorhynchus mykiss*). *Aquaculture*, 163: 307–321.
- Vielma, J., Ruohonen, K. & Lall, S.P. 1999. Supplemental citric acid and particle size of fish bone-meal influence the availability of minerals in rainbow trout *Oncorhynchus mykiss* (Walbaum). *Aquaculture Nutrition*, 5(1): 65–71.
- Vielma, J., Makinen, T., Ekholm, P., Koskela, J. 2000. Influence of dietary soy and phytase levels on performance and body composition of large rainbow trout (*Oncorhynchus mykiss*) and algal availability of phosphorus load. *Aquaculture*, 183(3–4): 349–362.
- Vielma, J., Ruohonen, K. & Peisker, M. 2002. Dephytinization of two soy proteins increases phosphorus and protein utilization by rainbow trout, *Oncorhynchus mykiss*. *Aquaculture*, 204(1–2): 145–156.
- Vielma, J., Ruohonen, K., Gabaudan, J. & Vogel, K. 2004. Top-spraying soybean meal-based diets with phytase improves protein and mineral digestibilities but not lysine utilization in rainbow trout, *Oncorhynchus mykiss* (Walbaum). *Aquaculture Research*, 35(10): 955–964.
- Vijayan, K.K., Raj, V.S., Balasubramanian, C.P., Alavandi, S.V., Sekhar, V.T. & Santiago, T.C. 2005. Polychaete worms – a vector for white spot syndrome virus (WSSV). *Diseases of Aquatic Organisms*, 63(2–3): 107–111.
- Villarreal, H., Hernandez-Llamas, A., Rivera, M.C., Millan, A. & Rocha, S. 2004. Effect of substitution of shrimp meal, fish meal and soy meal with red crab *Pleuroncodes planipes* (Stimpson) meal in pelleted diets for postlarvae and juvenile *Farfantepenaeus californiensis* (Holmes). *Aquaculture Research*, 35(2): 178–183.
- Villarreal, H., Civera-Cerecedo, R. & Hernandez-Llamas, A. 2006. Effect of partial and total replacement of fish, shrimp head, and soybean meals with red crab meal *Pleuroncodes planipes* (Stimpson) on growth of white shrimp *Litopenaeus vannamei* (Boone). *Aquaculture Research*, 37(3): 293–298.
- Virtanen, E., Hole, R., Resink, J.W., Slinning, K.E. & Junnila, M. 1994. Betaine/amino acid additive enhances the seawater performance of rainbow trout (*Oncorhynchus mykiss*) fed standard fish-meal-based diets. *Aquaculture*, 124(1–4): 220.
- Viviani, R., Rossi, E., Nasi, G. & Serrazanetti, G.P. 1998. Use of protein concentrates of plant origin of domestic production in the feeding of sea bass (*Dicentrarchus labrax*) and sea bream (*Sparus aurata*) raised in intensive Italian farming systems. Proceedings: Investigations on Fisheries and Aquaculture within the Framework of Law Number 41/82. Part 3: Aquaculture, hygiene, economy. Rome, 15–16 December 1998. Atti 'Le Ricerche sulla Pesca e sull'Acquacoltura nell'ambito della L. 41/82'. Parte terza: Acquacoltura, igiene, economia. Roma, 15–16 Dicembre 1998. pp. 2169–2178. *Biologia Marina Mediterranea*, 5(3).

- Voss, K.A., Smith, G.W. & Haschek, W.M. 2007. Fumonisin: Toxicokinetics, mechanism of action and toxicity. *Animal Feed Science and Technology*, 137, 299–325.
- Wache, Y., Auffray, F., Gatesoupe, F.J., Zambonino, J., Gayet, V., Labbe, L. & Quentel C. 2006. Cross effects of the strain of dietary *Saccharomyces cerevisiae* and rearing conditions on the onset of intestinal microbiota and digestive enzymes in rainbow trout, *Onchorhynchus mykiss*, fry. *Aquaculture*, 258(1–4): 470–478.
- Wagner, G.N., Balfry, S.K., Higgs, D.A., Lall, S.P. & Farrell, A.P. 2004. Dietary fatty acid composition affects the repeat swimming performance of Atlantic salmon in seawater. *Comparative Biochemistry and Physiology a-Molecular and Integrative Physiology*, 137(3): 567–576.
- Walker, A.B., Fournier, H.R., Neffus, C.D., Nardi, G.C. & Berlinsky, D.L. 2009. Partial replacement of fish meal with Laver *Porphyra* spp. in diets for Atlantic cod. *North American Journal of Aquaculture*, 71(1): 39–45.
- Wang, G., Wu, R., Xie, J. & Yu, D. 2005. Partial replacement for fish meal with soybean meal in feed for Cobia (*Rachycentron canadum*). *Journal of Dalian Fisheries University/Dalian Shuichan Xueyuan Xuebao*, 20(4): 304–307.
- Wang, G., Leng, X., Li, X., Hu, B. & Wang, W. 2006. Effect of adding coated amino acid on growth and body composition of allogynogenetic crucian carp. *Journal of Shanghai Fisheries University/Shanghai Shuichan Daxue Xuebao*, 15(3): 365–369.
