FAO
FISHERIES AND
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TECHNICAL
PAPER

540

ISSN 2070-7010

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).

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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

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, 2009

ISBN 978-92-5-106421-4

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.

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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_2O	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_2O_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	Thiobarbaturic 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

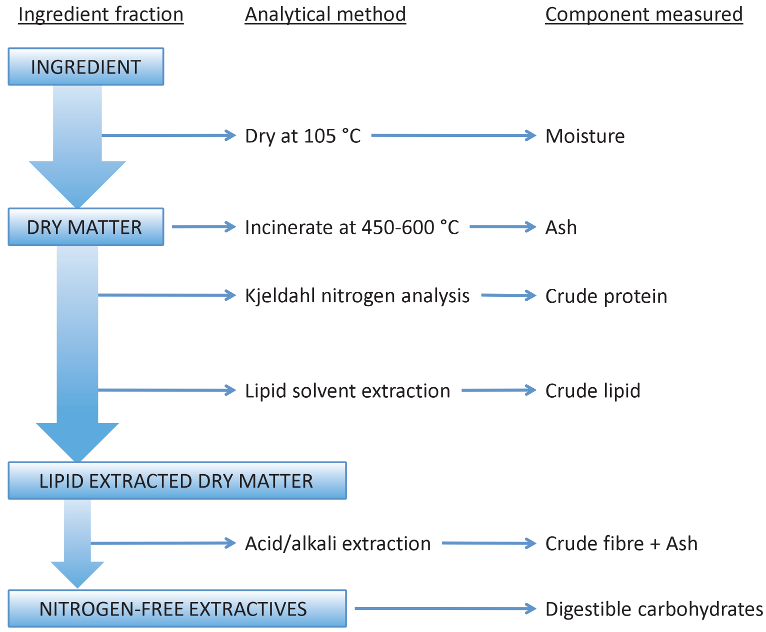
The chemical composition of feed ingredients and fertilizers is usually determined using validated analytical methods such as those published by the Association of Analytical Communities International (AOAC, 2005), formerly known as the Association of Official Analytical Chemists, and before that the 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

FIGURE 1
Weende proximate analysis flow diagram



Source: adapted from Tacon (1987).

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 x 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_2S0_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 H2S04) 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 B_6 (AOAC Official Method 961.15); Folic acid (AOAC Official Method 944.12, 2004.05); Vitamin B_{12} (AOAC Official Method 952.20); Vitamin K_3 (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 – flurometric method
0953.17 - Thiamine (Vitamin B_1) in grain products – flurometric (rapid) method
0957.17 - Thiamine (Vitamin B_1) – flurometric method
0940.33 - Riboflavin (Vitamin B_2) in vitamin preparations – microbiological method
0970.65 - Riboflavin (Vitamin B_2) in foods and vitamin preparations – flurometric 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 – spectrophpotometric 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 – microflurometric 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, Slaframine, 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 *Oryza sativum*	1,2,5,8,13
Wheat *Triticum vulgare*	1,2,5,8,11,18,22
Corn/maize *Zea mays*	1,5,8,19
Root tubers	
Potato *Solanum tuberosum*	1,2,4,8,18,19
Legumes	
Cow pea *Vigna unguiculata*	1 (T,C),2,5,11
Lentil *Lens culinaris*	1 (T),2,6,28
Lupin *Lupinus albus*	1 (T,C),2,4,5,7,28
Field pea *Pisum sativum*	1 (T),2,4,5,6,12
Oilseeds	
Rapeseed *Brassica campestris napus*	1 (T),3,5,7,28,29
Indian mustard *Brassica juncea*	1 (T),3,5,7,13,28,29
Soybean *Glycine max*	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-elastin, Mc-microbial proteases), 2 – Phyto-haemagglutinins, 3 – Glucosinolates, 4 – Cyanogens, 5 – Phytic acid, 6 – Saponins, 7 – Tannins, 8 – Estrogenic factors, 9 – Lathyrogens, 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 B_{12} 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 (NH_2) 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, Dali Chos 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 concentratration 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 maize, 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 C6H1206 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 trihydricalcohol to which three fatty acid molecules are esterified in the formation of triacyglycerols (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 phase "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 C6H1206. 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-glucoronic and D-galacturonic acids along with other simple sugars such as arabinose and shammose (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 unsaponfiable 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).

Unsaponifiable 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 Iess 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-H_2O; Crude Protein-CP; Lipid or Ether Extract-EE; Crude Fibre-CF; Ash; Calcium-Ca; Phosphorus-P

Fish product		H_2O	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_2O	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	11–16
	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	11,12
	mean	7.2	44.2	1.4	19.6	31.7	9.91	2.71	
Sergestid shrimp (*Acetes* sp. whole)	min	8.2	46.9	3.2	3.6	13.1	-	-	2,3,
	max	14.0	68.6	6.8	4.4	16.3	-	-	13, 15
	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	-	-	17
	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	25
	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	11,13
	mean	9.2	67.6	8.2	1.4	8.6	0.79	1.17	16,19
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	19
	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 – Ezquerra-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%∑EAA	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%∑EAA	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%∑EAA	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%∑EAA	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%∑EAA	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)	min	4.3	-	3.0	4.7	3.4	6.0	6.5	4.3	3.0	0.45	6.1	2.0	13
(g/100g protein or g/16gN)	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%∑EAA	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%∑EAA	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)	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
(process residue)	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%∑EAA	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	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
(% dry matter basis)	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%∑EAA	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)	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
(g/100g protein or g/16gN)	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,
	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	15
	AA%∑EAA	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	min	4.85	0.14	1.21	1.67	0.87	3.37	3.44	1.16	1.71	-	2.26	1.40	12
(% dry matter basis)	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/lLangostilla	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
(g/100g protein or g/16gN)	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%∑EAA	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	min	6.50	0.40	3.00	4.10	0.50	7.30	8.00	4.80	3.60	-	4.10	1.80	2
(g/100g total amino acids)	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,
	max	5.17	0.88	2.26	3.55	3.30	5.23	5.41	3.15	2.11	-	3.02	4.15	Upd
	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%∑EAA	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	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
(g/100g protein or g/16N)	max	6.90	-	2.90	4.50	5.50	7.10	6.70	4.92	3.45	-	4.70	5.50	Upd
	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%∑EAA	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	min	3.95	-	1.19	2.30	2.15	3.37	3.51	2.22	-	-	1.85	0.89	2,5
(g/100g protein or g/16N)	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; Ricqque-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); Minnow: 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 vicera: 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); Julshamn *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 B_{12}, inositol, vitamin A, vitamin D_3, 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-H_2O; Crude Protein-CP; Lipid or Ether Extract-EE; Crude Fibre-CF; Ash; Calcium-Ca; Phosphorus-P

Terrestrial livestock product		H_2O	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%∑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%∑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%∑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%∑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%∑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	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
(g/100g protein or g/16N)	max	-	-	-	-	-	-	-	-	-	-	-	-	
	mean	-	-	-	-	-	-	-	-	-	-	-	-	
	AA%∑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); Brasilian 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); Samocha *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); Rahnema 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-H_2O; Crude Protein-CP; Lipid or Ether Extract-EE; Crude Fibre-CF; Ash; Calcium-Ca; Phosphorus-P

Terrestrial invertebrate product		H_2O	CP	EE	CF	Ash	Ca	P	Ref.[1]
Insecta/insects									
Silkworm pupae meal, whole	min	4.9	49.4	14.2	3.9	2.2	0.63	1.25	1,7,8
(% dry matter basis)	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	min	1.5	44.5	0.7	4.6	4.4	0.63	1.25	1
(% dry matter basis)	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 (*Musca domestica*)	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 (Hermetia illucens) larvae meal		7.9	42.1	34.8	7.0	14.6	5.0	1.5	5
Locust (Schistocerca gregaria) 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)	min	8.2	54.3	4.2	4.1	1.0	1.13	0.15	1,4,9
(% dry matter basis)	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 (*Eisensia foetida*) meal		7.4	56.4	7.8	1.6	8.8	0.48	0.87	5
Earthworm (Dendodrilus subrubicundus) meal		9.1	65.1	9.6	-	13.0	0.18	-	5
Earthworm (Hyperiodrilus euryalos) meal		8.6	63.0	5.9	1.9	8.9	0.53	0.94	4
Earthworm (Eudrilus eugenige) meal		0.0	60.4	12.0	-	10.5	1.49	0.89	5
Polychaete (Nereis virens) 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%∑EAA	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 min	3.6	-	1.8	3.6	7.5		2.5	-	-	0.6	1.8	3.2	1
(g/100g protein or g/16N) max	7.8	-	1.9	5.6	8.0		10.1	-	-	1.5	3.2	3.3	
mean	6.0	-	1.9	4.6	7.8		6.1	4.7	-	1.1	2.5	3.3	
Magmeal (*M. domestica* (% 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 (g/100g protein or g/16N)	12.0	-	1.33	5.91	6.23	6.79	5.10	5.90	-	-	5.04	1.77	2
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 min	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) max	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%∑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	
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%∑EAA	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-H_2O; Crude Protein-CP; Lipid or Ether Extract-EE; Crude Fibre-CF; Ash; Calcium-Ca; Phosphorus-P

Plant proteins – cereal products		H_2O	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)	min	6.0	20.9	3.5	8.0	1.8	0.09	0.39	1–4
(barley/corn/maize/rye/sorghum/wheat)	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)	min	5.1	26.5	0.2	3.4	7.2	0.32	0.61	1–4
(barley/corn/maize/rye)	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)	min	5.0	26.7	4.1	8.1	4.2	0.14	0.65	1–4
(barley/corn/maize/rye/sorghum)	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%∑EAA	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%∑EAA	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%∑EAA	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%∑EAA	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%∑EAA	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%∑EAA	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%∑EAA	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%∑EAA	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%∑EAA	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%∑EAA	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%∑EAA	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%∑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%∑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%∑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: [1]Hertrampf 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); Robinson 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 wich 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 then 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 abyssinian* 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-l 10 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 afier 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 l-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-H_2O; Crude Protein-CP; Lipid or Ether Extract-EE; Crude Fibre-CF; Ash; Calcium-Ca; Phosphorus-P

Plant proteins – cereal products		H_2O	CP	EE	CF	Ash	Ca	P	Ref.[1]
Canola/Mustard/Rapeseed products *(Brassica campestris / B. napus, B. juncea)*									
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.)	min	8.0	34.1	7.2	12.0	6.5	0.57	0.90	4–6
(5-03-870)	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)	min	7.0	37.0	1.7	11.1	6.8	0.61	0.95	4–5
(5-03-871)	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 (*Cocus nucifera*)									
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.)	min	7.9	21.0	1.6	14.0	6.0	0.17	0.59	4–5
(5-01-573)	max	9.8	22.0	6.7	17.3	9.7	0.18	0.60	8–9
	mean	8.7	21.5	3.5	14.8	7.1	0.18	0.60	
Cotton products (*Gossypium* spp.)									
Cotton seeds (kernel), whole		7.9	20.4	20	21.1	4.3	0.14	0.64	4
Cottonseed oilcake (expeller, mech. extr.)	min	10.3	21.9	4.9	21.9	5.4	-	-	4–5
(corticated – with hulls)	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)	min	7.0	41.0	4.6	11.1	6.0	0.19	1.06	4–6,
(decorticated – without hulls) (5-01-617)	max	7.9	41.2	6.2	11.9	6.4	0.20	1.16	8
	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)	min	9.2	41.2	1.2	9.7	6.5	0.16	1.09	4–6,8
(decorticated – 41% protein)	max	9.8	44.2	1.5	12.1	6.9	0.21	1.41	
(5-01-621)	mean	9.3	42.4	1.4	11.0	6.7	0.18	1.20	
Cottonseed meal (solvent extracted)	min	7.0	50.0	1.3	8.2	6.5	0.17	1.08	4,8
(decorticated – 50% protein)	max	7.5	50.3	1.6	8.2	6.6	0.18	1.16	
(5-07-874)	mean	7.25	50.1	1.4	8.2	6.5	0.17	1.12	
Groundnut/peanut products (*Arachis hypogaea*)									
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.)	min	8.9	30.2	9.1	18.1	5.4	-	-	4–5
(corticated – with hulls)	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.)	min	7.0	46.2	5.8	6.1	5.1	0.14	0.57	4–5
(decorticated)	max	9.6	48.1	7.0	7.5	6.0	0.19	0.71	6,8
(5-03-649)	mean	8.5	46.9	6.5	6.8	5.4	0.16	0.63	
Groundnut meal (solvent extracted)	min	7.8	31.7	1.9	25.0	4.3	-	-	4–5
(corticated – with hulls)	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)	min	8.0	46.5	1.0	7.7	5.4	0.25	0.59	4–5,
(decorticated)	max	9.8	48.7	1.3	9.9	6.0	0.29	0.96	6,8
(5-03-650)	mean	8.8	47.8	1.1	8.6	5.7	0.27	0.72	

TABLE 28 – CONTINUED

Plant proteins – cereal products		H_2O	CP	EE	CF	Ash	Ca	P	Ref.[1]
Linseed/flax products (*Linum usitatissimum*)									
Linseed (kernel)		6.7	25.6	34.7	5.4	4.7	0.2	0.54	4
Linseed oilcake (expeller, mech. extr.)	min	9.0	33.4	5.4	8.8	5.7	0.38	0.80	4–6
(5-02-045)	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)	min	10.0	34.1	1.3	9.1	5.8	0.37	0.80	4–6
(5-02-048)	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 (*Elaeis guineesis*)									
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 (*Carthamus tinctorius*)									
Safflower seed (kernel)		7.0	17.1	31.1	27.6	2.9	0.24	0.62	4
Safflower oilcake (expeller, mech. extr.)	min	8.1	20.2	5.6	30.7	3.8	0.22	0.64	4–6
(corticated – with hulls)	max	9.0	21.7	6.1	32.4	4.8	0.25	0.71	
(5-04-109)	mean	8.7	21.0	5.9	31.4	4.3	0.24	0.68	
Safflower meal (solvent extracted)	min	8.0	22.5	1.0	30.0	4.7	0.32	0.75	4–6
(corticated – with hulls)	max	8.7	23.4	1.4	32.8	5.4	0.34	0.92	
(5-04-110)	mean	8.5	23.0	1.3	31.4	5.0	0.33	0.82	
Safflower oilcake (expeller, mech. extr.)	min	8.6	41.1	6.4	10.4	7.3	0.45	1.0	4–5
(decorticated – without hulls)	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)	min	8.8	42.3	1.2	11.5	7.1	0.38	0.64	4–5
(decorticated – without hulls)	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 (*Sesamum orientale/S. radiatum*)									
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 (*Glycine max*)									
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)	min	5.6	35.8	17.8	3.1	4.4	0.25	0.59	4–6,
(5-04-597)	max	10.8	38.0	20.6	5.4	5.6	0.28	0.66	8–10
	mean	8.9	37.3	19.0	4.7	5.0	0.26	0.61	
Soybean oilcake (expeller – mech. extr.)	min	10.0	41.6	4.8	5.4	6.0	0.20	0.61	4–6,8
(corticated – with hulls)	max	11.4	43.5	5.6	5.9	6.2	0.26	0.63	
(5-04-600)	mean	10.8	42.7	5.2	5.7	6.1	0.24	0.62	
Soybean meal (solvent extracted)	min	8.4	43.6	1.0	5.5	6.1	0.28	0.63	4–6,
(corticated – with hulls)	max	11.6	45.9	1.5	6.3	7.7	0.30	0.68	8–9
(5-20-604/637)	mean	10.3	44.7	1.3	6.0	6.7	0.29	0.65	
Soybean meal (solvent extracted)	min	10.0	49.0	0.8	3.0	5.6	0.25	0.63	4–6,
(decorticated – without hulls)	max	10.5	49.8	0.9	3.4	5.9	0.28	0.66	8
(5-04-612)	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 (Helianthus annus)									
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.)	min	7.3	31.6	8.2	17.3	6.4	-	-	4–5
(corticated – with hulls)	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_2O	CP	EE	CF	Ash	Ca	P	Ref.[1]
Sunflower oilcake (expeller – mech. extr.)	min	7.0	37.1	8.0	12.2	6.3	0.36	1.06	4–6
(decorticated – without hulls)	max	7.8	41.4	9.3	12.3	6.6	0.39	1.08	
(5-04-738)	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)	min	7.0	43.4	2.5	11.1	6.6	0.39	0.91	4–6,8
(decorticated – without hulls)	max	7.7	46.3	3.2	12.5	7.6	0.43	1.30	
(5-04-739)	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.bioexx.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-Try; 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 (*Brassica campestris/ B. napus, B. juncea*)														
Canola meal, solv. extr.	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
(5-06-145)	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%∑EAA	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%∑EAA	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.	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
(5-03-870)	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%∑EAA	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.	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
(5-03-871)	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%∑EAA	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%∑EAA	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 *(Cocus nucifera)*														
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%∑EAA	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%∑EAA	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		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
(5-01-573)	AA%∑EAA	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 (*Gossypium* 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%∑EAA	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. min	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
(5-01-617) 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%∑EAA	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. min	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
(5-01-621) 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%∑EAA	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.	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
extr. (5-07-874) AA%∑EAA	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 (*Linum usitatissimum*)													
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%∑EAA	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. min	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
(5-02-045) 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%∑EAA	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. min	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
(5-02-048) 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%∑EAA	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 (*Elaeis guineesis*)													
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%∑EAA	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%∑EAA	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 (*Arachis hypogaea*)													
Peanut meal, mech. extr.	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
(5-03-649) AA%∑EAA	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. min	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
(5-03-650) 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%∑EAA	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 (*Carthamus tinctorius*)													
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%∑EAA	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%∑EAA	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.		1.93	0.36	0.34	0.51	0.28	1.20	0.71	1.0	-	0.27	1.0	0.50	6
solv. extr.	AA%∑EAA	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 – finfish	205	163	78	59	45	110	52	129	-	194	129	129	
	Amino acid score – shrimp	123	215	99	79	41	104	82	135	-	182	124	144	
Safflower oilcake, decorticated		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
mech. extr.	AA%∑EAA	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 – finfish	139	152	85	74	124	105	36	131	85	235	107	110	
	Amino acid score – shrimp	83	200	108	99	113	100	57	137	67	221	103	123	
Safflower oilmeal, decorticated		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
solv. extr.	AA%∑EAA	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 – finfish	170	141	68	67	116	98	41	132	88	188	102	117	
	Amino acid score – shrimp	102	185	87	89	106	94	65	137	69	177	98	130	
Sesame (*Sesamum orientale/S. radiatum*)														
Sesame seed (kernel)		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
	AA%∑EAA	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 – finfish	212	137	105	68	97	101	33	98	98	159	95	102	
	Amino acid score – shrimp	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%∑EAA	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 (*Glycine max*)														
Soybean seeds (5-04-597)	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
heat processed	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%∑EAA	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.	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
(5-04-600) undecorticated	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%∑EAA	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.	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
(5-04-604) undecorticated	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%∑EAA	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.	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	
(5-04-612) dehulled	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	1,5–7
	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%∑EAA	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	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
(5-08-038)	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	9–10
	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%∑EAA	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	
Sunflower products (*Helianthus annus*)														
Sunflower seed (kernel), whole		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
with hulls	AA%∑EAA	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 – finfish	155	122	78	78	129	107	49	119	65	176	105	110	
	Amino acid score – shrimp	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	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
(5-09-340) solvent extr.	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%∑EAA	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.		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
min (5-04-738) mech. extr.	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%∑EAA	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.	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
(5-04-739) solvent extr.	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%∑EAA	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); Grasscarp: 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); Grasscarp: 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); Rinchard *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); Rinchard *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-Suhaimee *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); Grasscarp: 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 gouramy: 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); Grasscarp: Lin *et al.* (2001); Greenback flounder: Bransden 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); Bjerkeng *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); Sharpsnout 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.* (2008); 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);