- Wang, J. & Lied, E. 2001. Two types of fish silage and its use in fish feed. *Marine Fisheries Research/Haiyang Shuichan Yanjiu. Qingdao*, 22(4): 80–86.
- Wang, J.T., Liu, Y.J., Tian, L.X., Mai, K.-S., Du, Z.Y., Wang, Y. & Yang, H.J. 2005. Effect of dietary lipid level on growth performance, lipid deposition, hepatic lipogenesis in juvenile cobia (*Rachycentron canadum*). *Aquaculture*, 249(1–4): 439–447.
- Wang, Q., Wang, J., Zhao, H. & Xie, Z. 2006. Nutrient analysis of the feed containing different levels of squid liver and their effects on growth of white legged-shrimp *Litopenaeus vannamei* juveniles. *Journal of Dalian Fisheries University/Dalian Shuichan Xueyuan Xuebao*, 21(3): 259–263
- Wang, Y., Guo, J.L., Bureau, D.P. & Cui, Z.H. 2006. Replacement of fish meal by rendered animal protein ingredients in feeds for cuneate drum (*Nibea mitchthioides*). *Aquaculture*, 252(2–4): 476–483.
- Wang, Y.J., Chien, Y.H. & Pan, C.H. 2006b. Effects of dietary supplementation of carotenoids on survival, growth, pigmentation, and antioxidant capacity of characins, *Hyphessobrycon callistus*. *Aquaculture*, 261(2): 641–648.
- Wang, Y., Li, K., Han, H., Zheng, Z.X. & Bureau, D.P. 2008. Potential of using a blend of rendered animal protein ingredients to replace fish meal in practical diets for malabar grouper (*Epinephelus malabricus*). *Aquaculture*, 281(1–4): 113–117.
- Wassef, E.A., El Masry, M.H. & Mikhail, F.R. 2001. Growth enhancement and muscle structure of striped mullet, *Mugil cephalus* L., fingerlings by feeding algal meal-based diets. *Aquaculture Research*, 32(1): 315–322.
- Wassef, E.A., Wahby, O.M. & Sakr, E.M. 2007. Effect of dietary vegetable oils on health and liver histology of gilthead seabream (*Sparus aurata*) growers. *Aquaculture Research*, 38: 852–861.
- Watanabe, T. 2002. Strategies for further development of aquatic feeds. *Fisheries Science*, 68: 242–252.
- Watanabe, T., Takeuchi, T., Satoh, S. & Kiron, V. 1996. Digestible crude protein contents in various feedstuffs determined with four freshwater fish species. *Fisheries Science* (Tokyo) 62(2): 278–282.
- Watanabe, T., Aoko, H., Shimamoto, K., Hadzuma, M., Maita, M., Yamagata, Y., Kiron, V. & Satoh, S. 1998. A trial to culture yellowtail with non-fishmeal diets. *Fisheries Science* (Tokyo) 64(4): 505–512.
- Watanabe, T., Aoki, H., Watanabe, K. & Maita, M. 2001. Quality evaluation of different types of non-fish meal diets for yellowtail. *Fisheries Science* (Tokyo) 67(3): 461–469.
- Wathne, E., Bjerkeng, B., Storebakken, T., Vassvik, V. & Odland, A.B. 1998. Pigmentation of Atlantic salmon (*Salmo salar*) fed astaxanthin in all meals or in alternating meals. *Aquaculture*, 159(3): 217–231.
- Whiteman, K.W. & Gatlin, D.M. 2005. Evaluation of fisheries by-catch and by-product meals in diets for red drum *Sciaenops ocellatus* L. *Aquaculture Research*, 36(16): 1572–1580.
- Webster, C.D., Goodgame-Tiu L.S. & Tidwell, J. H. 1995. Total replacement of fish meal by soy bean meal, with various percentages of supplemental L-methionine, in diets for blue catfish, *Ictalurus furcatus* (Lesueur). *Aquaculture Research*, 26(5): 299–306.
- Webster, C.D., Tiu, L.G., Tidwell, J.H. & Grizzle, J.M. 1997. Growth and body composition of channel catfish (*Ictalurus punctatus*) fed diets containing various percentages of canola meal. *Aquaculture*, 150(1–2): 103–112.
- Webster, C.D., Thompson, K.R., Morgan, A.M., Grisby, E.J. & Gannam, A.L. 2000. Use of hempseed meal, poultry by-product meal, and canola meal in practical diets without fish meal for sunshine bass (*Morone chrysops* x *M. saxatilis*). *Aquaculture*, 188(3–4): 299–309.
- Wei, S. & Yu, Y. 2003. Efectos del reemplazo parcial de la harina de pescado con harina de carne y hueso o harina de subproductos avícolas, pp.17–20. In: A. Tacon and R. Hardy (eds), *Reciclaje*, 15. Virginia, USA, National Renderers Association.