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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. augustifolius* (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. augustifolius* (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. augustifolius* (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-H_2O; 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_2O	CP	EE	CF	NFE	Ash	Ca	P	
Pigeon pea/red gram/dahl (Cajanus cajan)									
Seed (pea), mature, dry	10.0	20.1	2.1	7.5	56.1	4.2	0.17	0.30	1
Jack/sword bean (Canavalia ensiformis)									
Seed (bean), mature, dry	11.1	31.2	2.1	9.4	43.5	2.7	0.13	0.29	1
Carob/locust bean (Ceratonia siliqua)									
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_2O	CP	EE	CF	NFE	Ash	Ca	P	
Chickpea/garbanzo bean/Egyptian pea/gram pea/Bengal gram *(Cicer arietinum)*										
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 *(Cyamopsis tetragonoloba)*										
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 *(Lablab purpureus/Dolichos lablab)*										
Seed (bean), mature, dry		9.8	23.8	0.9	5.6	56.2	3.7	0.20	0.39	1
Grass pea *(Lathyrus sativus)*										
Seed (pea), mature, dry		10.3	22.8	1.2	9.3	53.1	3.3	0.38	0.27	1
Lentil/red dahl *(Lens esculenta)*										
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 *(Leucaena leucocephala)*										
Seed, mature, dry		9.0	32.6	6.8	10.4	37.2	4.0	-	-	1
Lupin *(Lupinus albus, L. angustifolius, L. luteus, L. mutabilis)*										
Seed, mature, dry	min	9.0	29.8	3.0	12.1	16.1	2.8	0.19	0.30	1,2
(5-02-707)	max	11.5	40.0	12.8	15.5	43.3	4.1	0.26	0.57	5
	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 *(Mucana pruriens/M. utilis)*										
Seed (bean), mature, dry		8.7	24.1	3.2	7.8	52.9	3.3	0.21	0.65	1
African locust bean *(Parkia filicoidea)*										
Seed (bean), mature, dry		7.2	30.8	12.8	8.2	36.9	4.1	-	-	1
Lima bean *(Phaseolus lunatus)*										
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 *(Phaseolus vulgaris)*										
Seed (bean), mature, dry	min	10.5	22.6	1.3	4.2	57.0	4.1	0.16	0.48	1,3
(5-00-623)	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 *(Pisum sativum)*										
Seed (pea), mature, dry	min	11.0	22.5	1.2	5.7	55.1	3.0	0.11	0.28	1-3
(5-03-600)	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 *(Prosopsis velutina)*										
Seed, mature, dry		10.0	49.7	8.0	4.0	24.3	4.0	-	-	1
Saman/rain tree/monkey pod/cow tamarind *(Samanea saman)*										
Seed, mature, dry		13.5	27.3	5.2	12.1	38.2	3.7	0.14	0.29	1
Sesbania (Sesbania 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 (Vigna mungo)										
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 *(Vigna radiata/Phaseolus aureus)*										
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_2O	CP	EE	CF	NFE	Ash	Ca	P	
Horse gram *(Vigna unguiculata/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 *(Vicia faba)*										
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 *(Vigna umbellata)*										
Seed (bean), mature, dry		10.0	22.6	1.4	5.8	55.9	4.3	0.34	0.36	1
Winged bean *(Psophocarpus tetragonolobus)*										
Seed (bean), mature, dry		9.7	37.3	18.1	5.4	25.2	4.3	-	-	1
Cowpea *(Vigna unguiculata/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 *(Voandzeia subterranea)*										
Seed, mature, dry		9.8	18.4	6.6	5.6	56.4	3.2	0.01	0.28	1
Ground bean/Kerstings groundnut *(Kerstingiella geocarpa)*										
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-Try; 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		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
(C. cajan)	AA%ΣEAA	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		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
(C. ensiformis)	AA%ΣEAA	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		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
(C. arietinum)	AA%ΣEAA	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		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
(L. purpureus)	AA%ΣEAA	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		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
(L. esculenta)	AA%ΣEAA	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		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
(Lupinus spp.*)*	AA%ΣEAA	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)	min	10.7	1.6	1.0	3.9	3.8	6.8	5.7	3.3	3.4	-	3.6	2.3	3
(L. angustifolius)	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%ΣEAA	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		Arg	Cyt	Met	Thr	Iso	Leu	Lys	Val	Tyr	Try	Phen	His	Ref.[2]
		Average EAA composition (%)												
Velvet bean		2.59	0.29	0.39	1.31	1.57	2.49	2.04	1.81	1.67	-	1.57	0.69	1
(M. utilis)	AA%∑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		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
(P. filicoidea)	AA%∑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		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
(P. lunatus)	AA%∑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		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
(P. vulgaris)	AA%∑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	
Pea/field pea	min	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
(*P. sativum*)	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%∑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		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%∑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		2.23	0.22	0.18	0.77	0.82	1.38	1.22	0.96	0.69	-	0.86	0.64	1
(S. grandiflora)	AA%∑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		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
(V. mungo)	AA%∑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		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
(V. faba)	AA%∑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		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
(V. unguiculata)	AA%∑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		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
(V. subterranea)	AA%∑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		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
(K. geocarpa)	AA%∑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 *(Cyamposis 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 tetragonaloba)*

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 tetraganolobus)*

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".

Reported proximate and essential amino acid composition and usage

The average reported proximate and essential amino acid composition of some miscellaneous plant protein sources which have been successfully used in compound aquafeeds is shown in Table 35, 36 and 37, respectively.

TABLE 35

Reported average proximate composition of selected miscellaneous protein-rich plant products – all values are expressed as percent by weight on as-fed basis: Water-H_2O; 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_2O	CP	EE	CF	NFE	Ash	Ca	P	
Artificially dehydrated leaves – leaf meals										
Alfalfa lucerne	min	7.8	17.3	2.7	24.4	38.3	9.5	1.37	0.23	1,2
(*Medicago sativa*)	max	8.0	17.3	2.7	24.0	38.8	9.7	1.40	0.23	
	mean	7.9	17.3	2.7	24.2	38.3	9.6	1.38	0.23	
Cassava	min	5.9	22.1	4.6	12.4	25.0	6.3	0.60	0.35	1,3
(*Manihot esculenta*)	max	10.0	27.0	9.3	27.1	43.3	7.0	-	-	
	mean	7.9	24.5	6.9	19.7	34.1	6.6	0.60	0.35	
Papaya	min	5.4	20.7	3.9	9.8	37.2	11.4	-	-	1,3
(*Carica papaya*)	max	7.5	21.7	11.6	11.2	45.7	13.9	-	-	
	mean	6.4	21.2	7.7	10.5	41.4	12.6	-	-	
Lead tree/ipil-ipil	min	7.8	24.5	5.4	10.6	26.5	6.9	0.37	0.07	1–4
(Leucaena leucocephala)	max	10.3	29.3	8.8	11.6	44.8	13.5	2.52	1.47	
	mean	8.8	26.2	6.3	11.1	38.6	9.0	1.76	0.35	
Acacia (*Acacia* sp.)		4.4	25.7	5.6	21.2	37.3	5.8	-	-	3
Horseradish tree/malunggay (*Moringa* oleifera)		3.5	30.4	8.4	8.3	40.2	9.2	-	-	3
Sweet potato/camote (*Ipomoea batatas*)		4.5	29.7	4.9	10.0	38.7	12.2	-	-	3
Chinese water spinach (*Ipomea aquatica*)		5.7	28.5	5.4	10.5	37.9	12.0	-	-	3
Miscellaneous plant protein concentrates										
Leaf protein concentrate (Rye grass)		5.4	57.7	20.6	1.7	10.9	3.7	0.27	0.35	1
Potato protein concentrate *(Solanum tuberosum)*		8.5	78.1	0.4	0.1	11.6	1.3	0.07	0.25	1

[1] 1 – Tacon (1987); 2 – NRC (1982); 3 – Catacutan (2002); 4 – Hertrampf and Pascual (2000).

TABLE 36

Reported essential amino acid (EAA) composition of selected miscellaneous protein-rich plant 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

Product	Average EAA composition (%)												Ref.[2]
	Arg	Cys	Met	Thr	Iso	Leu	Lys	Val	Tyr	Try	Phe	His	
Leaf protein concentrate	3.75	0.52	1.04	2.88	2.88	5.48	3.81	3.75	2.37	0.86	3.63	1.32	1
(Rye grass)	11.6	1.6	3.2	8.9	8.9	17.0	11.8	11.6	7.3	2.7	11.2	4.1	
AA%ΣEAA Amino acid score – finfish[1]	100	59	59	84	119	126	70	122	112	159	118	85	
Amino acid score – shrimp[1]	60	78	75	112	108	120	111	127	89	149	113	95	
Potato protein concentrate	3.70	1.40	2.10	4.20	4.70	7.60	6.00	4.50	4.80	0.95	5.00	1.40	1
(Solanum tuberosum) AA%ΣEAA	8.0	3.0	4.5	9.1	10.1	16.4	12.9	9.7	10.3	2.0	10.8	3.0	
Amino acid score – finfish	69	111	83	86	135	121	77	102	158	118	114	62	
Amino acid score – shrimp	41	146	106	114	123	115	121	107	125	110	109	70	
Cassava leaf meal	1.41	0.32	0.39	1.27	1.11	2.72	2.78	1.67	1.07	0.29	1.05	0.67	1
(*M. esculenta*)	9.6	2.2	2.6	8.6	7.5	18.4	18.8	11.3	7.2	2.0	7.1	4.5	
AA%ΣEAA	83	81	48	81	100	136	112	119	111	118	75	94	
Amino acid score – finfish	50	107	61	108	91	129	176	124	87	110	72	105	
Amino acid score – shrimp													
Ipil-ipil leaf meal (g/100g protein)	5.2	0.6	1.2	5.1	6.6	6.6	6.1	6.3	3.4	-	3.9	1.4	2
(*L. leucocephala*) AA%ΣEAA	11.2	1.3	2.6	11.0	14.2	14.2	13.1	13.6	7.3	-	8.4	3.0	
Amino acid score – finfish	96	48	48	104	189	105	78	143	112	-	88	62	
Amino acid score – shrimp	58	63	61	138	172	100	123	149	89	-	85	70	

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	3.7	0.3	1.8	4.4	3.7	7.9	4.4	5.8	6.5	-	6.5	2.8	2
(g/100g protein) (*I.batatas)*	7.7	0.6	3.8	9.2	7.7	16.5	9.2	12.1	13.6	-	13.6	5.9	
AA%∑EAA 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	3.3	0.5	1.5	3.9	3.4	6.5	4.6	5.3	4.1	-	5.7	2.7	2
(g/100g protein) AA%∑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)	2.2	0.5	0.9	2.7	2.4	4.8	2.9	3.5	3.5	-	3.8	3.9	2
(Acacia sp.*)* AA%∑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)	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
(M. sativa) AA%∑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); Penaflorida (1995);

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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: Penaflorida (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 concems when used in direct-fed microbial products:

- _Aspergillus figer_
- _Aspergillus oiyzae_
- _Bacillus coagulans_
- _Bacillus lentus_
- _Bacillus licheniformis_
- _Bacillus pumilus_
- _Bacillus subtilis_
- _Bacteroides amylophilus_
- _Bacteroides capillosus_
- _Bacteroides ruminocola_
- _Bacteroides suis_
- _Bifidobacterium adolescentis_
- _Bifidobacterium animalis (cattle only)_
- _Propionibacterium freudenreichii_
- _Propionibacterium shermanii_
- _Saccharomyces cerevisiae_
- _*Enterococcus cremoris_
- _*Enterococcus diacetylactis_
- _*Enterococcus faecium_
- _*Enterococcus intermedius_
- _*Enterococcus lactis_
- _*Enterococcus thermophilus_
- _Yeast (as defined elsewhere)_
- _Lactobacillus curvatus_
- _Lactobacillus delbruekii_
- _Lactobacillus fermentum_
- _Lactobacillus helveticus_
- _Lactobacillus lactis_
- _Lactobacillus plantarum_
- _Lactobacillus reuteri_
- _Leuconostoc mesenteroides_
- _Pediococcus acidilacticii_
- _Pediococcus cerevisiae (_damnosus_)_
- _Pediococcus pentosaceus_
- _Propionibacterium acidipropionici_
- _Bifidobacterium bifidum_
- _Bifidobacterium infantis_
- _Bifidobacterium longum_
- _Bifidobacterium thermophilum_
- _Lactobacillus acidophilus_
- _Lactobacillus brevis_
- _Lactobacillus buchneri (cattle only)_
- _Lactobacillus bulgaricus_
- _Lactobacillus casei_
- _Lactobacillus farciminis (swine only)_
- _Lactobacillus cellobiosus_

* 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, nontoxigenic, 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 *Bacilius 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 *Lactobaciilus 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 day 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 B_{12} supplement (IFN 7-05-146 Vitamin B_{12} supplement) is a feeding material used for its vitamin B_{12} activity. It must contain a minimum vitamin B_{12} 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 Rebolloso-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 B_{12}; 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-H_2O; 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_2O	CP	EE	CF	NFE	Ash	Ca	P	
Bacterial SCP *Pseudomonas/Methylophilus* spp.										
Methanol substrate		6.4	73.1	5.7	0.4	2.7	11.7	0.54	2.33	1
Bacterial SCP *Methylococcus capsulatus, Alcaligenes acidovorans, Bacillus brevis and B. firmus*										
Natural gas substrate		6.5	69.5	8.1	-	-	6.2	-	1.59	8
Yeast SCP *Saccharomyces* spp.										
Brewers yeast (*S. cerevisiae*) / Malt	min	7.0	43.8	0.8	2.4	24.3	6.6	0.12	1.26	1–4
7-05-527	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 (*Torulopsis utilis*)	min	7.0	45.9	1.6	2.1	28.7	7.7	0.45	1.42	1,2,4
7-05-534	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: *S. cerevisiae*)		6.0	51.1	0.2	0.4	37.7	4.6	0.05	1.53	5
Molasses yeast (*S. cerevisiae*) / Molasses		9.2	46.8	5.7	1.6	30.5	6.2	0.45	0.65	1,4
Candida utilis / Sulphite liquor		8.3	47.3	5.2	1.1	30.8	7.3	-	-	1
Candida boidinii / Methanol		6.2	36.4	7.2	10.0	34.5	5.7	-	-	1
Candida lipolytica / n-Paraffin		6.0	58.8	7.2	3.9	16.4	7.7	0.01	0.80	1
Candida lipolytica / Gas-oil		9.0	53.3	7.1	3.8	19.1	7.7	-	-	1
Candida pseudotrophus / Whey		10.0	57.6	5.0	4.5	13.9	9.0	-	-	1
Candida spp./ Citrus molasses		7.6	43.3	0.2	8.1	33.7	7.1	0.20	1.42	1
Filamentous fungal SCP										
Aspergillus oryzae / Soybean waste		6.3	44.1	3.5	13.2	25.0	7.9	0.34	1.63	1
Aspergillus tomarii / 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										
Spirulina maxima	min	6.7	58.6	2.3	0.5	22.7	6.7	1.14	0.08	1-6
5-19-931	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	
Chlorella vulgaris		5.7	47.2	7.4	8.3	20.8	10.6	-	-	1
Scenedesmus obliquus		6.0	52.6	13.0	6.5	13.5	8.0	0.16	1.76	1
Scenedesmus acutus		8.1	43.6	10.5	6.0	24.4	7.4	0.59	3.66	1
Cladophora glomerata		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													
Pseudomonas/Methylophilus 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%∑EAA	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	
M. capsulatus, A.acidovorans, B. brevis and B. firmus	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%∑EAA	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 (*S. cerevisiae*) 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%∑EAA	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 (*S. cerevisiae*)	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
AA%∑EAA	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 (*T. utilis*) 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%∑EAA	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	
Candida spp. (alkane substrate)	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
AA%∑EAA	8.5	2.3	4.1	10.9	10.2	16.0	13.4	11.4	7.7	2.8	8.5	4.1	
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	
Aspergillus oryzae (waste starch)	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
AA%∑EAA	11.3	2.0	2.9	9.3	9.1	15.1	11.5	11.1	12.7	2.9	7.1	4.9	
Amino acid score – finfish	97	74	54	88	121	112	68	117	195	171	75	102	
Amino acid score – shrimp	58	98	68	117	111	106	108	122	154	160	72	114	
Rhodotorula pilimanae	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
AA%∑EAA	15.0	0.5	5.0	10.7	8.5	14.1	17.4	10.7	5.4	0.6	6.8	5.3	
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													
Spirulina maxima 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%∑EAA	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	1.60	0.25	0.25	1.85	1.41	2.46	1.67	2.21	0.72	-	2.07	0.69	1
AA%∑EAA	10.5	1.6	1.6	12.2	9.3	16.2	11.0	14.5	4.7	-	13.6	4.5	
Amino acid score – finfish	90	59	30	115	124	120	65	223	276	-	143	94	
Amino acid score – shrimp	54	78	38	153	113	114	103	176	260	-	137	105	
Activated sludge / brewers waste	1.95	0.0	0.98	1.82	1.64	2.62	1.55	2.31	1.11	-	1.60	0.40	1
AA%∑EAA	12.2	-	6.1	11.4	10.3	16.4	9.7	14.4	6.9	-	10.0	2.5	
Amino acid score – finfish	105	-	113	107	137	121	58	152	106	-	105	52	
Amino acid score – shrimp	63	-	144	143	125	115	91	158	84	-	101	58	
Activated sludge / paper waste	3.07	0.14	1.20	2.23	2.05	3.50	2.07	2.69	1.51	-	2.02	0.90	1
AA%∑EAA	14.4	0.6	5.6	10.4	9.6	16.4	9.7	12.6	7.1	-	9.4	4.2	
Amino acid score – finfish	124	22	104	98	128	121	58	133	109	-	99	87	
Amino acid score – shrimp	74	29	132	130	117	115	91	138	86	-	95	98	
Activated bacterial SCP / brewery	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
AA%∑EAA	10.7	1.6	4.2	9.3	10.1	15.1	12.9	10.5	8.4	2.9	9.8	4.3	
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: Nandeesha *et al.* (1998); Indian major carp: Nandeesha *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; 20:5n-3) and docosahexaenoic acid (DHA; 22:6n-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 D_3: 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.qrill.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-ichytrid[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 *Schizochytium* sp.; [3] Heterotrophically grown alga (*Crypthecodinium* 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 (thiobarbaturic 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 tricornutum, 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); Gjoeen *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: McKenzzie *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);