- Weimin, M. & Mengqing, L. 2007. *Analysis of feeds and fertilizers for sustainable aquaculture development in China*, pp. 141–190. In: M.R. Hasan, T. Hecht, S.S. De Silva and A.G.J Tacon (eds), *Study and analysis of feeds and fertilizers for sustainable aquaculture development*. FAO Fisheries Technical Paper No. 497. Rome. 510 pp.

- Weirich, C.R., O'Neal, C.C. & Belhadjali, K. 2005. Growth, body composition, and survival of channel catfish, *Ictalurus punctatus*, fry fed hatchery diets supplemented with krill meal. *Journal of Applied Aquaculture*, 17(3), 21–35.
- Welker, T.L. & Congleton, J.L. 2003. Relationship between dietary lipid source, oxidative stress, and the physiological response to stress in sub-yearling chinook salmon (*Oncorhynchus tshawytscha*). *Fish Physiology and Biochemistry*, 29(3): 225–235.
- Welker, T., Lim, C., Yildirim-Aksoy, M., Shelby, R. & Klesius, P. 2007. Immune response and resistance to stress and *Edwardsiella ictaluri* challenge in Channel catfish, *Ictalurus punctatus*, fed diets containing commercial whole-cell yeast or yeast subcomponents. *Journal of the World Aquaculture Society*, 38(1): 24–35.
- White, D.A., Moody, A.J., Serwata, R.D., Bowen, J., Soutar, C., Young, A.J. & Davies, S.J. 2003. The degree of carotenoid esterification influences the absorption of astaxanthin in rainbow trout, *Oncorhynchus mykiss* (Walbaum). *Aquaculture Nutrition*, 9(4): 247–251.
- Williams, K., Barlow, C. & Rodgers, L. 2001. Efficacy of crystalline and protein-bound amino acids for amino acid enrichment of diets for barramundi/Asian seabass (*Lates calcarifer* Bloch). *Aquaculture Research*, 32(s1): 415–429.
- Williams, K.C., Paterson, B.D., Barlow, C.G., Ford, A. & Roberts, R. 2003a. Potential of meat meal to replace fish meal in extruded dry diets for barramundi, *Lates calcarifer* (Bloch). II. Organoleptic characteristics and fatty acid composition. *Aquaculture Research*, 34(1): 33–42.
- Williams, K.C., Paterson, B.D., Barlow, C.G., Ford, A. & Roberts, R. 2003b. Potential of meat meal to replace fish meal in extruded dry diets for barramundi, *Lates calcarifer* (Bloch). I. Growth performance. *Aquaculture Research*, 34(1): 23–32.
- Williams, K.C., Smith, D.M., Barclaya, M.C., Tabretta, S.J. & Riding, G. 2005. Evidence of a growth factor in some crustacean-based feed ingredients in diets for the giant tiger shrimp *Penaeus monodon*. *Aquaculture*, 250: 377–390.
- Wilson, C.M., Friesen, E.N., Higgs, D.A. & Farrell, A.P. 2007. The effect of dietary lipid and protein source on the swimming performance, recovery ability and oxygen consumption of Atlantic salmon (*Salmo salar*). *Aquaculture*, 273(4): 687–699.
- Winberg, S., Oeverli, O. & Lepage, O. 2001. Suppression of aggression in rainbow trout (*Oncorhynchus mykiss*) by dietary L-tryptophan. *Journal of Experimental Biology*, 204(22): 3867–3876.
- Wonnacott, E.J., Lane, R.L. & Kohler, C.C. 2004. Influence of dietary replacement of menhaden oil with canola oil on fatty acid composition of sunshine bass. *North American Journal of Aquaculture* 66: 243–250.
- Woolford, M. 2004. Antioxidants. *Aqua Feeds: Formulation and Beyond*, 1(1): 13–15.
- Wouters R., Zambrano B., Espin M., Calderon J., Lavens P. & Sorgeloos, P. 2002. Experimental broodstock diets as partial fresh food substitutes in white shrimp *Litopenaeus vannamei*. *Aquaculture Nutrition*, 8: 249–256.
- Wright, I. 2003. Fish hydrolysate: more than just a flavor enhancer? *International Aquafeed*, 6(3): 8–12.
- Wright, I. 2004. Salmon by-products. *Aqua Feeds: Formulation and Beyond*, 1(1): 10–12.
- Wu, F.C., Ting, Y.Y. & Chen, H.Y. 2002. Docosahexaenoic acid is superior to eicosapentaenoic acid as the essential fatty acid for growth of grouper, *Epinephelus malabancus*. *Journal of Nutrition*, 132(1): 72–79.
- Wu, J., Yong, W., You, W., Wen, H. & Liao, C. 2000. Nutritional value of proteins in 13 feed ingredients for *Oreochromis niloticus*. *J. Fish. Sci. China/Zhongguo Shuichan Kexue*, 7(2): 37–42.
- Wu, Y.V., Rosati, R.R., Sessa, D.J. & Brown, P.B. 1995a. Evaluation of corn gluten meal as a protein source in tilapia diets. *Journal of Agricultural and Food Chemistry*, 43(6): 1585–1588.