TALLOWS/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 degurnming 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); Sharpsnout seabream: Almaida-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-Madrigal *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, 20076b, 2007c); Turchini *et al.* (2006); Red seabream: Glencross *et al.* (2003c, 2003d); Huang *et al.* (2007); Salmon: Bahuaud *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: Gjoeen *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); Sharpsnout seabream: Almaida-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.* 92005); 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 wt al. (2001);

Soy acid oil: Common carp: Yilmaz and Genc (2006);

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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 alter 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 l-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 l-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 l-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 l-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 l-12-232 Alfalfa straw ground, IFN l-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 4-05-20 1 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-H_2O; Crude Protein-CP; Lipid or Ether Extract-EE; Crude Fibre-CF; Nitrogen-Free Extractives-NFE; Ash; Calcium-Ca; Phosphorus-P

	Average composition (% by weight)								
Product	**H_2O**	**CP**	**EE**	**CF**	**NFE**	**Ash**	**Ca**	**P**	**Ref.[1]**
CEREAL PRODUCTS									
Barley products *(Hordeum vulgare/H. distichum)*									
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 *(Zea mays)*									
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 *(P. typhoideum; S. italica; E. crusgalli; P. miliaceum; E. coracana; P. scrobiculatum)*									
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 *(Avena sativa)*									
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 *(Oryza sativa)*									
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_2O	CP	EE	CF	NFE	Ash	Ca	P	
Rye *(Secale cereale)*									
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 *(Sorghum bicolor/S. vulgare)*									
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 *(Triticum aestivum/T. vulgare/T. Sativum/T. durum)*									
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 *(Prunus amygdalus)*									
Almond hulls	9.7	3.2	3.3	13.9	64.0	5.9	0.21	0.10	1
Cocoa *(Theobroma cacao)*									
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 *(Cocus nucifera)*									
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 *(Gossypium* spp.*)*									
Hulls	9.6	4.2	1.9	44.5	37.3	2.5	0.14	0.09	1
Groundnut/peanut *(Arachis hypogaea)*									
Hulls	11.4	6.2	1.6	54.3	21.4	5.1	1.10	0.91	1
Linseed/flax *(Linum usitatissimum)*									
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 *(Olea europaea)*									
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 *(Elaeis guineesis)*									
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 *(Carthamus tinctorius)*									
Hulls	8.7	3.5	4.1	53.1	29.1	1.5	-	-	1
Soybean *(Glycine max)*									
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_2O	CP	EE	CF	NFE	Ash	Ca	P	
Sunflower *(Helianthus annus)*									
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 *(Cajanus cajan)*									
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 *(Canavalia ensiformis)*									
Pod husks	8.0	4.1	1.4	44.3	38.7	3.5	0.28	0.01	1
Carob/locust bean *(Ceratonia siliqua)*									
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 *(Cicer arietinum)*									
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 *(Cyamopsis tetragonoloba)*									
Bean pods with seeds, green	82.5	3.7	0.2	2.3	9.9	1.4	0.13	0.25	1
Grass pea *(Lathyrus sativus)*									
Bran (Bangladesh)	12.5	11.0	1.8	38.8	40.4	8.1	-	-	3
Egyptian bean/Hyacinth bean *(Lablab purpureus/Dolichos lablab)*									
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 *(lens esculenta)*									
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 *(Mucana pruriens/M. utilis)*									
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 (*Parkia filicoidea)*									
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 *(Phaseolus lunatus)*									
Bean pods with seeds, dry	4.6	17.9	0.6	16.7	56.4	3.8	-	-	1
Pea/Field pea *(Pisum sativum)*									
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 *(Prosopsis velutina)*									
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 *(Samanea saman)*									
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 *(Vigna mungo)*									
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 Vigna radiate *(Phaseolus aureus)*									
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 *(Vigna unguiculata/Macrotyloma uniflorum)*									
Bean pods, dry	8.0	6.6	1.1	34.5	39.2	10.6	1.53	0.12	1
Broad bean/Horse bean *(Vicia faba)*									
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

	Average composition (% by weight)								
Product	**H_2O**	**CP**	**EE**	**CF**	**NFE**	**Ash**	**Ca**	**P**	**Ref.**[1]
Winged bean *(Psophocarpus tetragonolobus)*									
Green pod, immature, fresh	84.0	2.4	0.3	1.9	10.3	1.1	0.04	0.05	1
Cowpea *(Vigna unguiculata/V. sinensis)*									
Pod husks	7.4	12.0	0.6	30.9	42.4	6.7	-	-	1
Bambara groundnut *(Voandzeia subterranea)*									
Seed pods, dry	3.4	17.6	5.3	13.7	54.8	5.2	-	-	1
ROOT CROP PRODUCTS									
Giant taro/Alocasia *(Alocasia macrorrhiza)*									
Fresh tuber	81.2	0.6	0.1	-	-	-	0.15	0.05	1
Elephant yam *(Amorphophallus* spp.*)*									
Fresh tuber	74.2	5.1	0.4	0.6	18.0	1.7	0.05	0.02	1
Mangold/Mangel *(Beta vulgaris macrorhiza)*									
Fresh root	88.5	1.2	0.1	0.8	8.5	0.9	0.02	0.03	1
Sugar beet *(Beta vulgaris altissima)*									
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 *(Brassica napus)*									
Fresh root	91.0	0.8	0.1	1.1	6.3	0.7	0.06	0.02	1
Turnip *(Brassica rapa rapa)*									
Fresh root	91.0	1.2	0.2	1.0	5.8	0.8	0.06	0.02	1
Queensland arrowroot *(Canna edulis)*									
Fresh tuber	70.9	1.1	0.2	0.8	25.1	1.9	-	-	1
Taro/Old cocoyam/Dasheen *(Colocasia esculenta)*									
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 *(Cyrtosperma chamissonis)*									
Fresh tuber	60.0	1.0	0.5	1.0	36.5	1.0	-	-	1
Cufa/Tiger nut *(Cyperus esculentus)*									
Tuber	19.8	5.3	24.2	10.0	38.9	1.8	-	-	1
Carrot *(Daucus carota)*									
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 *(Dioscorea alata)*									
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 *(Dioscorea bulbifera)*									
Fresh tuber	65.0	1.3	<0.1	0.7	31.6	1.3	-	-	1
Yellow yam *(Dioscorea cayenensis)*									
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 *(Dioscorea esculenta)*									
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 *(Dioscorea dumetorum)*									
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)								
	H_2O	CP	EE	CF	NFE	Ash	Ca	P	Ref.[1]
Intoxicating yam *(Dioscorea hispida)*									
Fresh tuber	78.0	1.8	0.2	0.9	18.4	0.7	-	-	1
White yam *(Dioscorea rotundata)*									
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 *(Helianthus tuberosus)*									
Fresh tuber	77.9	2.1	0.2	1.2	16.4	1.7	0.02	0.10	1
Sweet potato/Spanish potato *(Ipomoea batatas)*									
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 *(Manihot esculenta)*									
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 *(Maranta arundinacea)*									
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 *(Oxalis tuberosa)*									
Fresh tuber	84.0	1.1	0.8	1.0	12.3	0.8	-	-	1
Yam bean/Potato bean *(Pachyrrhizus erosus)*									
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 *(Polymnia sonchifolia/P. edulis)*									
Fresh tuber	75.2	1.4	0.1	1.5	20.2	1.6	-	-	1
Kudzu *(Pueraria lobata)*									
Fresh root, peeled	68.6	2.1	0.1	0.7	27.1	1.4	0.02	0.02	1
Radish *(Raphanus sativus)*									
Fresh root	92.4	0.8	0.1	0.7	5.2	0.8	0.04	0.02	1
Potato/Irish potato *(Solanum tuberosum)*									
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 *(Solenostemon rotundifolius)*									
Fresh tuber	75.2	1.4	0.4	0.6	21.4	1.0	0.02	-	1
African yam bean *(Sphenostylis stenocarpa)*									
Fresh tuber	64.7	3.7	0.1	0.4	30.4	0.7	0.01	-	1
New cocoyam/Tannia *(Xanthosoma sagittifolium)*									
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 *(Ananas comosus)*									
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 *(Artocarpus altilis)*									
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

	Average composition (% by weight)								
Product	**H_2O**	**CP**	**EE**	**CF**	**NFE**	**Ash**	**Ca**	**P**	**Ref.**[1]
Breadnut tree *(Brosimum alicastrum)*									
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 *(Carica papaya)*									
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 *(Citrullus lanatus)*									
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 *(Citrus aurantiifolia)*									
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 *(Citrus limon)*									
Fruit pulp, dehydrated	7.0	6.4	1.4	14.8	65.1	5.3	-	-	1
Grapefruit *(Citrus paradisi)*									
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 *(Citrus reticulata)*									
Fruit pulp, dehydrated	13.0	7.0	4.9	9.6	61.1	4.4	1.40	0.12	1
Sweet orange *(Citrus sinensis)*									
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 (*Citrus* 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 *(Citrus* spp.*)*									
Citrus molasses, fresh	32.0	5.6	0.2	0.0	57.3	4.9	1.12	0.09	1
Coffee *(Coffea arabica/robusta)*									
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 *(Cucurbita* spp.*)*									
Fruit, ripe, fresh	91.5	1.2	0.4	1.0	5.2	0.7	0.02	0.04	1
Mango (Mangifera indica)									
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 *(Lycopersicon esculentum)*									
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