- Wu, Y.V., Rosati, R.R., Sessa, D.J. & Brown, P.B. 1995b. Utilization of corn gluten feed by Nile tilapia. *Progressive Fish-Culturist*, 57(4): 305–309.
- Wu, Y.V., Warner, K., Rosati, R., Sessa, D.J. & Brown, P. 1996. Sensory evaluation and composition of tilapia (*Oreochromis niloticus*) fed diets containing protein-rich ethanol by-products from corn. *Journal of Aquatic Food Product Technology*, 5(3): 7–16.
- Wu, Y.V., Tudor, K.W., Brown, P.B. & Rosati, R.R. 1999. Substitution of plant proteins or meat and bone meal for fish meal in diets of Nile tilapia. *North American Journal of Aquaculture*, 61(1): 58–63.
- Wu, Y.V., Tudor, K.W., Brown, P.B. & Rosati, R.R. 2000a. Growth response of Tilapia fed diets rich in high-lysine corn and corn gluten. *Journal of Aquatic Food Product Technology*, 9(2): 19–27.
- Wu, Y.V., Rosati, R., Warner, K. & Brown, P. 2000b. Growth, feed conversion, protein utilization, and sensory evaluation of Nile tilapia fed diets containing corn gluten meal, full-fat foy, and synthetic amino acids. *Journal of Aquatic Food Product Technology*, 9(1): 77–88.
- Wu, X., Cheng, Y., Sui, L., Zeng, C., Southgate, P.C. & Yang, X. 2007. Effect of dietary supplementation of phospholipids and highly unsaturated fatty acids on reproductive performance and offspring quality of Chinese mitten crab, *Eriocheir sinensis* (H. Milne-Edwards), female broodstock. *Aquaculture*, 273(4): 602–613.
- Xie, S. & Jokumsen, A. 1997a. Incorporation of potato protein concentrate in diets for rainbow trout: Effect on feed intake, growth and feed utilization. *Aquaculture Nutrition*, 3(4): 223–226.
- Xie, S. & Jokumsen, A. 1997b. Replacement of fish meal by potato protein concentrate in diets for rainbow trout, *Oncorhynchus mykiss* (Walbaum): Growth, feed utilization and body composition. *Aquaculture Nutrition*, 3(1): 65–69.
- Xie, S. & Jokumsen, A. 1998a. Effects of dietary incorporation of potato protein concentrate and supplementation of methionine on growth and feed utilization of rainbow trout. *Aquaculture Nutrition*, 4(3): 183–186.

- Xie, S. & Jokumsen, A. 1998b. Effect of dietary potato protein concentrate inclusion on rainbow trout *Oncorhynchus mykiss*. *J. Shanghai Fish. Univ./Shanghai Shuichan Daxue Xuebao* 7(Suppl. suppl): 67–76.
- Xie, S. & Jokumsen, A. 1999. The effect of replacement of fish meal by potato protein concentrate in the diet for rainbow trout on feeding rate, digestibility and growth. *Acta hydrobiologica sinica/Shuisheng Shengwu Xuebao*, 23(2): 127–133.
- Xie, S., He, X. & Yang, Y. 1998. Effects on growth and feed utilization of Chinese longsnout catfish *Leiocassis longirostris* Guenther of replacement of dietary fishmeal by soybean cake. *Aquaculture Nutrition*, 4(3): 187–192.
- Xu, W., Mai, K., Zhang, W., Liufu, Z., Tan, B., Ma, H. & Ai, Q. 2004. Influence of dietary lipid sources on growth and fatty acid composition of juvenile abalone, *Haliotis discus hannai* Ino. 5. Intl. Symp. on Abalone Biology, Fisheries, and Culture, Qingdao (China), 12–17 October 2003 23(4): 1041–1044.
- Xue, M., Xie, S.Q. & Cui, Y.B. 2004. Effect of a feeding stimulant on feeding adaptation of gibel carp *Carassius auratus gibelio* (Bloch), fed diets with replacement of fish meal by meat and bone meal. *Aquaculture Research*, 35(5): 473–482.
- Xue, M., Luo, L., Wu, X., Ren, Z., Gao, P., Yu, Y. & Pear, G. 2006. Effects of six alternative lipid sources on growth and tissue fatty acid composition in Japanese sea bass (*Lateolabrax japonicus*). *Aquaculture*, 260: 206–214.
- Yacoob, S.Y., Anraku, K., Marui, T., Matsuoka, T., Kawamura, G. & Archdale, M.V. 2001. Gustatory sensitivity of the external taste buds of *Oreochromis niloticus* L. to amino acids. *Aquaculture Research*, 32(3): 217–222.
- Yacoob, S.Y., Browman, H.I. & Jensen, P.A. 2004. Electroencephalogram recordings from the olfactory bulb of juvenile (0 year) Atlantic cod in response to amino acids. *Journal of Fish Biology*, 65(6): 1657–1664.
- Yacoob, S.Y. & Browman, H.I. 2007a. Olfactory and gustatory sensitivity to some feed-related chemicals in the Atlantic halibut (*Hippoglossus hippoglossus*). *Aquaculture*, 263(1–4): 303–309.
- Yacoob, S.Y. & Browman, H.I. 2007b. Prey extracts evoke swimming behavior in juvenile Atlantic halibut (*Hippoglossus hippoglossus*). *Aquaculture*, 270(1–4): 570–573.
- Yamamoto, T. & Akiyama, T. 1995. Effect of carboxymethylcellulose, alpha-starch, and wheat gluten incorporated in diets as binders on growth, feed efficiency, and digestive enzyme-activity of fingerling Japanese flounder. *Fisheries Science*, 61(2): 309–313.
- Yamamoto, T., Unuma, T. & Akiyama, T. 1995. The effect of combined use of several alternative protein sources in fingerling rainbow trout diets. *Fisheries Science*. Tokyo [FISH. SCI.], 61(6):915–920.
- Yamamoto, T., Unuma, T., Akiyama, T. & Kishi, S. 1996a. Utilization of malt protein flour in fingerling carp diets. *Fisheries Science*, 62(5): 783–789.
- Yamamoto, T., Unuma, T., Akiyama, T. & Kishi, S. 1996b. Utilization of malt protein flour in the diets for fingerling red sea bream. *Fisheries Science*, 62(1): 59–63.
- Yamamoto, T., Ikeda, K., Unuma, T. & Akiyama, T. 1997. Apparent availabilities of amino acids and minerals from several protein sources for fingerling rainbow trout. *Fisheries Science*, 63(6): 995–1001.
- Yamamoto, T., Unuma, T. & Akiyama, T. 1998. Apparent availability of amino acids from several protein sources for fingerling Japanese flounder. *Bulletin of National Research Institute of Aquaculture (Japan)*, no. 27, pp.27–35.
- Yamamoto, T., Akimoto, A., Kishi, S., Unuma, T. & Akiyama, T. 1998. Apparent and true availabilities of amino acids from several protein sources for fingerling rainbow trout, common carp, and red sea bream. *Fish. Sci.*, 64(3): 448–458.
- Yamamoto, T., Shima, T., Furuita, H. & Suzuki, N. 2002. Influence of dietary fat level and whole-body adiposity on voluntary energy intake by juvenile rainbow trout *Oncorhynchus mykiss* (Walbaum) under self-feeding conditions. *Aquaculture Research*, 33(9): 715–723.
- Yamamoto, T., Sugita, T. & Furuita, H. 2005. Essential amino acid supplementation to fish meal-based diets with low protein to energy ratios improves the protein utilization in juvenile rainbow trout *Oncorhynchus mykiss*. *Aquaculture* 246(1–4): 379–391.
- Yamamoto, T., Suzuki, N., Furuita, H., Sugita, T., Tanaka, N. & Goto, T. 2007. Supplemental effect of bile salts to soybean meal-based diet on growth and feed utilization of rainbow trout *Oncorhynchus mykiss*. *Fisheries Science*, 73(1): 123–131.
- Yamamoto, T., Goto, T., Kine, Y., Endo, Y., Kitaoka, Y., Sugita, T., Furuita, H., Iwashita, Y. & Suzuki, N. 2008. Effect of an alcohol extract from a defatted soybean meal supplemented with a casein-based semi-purified diet on the biliary bile status and intestinal conditions in rainbow trout *Oncorhynchus mykiss* (Walbaum). *Aquaculture Research*, 39(9): 986–994.
- Yamashita, S., Yamada, T. & Hara, T.J. 2006. Gustatory responses to feeding- and non-feeding-stimulant chemicals, with an emphasis on amino acids, in rainbow trout. *Journal of Fish Biology*, 68(3): 783–800.
- Yamashita, Y., Katagiri, T., Pirarat, N., Futami, K., Endo, M. & Maita, M. 2009. The synthetic antioxidant, ethoxyquin, adversely affects immunity in tilapia (*Oreochromis niloticus*). *Aquaculture Nutrition*, 15(2): 144–151.
- Yan, W., Reigh, R.C. & Xu, Z. 2002. Effects of fungal phytase on utilization of dietary protein and minerals, and dephosphorylation of phytic acid in the alimentary tract of channel catfish *Ictalurus punctatus* fed an all-plant-protein diet. *Journal of the World Aquaculture Society*, 33: 10–22.
- Yanar, M., Ercen, Z., Hunt, A.O. & Buyukcapar, H.M. 2008. The use of alfalfa, *Medicago sativa* as a natural carotenoid source in diets of goldfish, *Carassius auratus*. *Aquaculture*, 284(1–4): 196–200

- Yang, H.-S., Li, D.-S. & Xu, N. 1998. Preliminary study on limiting nutrients in seawater ponds. *Chinese Journal of Oceanology and Limnology*, 16(3): 243–248.
- Yang, S.D., Lin, T.S., Liou, C.H. & Liu, F.K. 2005. *Effects of fermented soybean meal in diet on the growth performance and body composition of young silver perch*. Abstract of the Fisheries Society of Taiwan 2004 Annual Conference, Taipei (Taiwan), 25–26 December 2004 32(1): 29–30.