	Average composition (% by weight)								
Product	**H_2O**	**CP**	**EE**	**CF**	**NFE**	**Ash**	**Ca**	**P**	**Ref.**[1]
Apple *(malus sylvestris)*									
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 *(Musa sapientum/M. paradisiaca)*									
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 *(Persea americana)*									
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 *(Phoenix dactylifera)*									
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 *(Prunus 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 *(Punica granatum)*									
Fruit pulp, wet	74.0	2.2	1.3	4.3	17.2	1.0	-	-	1
Pear *(Pyrus communis)*									
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 *(Vitis spp.)*									
Fruit pulp, dried	11.0	9.5	7.7	16.0	50.4	5.4	-	-	1
Grape *(Vitis vinifera)*									
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 *(Medicago sativa)*									
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

	Average composition (% by weight)								
Product	**H_2O**	**CP**	**EE**	**CF**	**NFE**	**Ash**	**Ca**	**P**	**Ref.[1]**
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 *(Trifolium pratense)*									
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 *(Trifolium repens)*									
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 *(Vicia* spp.*)*									
Mid bloom	82.0	3.2	0.5	5.1	7.7	1.5	-	-	1
Trefoil *(lotus corniculatus)*									
Aerial part	77.4	4.0	0.8	5.8	9.9	2.1	0.34	0.05	1
Sesbania *(Sesbania* spp.*)*									
Leaves	77.0	6.6	0.5	2.6	11.0	2.3	0.52	0.10	1
Leadtree/Ipil-Ipil *(L. glauca)*									
Leaves	68.4	8.8	1.0	3.3	17.4	1.1	0.17	0.10	1
Saman *(S. saman)*									
Leaves	60.9	8.7	2.7	11.5	13.9	2.3	0.55	0.08	1
Kale *(Brassica oleracea)*									
Aerial crop	85.9	2.4	0.5	2.2	7.2	1.8	0.18	0.08	1
Mangold *(B. vulgaris)*									
Leaves and crowns (tops)	87.4	2.1	0.5	1.4	6.2	2.4	-	-	1
Sugar beet *(B. vulgaris)*									
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 *(M. esculenta)*									
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. batatas)*									
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 *(C. esculenta)*									
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 *(B. napus)*									
Leaves and crowns (tops)	88.0	2.3	0.5	1.5	5.5	2.2	-	-	1
Turnip *(B. rapa rapa)*									
Leaves and crowns (tops)	87.0	2.8	0.3	1.3	6.4	2.2	0.38	0.07	1
Carrot *(D. carota)*									
Leaves and crowns (tops)	84.0	2.1	0.6	2.9	8.0	2.4	0.31	0.03	1
Cabbage *(Brassica oleracea var. capitata)*									
Leaves	87.4	2.1	0.5	2.0	6.4	1.6	0.07	0.03	1
Brussels sprouts *(Brassica oleracea var.)*									
Leaves	85.0	4.9	0.4	1.6	6.9	1.2	0.04	0.08	1
Broccoli *(Brassica oleracea var. italica)*									
Leaves and stems	89.0	3.6	0.3	1.5	4.5	1.1	0.10	0.08	1
Lettuce *(Lactuca sativa)*									
Leaves	95.0	1.1	0.2	0.6	2.3	0.8	0.04	0.02	1
Ramie *(Boehmeria nivea)*									
Leaves	84.9	2.0	0.6	4.2	5.9	2.4	0.60	0.05	1

TABLE 50 – CONTINUED

	Average composition (% by weight)								
Product	H_2O	CP	EE	CF	NFE	Ash	Ca	P	Ref.[1]
Jerusalem artichoke *(H. tuberosus)*									
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 *(Amorphophallus* spp.)									
Leaves	86.5	3.0	0.5	5.6	-	-	-	-	1
Queensland arrowroot *(C. edulis)*									
Aerial part, early vegetative	83.5	1.7	0.8	3.2	8.1	2.7	-	-	1
Radish *(R. sativus)*									
Leaves	87.4	2.2	0.4	1.5	6.1	2.4	0.40	0.30	1
Sugar cane *(Saccharum officinarum)*									
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 *(Psidium guajava)*									
Leaves	62.5	3.8	2.8	7.2	20.8	2.9	0.41	0.10	1
Papaya *(C. papaya)*									
Leaves	77.4	5.3	1.1	3.6	9.7	2.9	0.31	0.06	1
Breadnut tree *(B. alicastrum)*									
Leaves	61.1	5.4	1.3	10.3	18.9	3.0	-	-	1
Pineapple *(A. comosus)*									
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 *(Cucurbita* spp.)									
Vine	82.5	1.5	0.9	5.6	6.6	2.9	-	-	1
Alocasia *(A. macrorrhiza)*									
Leaves	90.4	2.3	0.6	1.2	3.8	1.7	0.15	0.01	1
Banana *(Musa 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 *(Artocarpus heterophyllus)*									
Leaves	60.3	6.8	1.7	8.3	18.2	4.7	0.74	0.08	1
Neem tree *(Azadirachta indica)*									
Leaves	64.2	4.8	2.2	5.3	19.8	3.7	0.69	0.06	1
Groundnut *(A. hypogaea)*									
Leaves	73.1	4.7	0.6	5.4	13.9	2.3	0.25	0.05	1
Pigeon pea *(C. cajan)*									
Aerial part (forage)	71.0	5.9	1.5	8.1	11.7	1.8	0.22	0.06	1
Jack/Sword bean *(C. ensiformis)*									
Aerial part (forage)	76.8	5.2	0.5	6.4	8.4	2.7	-	-	1
Carob *(C. siliqua)*									
Leaves and stem	75.7	5.4	0.6	7.5	8.5	2.3	-	-	1
Chickpea *(C. arietinum)*									
Young shoots	60.6	8.2	0.5	-	-	3.5	0.31	0.21	1
Cluster bean *(C. tetragonoloba)*									
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 *(L. purpureus)*									
Aerial part	81.6	2.5	0.9	5.8	6.9	2.3	0.30	0.06	1
Soybean *(G. max)*									
Aerial part	74.0	3.7	1.1	10.5	8.3	2.4	0.35	0.07	1
Grass pea *(L. sativus)*									
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

	Average composition (% by weight)								
Product	H_2O	CP	EE	CF	NFE	Ash	Ca	P	Ref.[1]
Lupin *(Lupinus spp.)*									
Aerial part	88.3	3.1	0.3	2.2	4.5	1.6	0.15	0.03	1
Velvet bean *(M. pruriens)*									
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 *(V. faba)*									
Stems and leaves	85.0	2.5	0.4	4.9	5.4	1.8	0.22	0.04	1
Winged bean *(P. tetragonolobus)*									
Stems and leaves	78.9	6.3	1.0	4.1	7.9	1.8	0.37	0.12	1
Pea *(P. sativum)*									
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 *(V. mungo)*									
Aerial part	84.0	3.1	0.4	4.3	5.6	2.6	0.32	0.04	1
Horse gram *(V. unguiculata)*									
Aerial part	81.8	3.2	0.4	3.9	9.4	1.3	0.10	0.05	1
Red bean *(V. umbellata)*									
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 *(M. sativa)*	79.2	4.3	1.8	5.0	7.1	2.6	0.40	0.10	1
Red clover *(T. pratense)*	74.6	3.2	1.3	6.6	11.3	3.0	0.43	0.06	1
Maize/corn *(Z. mays)*	75.0	2.4	1.1	6.1	13.9	1.5	0.09	0.08	1
Oats *(A. sativa)*	76.0	2.5	0.7	7.9	11.2	1.7	0.10	0.07	1
Rye *(S. cereale)*	68.0	4.1	1.1	10.9	13.4	2.5	0.13	0.10	1
Sorghum *(S. bicolor)*	70.0	2.2	0.9	8.2	16.1	2.6	0.10	0.06	1
Wheat *(Triticum spp.)*	72.5	2.8	0.7	8.0	13.8	2.2	0.08	0.08	1
Soybean *(G. max)*	73.0	4.8	0.7	7.8	11.0	2.7	0.37	0.13	1
Pea *(P. sativum)*, vines only	76.0	3.1	0.8	7.2	10.8	2.1	0.31	0.06	1
Urd *(V. mungo)*	72.7	3.8	1.3	5.2	9.8	7.2	-	-	1
Sugar beet *(B. vulgaris)*, crowns with tops	79.0	2.8	0.6	2.9	7.6	7.1	0.38	0.05	1
Pineapple *(A. comosus)*, 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 *(Paspalum notatum)*	9.2	4.3	1.5	20.5	59.1	5.4	0.41	0.17	1
Orchard grass *(Dactylis glomerata)*, early bloom	11.0	13.4	2.5	27.6	37.7	7.8	-	-	1
Orchard grass *(Dactylis glomerata)*, late bloom	9.0	7.6	3.1	33.6	37.5	9.2	-	-	1
Pangola grass *(Digitaria decumbers)*	12.0	6.7	1.5	27.4	40.7	11.7	0.40	0.20	1
Rye grass *(Lolium perenne)*	14.0	7.4	1.9	26.1	40.7	9.9	0.56	0.28	1
Bermuda grass *(Cynodon dactylon)*	9.7	7.3	1.9	29.0	44.9	7.2	0.43	0.16	1
Alfalfa/lucerne *(M. sativa)*	9.5	12.3	1.4	31.6	38.2	7.0	1.33	0.24	1
Red clover *(T. pratense)*	11.9	12.9	2.8	26.2	39.6	6.6	1.11	0.17	1
White clover *(T. repens)*	12.5	17.6	2.9	20.9	38.1	8.0	1.21	0.28	1
Crimson clover *(T. incarnatum)*	13.0	16.1	2.1	26.3	32.9	9.6	1.22	0.19	1
Trefoil *(L. corniculatus)*	8.0	15.0	2.3	28.3	39.9	6.5	1.57	0.25	1
Barley *(H. vulgare)*	13.0	7.6	1.9	24.1	46.8	6.6	0.20	0.23	1
Oats *(A. sativa)*	12.0	8.2	2.5	27.6	42.8	6.9	0.22	0.20	1
Sorghum *(S. bicolor)*, early vegetative	8.0	14.7	3.0	25.8	36.5	12.0	0.46	0.17	1
Sorghum (*S. bicolor*), late vegetative	8.0	11.0	2.4	30.4	38.1	10.1	0.37	0.18	1