- Yang, Y., Xie, S.Q., Lei, W., Zhu, X.M. & Yang, Y.X. 2004a. Effect of replacement of fish meal by meat and bone meal and poultry by-product meal in diets on the growth and immune response of *Macrobrachium nipponense*. *Fish and Shellfish Immunology*, 17(2): 105–114.
- Yang, Y., Xie, S., Cui, Y., Lei, W., Zhu, X. & Yu, Y. 2004b. Effect of replacement of dietary fish meal by meat and bone meal and poultry by-product meal on growth and feed utilization of gibel carp, *Carassius auratus gibelio*. *Aquaculture Nutrition*, 10(5): 289–294.
- Yang, Y., Xie, S.Q., Cui, Y.B., Zhu, X.M., Lei, W. & Yang, Y.X. 2006. Partial and total replacement of fishmeal with poultry by-product meal in diets for gibel carp, *Carassius auratus gibelio* Bloch. *Aquaculture Research*, 37(1): 40–48.
- Yanik, T. & Aras, M.S. 1999. Economical analysis of replacing slaughterhouse byproduct meals in salmonid (*Oncorhynchus mykiss*) fry diets. *Turkish Journal of Veterinary & Animal Sciences*, 23: 155–160.
- Ye, S., Wang, K. & He, X. 2006. Pathological changes in common carp *Cyprinus carpio* fed oxidized fish oil. *Journal of Dalian Fisheries University/Dalian Shuichan Xueyuan Xuebao*, 21(1): 1–6.
- Yigit, M., Erdem, M., Koshio, S., Erguen, S., Tuerker, A. & Karaali, B. 2006. Substituting fish meal with poultry by-product meal in diets for black Sea turbot *Psetta maeotica*. *Aquaculture Nutrition*, 12(5): 340–347.
- Yildirim-Aksoy, M., Lim, C., Wan, P. & Klesius, P. 2004. Effect of natural free gossypol and gossypol-acetic acid on growth performance and resistance of channel catfish (*Ictalurus punctatus*) to Edwardsiella ictaluri challenge. *Aquaculture Nutrition*, 10(3): 153–165.
- Yildirim-Aksoy, M., Lim, C., Davis, D.A., Shelby, R. & Klesius, P.H. 2007a. Influence of dietary lipid source on the growth performance, immune response, and resistance of Nile tilapia, *Oreochromis niloticus*, to *Streptococcus iniae* challenge. *Journal of Applied Aquaculture*, 19: 29–49.
- Yildirim-Aksoy, M., Shelby, R., Lim, C. & Klesius, P.H. 2007b. Growth performance and proximate and fatty acid compositions of channel catfish, *Ictalurus punctatus*, fed for different duration with a commercial diet supplemented with various levels of menhaden fish oil. *Journal of the World Aquaculture Society*, 38(4): 461–474.
- Yildirim-Aksoy, M., Lim, C., Shelby, R. & Klesius, P.H. 2009. Increasing fish oil levels in commercial diets influences hematological and immunological responses of Channel catfish, *Ictalurus punctatus*. *Journal of the World Aquaculture Society*, 40(1): 76–86.
- Yildiz, M. & Sener, E. 2003. The effects of replacing fish oil with vegetable oils in starter feeds on the liver fat composition of sea bass (*Dicentrarchus labrax* L., 1758). *Turkish Journal of Veterinary and Animal Sciences*, 27(3): 709–717.
- Yildiz, M. & Sener, E. 2004. The effect of dietary oils of vegetable origin on the performance, body composition and fatty acid profiles of sea bass (*Dicentrarchus labrax* L., 1758) juveniles. *Turkish Journal of Veterinary and Animal Sciences*, 28(3): 553–562.
- Yilmaz, E. & Genc, E. 2006. Effects of alternative dietary lipid sources (soy-acid oil and yellow grease) on growth and hepatic lipidosis of common carp (*Cyprinus carpio*) fingerling: A preliminary study. *Turkish Journal of Fisheries and Aquatic Sciences*, 6: 37–42.
- Yilmaz, E., Naz, M. & Akyurt, I. 2004. Effect of dietary olive pomace oil and L-carnitine on growth and chemical composition of African catfish, *Clarias gariepinus* (Burchell, 1822). *Israeli Journal of Aquaculture-Bamidgeb*, 56(1): 14–21.
- Yildirim, M., Manning, B.B., Lovell, R.T., Grizzle, J.M. & Rottinghaus, G.E. 2000. Toxicity on moniliformin and fumonisin B1 fed singly and in combination in diets for young channel catfish (*Ictalurus punctatus*). *J. World Aquacult. Soc.*, 31(4): 599–608.
- Yoo, G.Y., Wang, X., Choi, S., Han, K., Kang, J.C. & Bai, S.C. 2005. Dietary microbial phytase increased the phosphorus digestibility in juvenile Korean rockfish *Sebastes schlegeli* fed diets containing soybean meal. *Aquaculture*, 243(1–4): 315–322.
- Yoshitomi, B., Aoki, M., Oshima, S. & Hata, K. 2006. Evaluation of krill (*Euphausia superba*) meal as a partial replacement for fish meal in rainbow trout (*Oncorhynchus mykiss*) diets. *Aquaculture*, 261(1): 440–446.
- Yoshitomi, B., Aoki, M. & Oshima, S.I. 2007. Effect of total replacement of dietary fish meal by low fluoride krill (*Euphausia superba*) meal on growth performance of rainbow trout (*Oncorhynchus mykiss*) in fresh water. *Aquaculture*, 266(1–4): 219–225.
- Yu, Y. 2006. Rendered products in shrimp aquaculture feeds, pp.195–212. In: D.L. Meeker (ed.), *Essential Rendering – All about the animal by-products industry*. Arlington, Virginia, USA, National Renderers Association. Kirby Lithographic Company, Inc.
- Yuan, W., Yang, S., Chen, J. & Chen, M. 2003. Effects of amino acid chelating microelements on *Micropterus salmoides*. *Journal of Fishery Sciences of China/Zhongguo Shuichan Kexue*, 10(5): 409–413.
- Yue, Y.R. & Zhou, Q.C. 2008. Effect of replacing soybean meal with cottonseed meal on growth, feed utilization, and hematological indexes for juvenile hybrid tilapia, *Oreochromis niloticus* x *O. aureus*. *Aquaculture*, 284(1–4): 185–189.
- Yufera, M., Kolkovski, S., Fernandez-Diaz, C. & Dabrowski, K. 2002. Free amino acid leaching from a protein-walled microencapsulated diet for fish larvae. *Aquaculture*, 214(1–4): 273–287.

- Zarate, D.D. & Lovell, R.T. 1997. Free lysine (L-lysine/HCl) is utilized for growth less efficiently than protein-bound lysine (soybean meal) in practical diets by young channel catfish (*Ictalurus punctatus*). *Aquaculture*, 159(1–2): 87–99.
- Zarate, D.D., Lovell, R.T. & Payne, M. 1999. Effects of feeding frequency and rate of stomach evacuation on utilization of dietary free and protein-bound lysine for growth by channel catfish *Ictalurus punctatus*. *Aquaculture Nutrition*, 5(1): 17–22.
- Zarei, A. & Hafezieh, M. 2007. Chemical analysis of the nutritional value of the fish meal produced from artemia sp. *Iranian Scientific Fisheries Journal*, 16(1): 63–72.
- Zelenka, J., Fajmonova, E., Komprda, T., Kladroba, D. & Sarmanova, I. 2003. Effect of dietary linseed and sunflower oil on cholesterol and fatty acid contents in rainbow trout (*Oncorhynchus mykiss*) filets. *Czech Journal of Animal Science*, 48(8): 321–330.
- Zerai, D.B., Fitzsimmons, K.M., Collier, R.J. & Duff, G.C. 2008. Evaluation of brewer's waste as partial replacement of fish meal protein in Nile tilapia, *Oreochromis niloticus*, diets. *Journal of the World Aquaculture Society*, 39(4): 556–564.
- Zhang, N., Yamashita, Y. & Nozaki, Y. 2002. Effect of protein hydrolysate from Antarctic krill meat on the state of water and denaturation by dehydration of lizard fish myofibrils. *Fisheries Science*, 68: 672–679.
- Zhang, S., Xie, S., Zhu, X., Lei, W., Yang, Y. & Zhao, M. 2006. Meat and bone meal replacement in diets for juvenile gibel carp (*Carassius auratus gibelio*): effects on growth performance, phosphorus and nitrogen loading. *Aquaculture Nutrition*, 12(5): 353–362.
- Zhang, S., Xie, S.Q., Zhu, X.M., Lei, W., Han, D. & Yang, Y.X. 2008. Effect of faecal collection interval and dietary meat and bone meal levels on digestibility of nutrients in gibel carp (*Carassius auratus gibelio*). *Acta Hydrobiologica Sinica*, 32(1): 79–90.
- Zhao, M., Xie, S., Zhu, X., Yang, Y., Gan, L. & Song, L. 2006. Effect of inclusion of blue-green algae meal on growth and accumulation of microcystins in gibel carp (*Carassius auratus gibelio*). *Journal of Applied Ichthyology*, 22(1): 72–78.
- Zhao, Y., Lu, J., Guo, Q. & Yang, J. 1997. A study on chelated amino acids to promote growth of *Tilapia nilotica*. *J.Fish.Sci.China/Zhongguo Shuichan Kexue*, 4(2): 40–43.
- Zheng, X., Tocher, D.R., Dckson, C.A., Bell, J.G. & Teale, A.J. 2004. Effects of diets containing vegetable oil on expression of genes involved in highly unsaturated fatty acid biosynthesis in liver of Atlantic salmon (*Salmo salar*). *Aquaculture*, 236(1–4): 467–483.