TABLE 50 – CONTINUED

	Average composition (% by weight)								
Product	**H_2O**	**CP**	**EE**	**CF**	**NFE**	**Ash**	**Ca**	**P**	**Ref.**[1]
Sorghum *(S. bicolor)*, early bloom	7.0	7.0	1.9	35.3	40.4	8.4	0.28	0.13	1
Wheat *(Triticum* spp.)	12.0	7.4	1.9	24.6	47.9	6.2	0.13	0.17	1
Groundnut *(A. hypogaea)*	9.2	9.2	2.7	30.3	40.2	8.4	0.97	0.13	1
Pigeon pea *(C. cajan)*	11.2	14.8	1.7	28.9	39.9	3.5	-	-	1
Cluster bean *(C. tetragonoloba)*	9.3	16.5	1.3	19.3	41.2	12.4	-	-	1
Soybean *(G. max)*	10.0	15.3	3.9	27.0	36.8	7.0	1.10	0.22	1
Grass pea *(L. sativus)*	12.8	13.0	2.4	31.8	32.0	8.0	-	-	1
Lentil *(L. esculenta)*	10.2	4.4	1.8	21.4	50.0	12.2	-	-	1
Lupin *(Lupinus spp.)*	5.9	15.4	3.1	23.3	44.6	7.7	0.99	0.19	1
Velvet bean *(M. pruriens)*	9.4	13.4	2.4	27.8	38.9	8.1	-	-	1
Pea *(P. sativum)*	11.3	12.6	2.3	27.4	39.4	7.0	1.20	0.25	1
Mung bean *(V. radiata)*	9.7	9.8	2.2	24.0	46.6	7.7	-	-	1
Cowpea *(V. unguiculata)*	9.7	17.4	2.7	23.9	35.6	10.7	1.33	0.32	1
Pineapple *(A. comosus)*, aerial part	11.0	6.9	2.5	26.3	47.8	5.5	0.35	0.21	1
Sweet potato *(I. batatas)*, vines	13.4	14.2	4.5	23.7	33.3	10.9	-	-	1
STRAWS AND CHAFF									
Barley *(H. vulgare)*	11.8	3.4	1.6	37.5	40.4	5.3	0.30	0.07	1
Maize/corn *(Z. mays)*	10.0	5.3	1.2	33.4	44.9	5.2	0.44	0.08	1
Oats *(A. sativa)*, straw	10.5	3.7	2.1	35.8	41.5	6.4	0.25	0.08	1
Oats *(A. sativa)*, chaff	14.0	6.0	2.1	22.8	44.8	10.3	-	-	1
Rice *(O. sativa)*	8.0	3.9	1.0	31.8	40.5	14.8	0.24	0.08	1
Rye *(S. cereale)*	11.7	2.9	1.5	37.8	42.3	3.8	0.23	0.08	1
Wheat (*Triticum spp.)*	10.4	2.7	1.4	36.4	41.4	7.7	0.15	0.06	1
Soybean *(G. max)*	12.0	4.6	1.3	38.9	37.6	5.6	1.40	0.05	1
Chickpea *(C. arietinum)*	9.4	5.4	0.4	40.2	32.6	12.0	0.31	0.11	1
Lima bean *(P. lunatus)*	10.0	6.8	1.6	27.9	46.3	7.4	0.09	0.37	1
Kidney bean *(P. vulgaris)*	11.0	6.0	1.5	40.0	34.0	7.5	1.70	0.10	1
Pea *(P. sativum)*	13.0	8.1	1.5	34.4	37.0	6.0	0.85	0.09	1
Broad bean *(V. faba)*	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 *(M. sativa)*	7.8	17.3	2.7	24.4	38.3	9.5	1.37	0.23	1
Cassava *(M. esculenta)*	10.0	27.0	4.6	27.1	25.0	6.3	0.60	0.35	1
Papaya *(C. papaya)*	7.5	21.7	3.9	9.8	45.7	11.4	-	-	1
Bambarra groundnut *(V. subterranea)*	9.8	14.3	1.6	28.6	38.9	6.8	-	-	1
Cabbage *(B. oleracea var. capitata)*	11.7	14.9	3.9	8.4	54.1	7.0	-	-	1
Banana *(Musa* spp.)	5.9	9.3	11.1	22.6	42.8	8.3	0.71	0.23	1
Cluster bean (*C. tetragonoloba)*	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 *(C. cinerariifolium)*, marc (fresh)	22.7	11.9	0.5	20.6	38.2	6.1	0.41	0.19	1
Pyrethrum *(C. cinerariifolium)*, marc, sun cured	14.5	12.6	0.5	20.6	45.4	6.4	0.34	0.26	1
Sago palm *(Metroxylon sagu)*, meal	14.0	1.8	1.1	4.9	74.4	3.8	0.05	0.04	1
Sago palm *(Metroxylon sagu)*, refuse (starch extr.)	22.9	2.0	0.2	7.7	51.0	16.2	0.29	0.02	1
Sugar cane *(S. officinarum),* bagasse, dried	9.6	1.5	0.8	40.3	42.7	5.1	-	-	1
Sugar cane *(S. officinarum),* bagasse, fresh	45.0	0.8	0.2	26.9	24.1	3.0	0.19	0.15	1
Sugar cane (*S. officinarum)*, filter press mud, fresh	75.5	2.7	2.6	3.0	10.9	5.3	0.64	0.27	1
Sugar cane (*S. officinarum)*, molasses, final	25.0	3.0	trace	trace	63.5	8.5	0.70	0.10	1
Sugar cane *(S. officinarum)*, 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: Tiamiyu *et al.* (2007);

Cocoa husks: Clariid catfish: Fagbenro (19950; 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 Bassey (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: Oresegun *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: Nandeesha *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 sponeococcum 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 Laminariacae and Fucaeae. 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-H_2O; Crude Protein-CP; Lipid or Ether Extract-EE; Crude Fibre-CF; Nitrogen-Free Extractives-NFE; Ash; Calcium-Ca; Phosphorus-P

	Average composition (% by weight)								
Product	**H_2O**	**CP**	**EE**	**CF**	**NFE**	**Ash**	**Ca**	**P**	**Ref.[1]**
FRESHWATER AQUATIC MACROPHYTES									
Alligator weed *(Alternanthera philoxeroides)*									
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 *(Azolla* 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 *(Ceratophyllum demersum)*									
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 *(Chara vulgaris/Chara* 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 *(Eichhornia crassipes)*									
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 *(Elodea canadensis)*									
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 *(Hydrilla verticillata)*									
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 *(Ipomoea aquatica/I. reptans)*									
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 *(Justicia americana)*									
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 *(Lemna minor)*									
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 *(Myriophyllum* 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 *(Najas guadalupensis)*									
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 *(Pistia stratiotes)*									
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

	Average composition (% by weight)								
Product	**H_2O**	**CP**	**EE**	**CF**	**NFE**	**Ash**	**Ca**	**P**	**Ref.**[1]
Pond weed *(Potamogeton* 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 *(Sagittaria* 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 *(Salvinia auriculata/S. molesta)*									
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 *(Sparganium americanum)*									
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 *(Typha latifolia)*									
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 *(Wolffia* 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									
Chaetomorpha spp., fresh (green seaweed)	90.4	3.1	0.6	1.1	2.5	2.3	-	-	1
Enteromorpha intestinalis, fresh (green seaweed)	81.4	3.7	0.5	-	-	6.0	-	-	1
Enteromorpha (lumot), dried (Philippines)	15.2	13.8	1.9	9.3	36.9	38.1	-	-	3
Ulva spp. (green seaweed), dried meal	11.5	8.0	0.15	-	-	26.4	-	-	7
Laminariales/Fucales spp. (brown seaweed) (d)	8.9	6.5	0.5	6.6	42.3	35.0	2.50	0.26	1
Gracilaria spp. (red seaweed), dried	7.0	10.2	0.4	5.8	44.8	38.8	-	-	3
Kappaphycus 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 polyrhiza*) leaf meal (fermented): Rohu: Bairagi *et al.* (2002); **Duckweed** (*Spirodela polyrhiza)*: 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: Penaflorida and Golez (1996);

Hypnea cervicornis: Shrimp: Da Silva and Barbosa (2009);

Kappaphycus alvarezii: Shrimp: Penaflorida 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 attractibility (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 produçt 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) surpressing 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); Rodehutscord *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); Grouper: 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 Cerqeira (1998); Sole: Reig *et al.* (2003); Sturgeon: Shamushaki *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: Penaflorida 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 $Ca(I0_3)_2.H_20$) is the calcium salt of iodic acid generally expressed as $Ca(10_3)_2$ 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 $Ca_5(I0_6)_2$) 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 $CaSO_4$; IFN 6-0l-090 Calcium sulphate dihydrate $CaS0_4.2H_20$) is the calcium salt of sulphuric acid generally expressed as $CaSO_4$ 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 6-0 1-566 Cobalt carbonate) is the cobalt salt of carbonic acid generally expressed as $CoCO_3$ 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 $CoSO_4.H_20$; IFN 6-01-564 Cobalt sulphate heptahydrate $CoSO_4.7H_20$) 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. $CuCl_2.2H_20$) 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_20; IFN 6-01-711 Cupric oxide CuO) is the oxide form of copper generally expressed as CuO or Cu_20. Minimum copper (Cu) content must be specified.