- Zhong, Y., Lall, S.P. & Shahidi, F. 2008. Effects of dietary oxidized oil and vitamin E on the growth, blood parameters and body composition of juvenile Atlantic cod *Gadus morhua* (Linnaeus 1758). *Aquaculture Research*, 39(15): 1 647–1 657.
- Zhou, J.S., Ji, H. & Jiang, Y. 2006. Digestibility in vitro for Apple Pomace by Common Carp, Crucian Carp and Grass Carp. *Fisheries Science/Shuichan Kexue*, 25(7): 346–348.
- Zhou, J., Ji, H., Wang, J. & Wang, L. 2008. Influence of fish oil on growth and lipid metabolism in common carp (*Cyprinus carpio*). *Periodical of Ocean University of China/Zhongguo Haiyang Daxue Xuebao*, 38(2): 275–280.
- Zhou, M., Cui, Y., Zhu, X., Lei, W., Yang, Y. & Xie, S. 2002. The effect of replacement of fish meal by soybean meal and potato protein concentrate in the diet for gibel carp on the growth and the energy budget. *Acta hydrobiologica sinica/Shuisheng Shengwu Xuebao*, 26(4): 370–377.
- Zhou, Q.C., Tan, B.P., Mai, K.S. & Liu, Y.J. 2004. Apparent digestibility of selected feed ingredients for juvenile cobia *Rachycentron canadum*. *Aquaculture*, 241(1–4): 441–451.
- Zhou, Q.C., Mai, K.S., Tan, B.P. & Liu, Y.J. 2005. Partial replacement of fishmeal by soybean meal in diets for juvenile cobia (*Rachycentron canadum*). *Aquaculture Nutrition*, 11(3): 175–182.
- Zhou, Q.C., Li, C.C., Liu, C.W., Chi, S.Y. & Yang, Q.H. 2007. Effects of dietary lipid sources on growth and fatty acid composition of juvenile shrimp, *Litopenaeus vannamei*. *Aquaculture Nutrition*, 13(3): 222–229.
- Zhou, Q.C., Zhou, J.B., Chi, S.Y., Yang, Q.H. & Liu, C.W. 2007b. Effect of dietary lipid level on growth performance, feed utilization and digestive enzyme of juvenile ivory shell, *Babylonia areolate*. *Aquaculture* 272(1–4): 535–540.
- Zhou, X.Q., Zhao, C.R. & Lin, Y. 2007c. Compare the effect of diet supplementation with uncoated or coated lysine on juvenile Jian Carp (*Cyprinus carpio* Var. Jian). *Aquaculture Nutrition*, 13(6): 457–461.
- Zhu, W. & Yu, Y. 2002. *Effect of partial replacement of dietary fish meal with meat and bone meal or poultry by-product meal (pet food grade) on growth performance of white leg shrimp (P. vannamei)*. Research Reports No. 19. Asia Region. National Renderers Association, Inc. 5 pp.
- Zhu, W., Mai, K., Zhang, B., Wang, F. & Yu, Y. 2004. A study on the use of meat and bone meal and poultry by-product meal as protein substitutes of fish meal in practical diets for *Penaeus vannamei* juveniles. *Journal of Ocean University of China*, 3(2): 157–160.
- Zhu, W., Mai, K., Zhang, B., Hu, Y. & Yu, Y. 2006. A study on the use of meat and bone meal or poultry by-product meal as protein substitutes of fishmeal in concentrated diets for *Paralichthys olivaceus*. *Journal of Ocean University of China*, 5(1): 63–66.
- Zoccarato, I., Benatti, G., Leveroni Calvi, S. & Bianchini, M.L. 1995. Use of pig manure as fertilizer with and without supplement feed in pond carp production in Northern Italy. *Aquaculture*, 129 (1–4): 387–390.

The present technical paper presents an up-to-date overview of the major feed ingredient sources and feed additives commonly used within industrially compounded aquafeeds, including feed ingredient sources commonly used within farm-made aquafeeds, and major fertilizers and manures used in aquaculture for live food production. Information is provided concerning the proximate and essential amino acid composition of common feed ingredient sources, as well as recommended quality criteria and relative nutritional merits and limitations, together with a bibliography of published feeding studies for major feed ingredient sources by cultured species. The main body of the document deals with the nutritional composition and usage of major feed ingredient sources in compound aquafeeds, as well as the use of fertilizers and manures in aquaculture operations. Major feed ingredient and fertilizer groupings discussed include: animal protein sources, plant protein sources, single cell protein sources, lipid sources, other plant ingredients, feed additives, and fertilizers and manures. The concluding section of the document undertakes a comparative analysis of the essential amino acid profiles of the major reported feed ingredient sources for cultured finfish and crustaceans, and presents average reported dietary inclusion levels of major feed ingredient sources used within practical feeds, including their major attributes and limitations. Finally, the importance of feed safety, traceability, and use of good feed manufacturing practices is stressed, together with the importance of considering the long-term sustainability of feed ingredient supplies.

ISBN 978-92-5-106421-4 ISSN 2070-7010



9 7 8 9 2 5 1 0 6 4 2 1 4

I1142E/1/10.09/1800