Copper sulphate (IFN 6-01-717 Cupric sulphate anhydrous; IFN 6-01-719 Cupric sulphate pentahydrate $CuSO_4.5H_20$) 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 $Fe_2(S0_4)_3$ and its hydrated forms. Minimum iron (Fe) content must be specified.

Ferrous carbonate (IFN 6-0 1-863 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 $FeSO_4.H_20$; IFN 6-20-734 Ferrous sulphate heptahydrate $FeSO_4.7H_20$) 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 $Fe_2 0_3$. 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 pentyhydrate) is a magnesium salt of carbonic acid generally expressed as $MgCO_3$ $Mg(OH)_2$ 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 $Mn_3(P0_4)_2$ 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 $MnHP0_4$ 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; IFIN 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 (IFN14 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 furnaced phosphoric acid) is a calcium salt of phosphoric acid generally expressed as $CaH_4(P0_4)2$ 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 $(NaPO_3)x.H_20$ (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 $Ca_3(P04)_2$. 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 $Kl0_3$. 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_2S0_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 $NaI0_3$. 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 Nal. 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	$Ca(H_2PO_4)_2.H_2O$	15.9% Ca, 24.6% P
Dicalcium phosphate, anhydrous	$CaHPO_4$	29.46% Ca, 22.77% P
Dicalcium phosphate, dihydrate	$CaHPO_4.2H_2O$	23.29% Ca, 18.01% P
Tricalcium phosphate	$Ca_3(PO_4)_2$	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	$CrCl_3.6H_2O$	19.6% Cr
Chromium picolinate	$Cr(C_6H_4NO_2)_3$	12.4% Cr
Cobalt sources		
Cobalt chloride, pentahydrate	$CoCl_2.5H_2O$	26.80% Co, 32.28% Cl
Cobalt chloride, hexahydrate	$CoCl_2.6H_2O$	24.77% Co, 29.84% Cl
Cobalt sulphate, monohydrate	$CoSO_4.H_2O$	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	$CuSO_4.5H_2O$	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	$C_2H_8N_2.2HI$	78.73% I
Iron sources		
Ferrous sulphate, heptahydrate	$FeSO_4.7H_2O$	19.2% Fe, 34.59% SO_4
Ferous (II) carbonate	$FeCO_3$	48.2% Fe
Ferrous oxide	FeO	77.7% Fe
Magnesium sources		
Magnesium chloride	$MgCl_2.6H_2O$	12.0% Mg
Magnesium oxide	MgO	60.3% Mg
Magnesium carbonate	$MgCO_3$	28.84% Mg, 71.16% CO_3
Dimagnesium phosphate, trihydrate	$MgHPO_4.3H_2O$	14.0% Mg, 17.8% P
Magnesium sulphate	$MgSO_4$	20.19% Mg, 79.81% SO_4
Magnesium sulphate, heptahydrate	$MgSO_4.7H_2O$	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	$MnCl_2.4H_2O$	27.76% Mn, 35.86% Cl
Manganese sulphate	$MnSO_4$	36.36% Mn, 63.64% SO_4
Manganese sulphate, hydrate	$MnSO_4.H_2O$	32.49% Mn, 56.86% SO_4
Manganese sulphate, tetrahydrate	$MnSO_4.4H_2O$	24.63% Mn, 43.10% SO_4
Molybdenum sources		
Sodium molybdate, dehydrate	$Na_2MoO_4.2H_2O$	39.66% Mo, 19.01% Na
Sodium molybdate, pentahydrate	$NaMO_4.5H_2O$	35.15% Mo, 8.43% Na
Phosphorus sources		
Monocalcium phosphate, monohydrate	$Ca(H_2PO_4)_2.H_2O$	24.6% P, 15.9% Ca
Dicalcium phosphate, anhydrous	$CaHPO_4$	22.77% P, 29.46% Ca
Dicalcium phosphate, dehydrate	$CaHPO_4.2H_2O$	18.01% P, 23.29% Ca
Tricalcium phosphate	$Ca_3(PO_4)_2$	19.97% P, 38.76% Ca
Potassium orthophosphate	K_2HPO_4	17.79% P, 44.90% K
Potassium dihydrogen orthophosphate	KH_2PO_4	22.76% P, 28.73% K
Sodium hydrogen orthophosphate	Na_2HPO_4	21.82% P, 32.40% Na
Sodium dihydrogen orthophosphate, hydrate	$NaH_3PO_4.H_2O$	22.45% P, 16.67% Na
Sodium dihydrogen orthophosphate, dihydr.	$NaH_3PO_4.2H_2O$	19.86% P, 14.74% Na
Dimagnesium phosphate, trihydrate	$MgHPO_4.3H_2O$	17.8% P, 14.0% Mg
Rock phosphate	$(Ca_3(PO_4)_2)_3CaF_2$	13.00% P, 35.00% Ca
Potassium sources		
Potassium chloride	KCl	52.44% K, 47.56% Cl
Potassium carbonate	K_2CO_3	56.58% K, 43.42% CO_3
Potassium bicarbonate	$KHCO_3$	39.05% K, 60.95% HCO
Potassium acetate	$KC_2H_3O_2$	39.84% K, 60.16% Acetate
Potassium orthophosphate	K_3PO_4	55.25% K, 14.59% P
Potassium sulphate	K_2SO_4	44.87% K, 55.13% SO_4
Selenium sources		
Sodium selenite	Na_2SeO_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_2SO_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	$ZnSO_4.H_2O$	36.42% Zn, 53.55% SO_4
Zinc sulphate, heptahydrate	$ZnSO_4.7H_2O$	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 D_3)".

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 D_2)".

Vitamin B_{12} supplement (IFN 7-05-146 Vitamin B_{12} supplement) is a feeding material used for its vitamin B_{12} activity. It must contain a minimum vitamin B_{12} 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 D_3 supplement (IFN 7-05-699 Vitamin D_3 supplement) is a feeding material used for its vitamin D_3 activity. lt must contain a minimum of 100 000 International Units of vitamin D_3 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

Erythrobic 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 B_1 sources

Potassium meta-bisulphite (IFN 8-26-203), FDA Reg. 582.3637,
Limitations or restrictions: not for use in meats or vitamin B_1 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 B_1 sources

Sodium metabisulphite (IFN 8-26-306), FDA Reg. 582.3766,
Limitations or restrictions: not for use in meats or vitamin B_1 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 B_1 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 B_1 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; Penaflorida 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 Tİryakİodđlu, 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 l-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, P_20_5 and K_20 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
Calcareous[2]					
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	$(NH_4)_2SO_4$	-	21.2	-	-
Ammonium nitrate	NH_4NO_3	-	35.0	-	-
Urea	$CO(NH_2)_2$	-	46.7	-	-
Ammonium phosphate, dibasic	$(NH_4)_2HPO_4$	-	21.2	23.5	-
Ammonium phosphate, monobasic	$(NH_4)H_2PO_4$	-	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_2SO_4	-	-	-	44.9
Sulphate of potash-magnesia	$K_2SO_4.2MgSO_4$	-	-	-	18.8
Phosphate fertilizers					
Di-calcium phosphate, anhydrous	$CaHPO_4$	29.5	-	22.8	-
Bone meal		30.0	-	15.0	-
Rock phosphate (fluoroapatite)	$(Ca_3(PO_4)_3CaF_2$	35.0	-	13.0	-
Single superphosphate[3]	$Ca(H_2PO_4)_2 + CaSO_4$	-	-	7–8.7	-
Triple superphosphate[4]	$Ca(H_2PO_4)_2$	-	-	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 $CaCO_3$, $CaMg(CO_3)_2$ and CaO being 100%, 109%, 136% and179% respectively (Boyd, 1979).
[3] Super phosphate is a mixture of $Ca(H_2PO_4)_2$ and $CaSO_4$ (gypsum) and has a P_2O_5 equivalence of 16–20%, 85% of which is water soluble (Boyd, 1979).
[4] Triple superphosphate is a more concentrated form of $Ca(H_2PO_4)_2$ and has a P_2O_5 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
Azolla sp.	-	3.68	0.20	0.15
Lemna sp.	-	3.31	0.20	0.69
Chara vulgaris	-	1.27	0.19	0.84
Ceratophylum sp.	-	3.30	0.47	5.90
Elodia Canadensis	-	3.29	0.51	3.26
Hydrilla sp.	-	2.70	0.28	2.90
Myriophyllum sp.	-	2.81	0.17	1.20
Pistia stratiotes	-	2.10	0.30	3.50
Potamogeton sp.	-	2.51	0.33	2.28
Typha 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; Petrinec *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) score[1] of different animal and plant feed ingredients compared with the estimated EAA requirement profile of fish and crustaceans[2] – 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[2]
Ingredient EAA profile compared with estimated dietary EAA requirements of fish[3]													
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
Bambarra 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													
Pseudomonas/*Methylophilus* 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 (*S. cerevisiae*)	89	92	65	95	133	107	87	118	108	153	88	108	98
Extracted yeast (*S. cerevisiae*)	80	93	67	89	125	129	79	125	111	141	95	98	74
Torula yeast (*T. utilis*)	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 shrimp[4]													
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													
Pseudomonas/*Methylophilus* 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 (*S. cerevisiae*)	53	122	82	127	121	102	137	123	85	144	85	121	91
Extracted yeast (*S. cerevisiae*)	48	122	85	118	114	123	124	131	87	133	91	109	85
Torula yeast (*T. utilis*)	51	112	68	124	131	94	133	122	92	105	110	119	82
Candida spp. (alkane substrate)	44	112	97	137	124	113	126	125	93	155	86	95	111
Aspergillus oryzae (waste starch)	58	98	58	117	111	106	108	122	154	160	72	114	102
Rhodotorula pilimanae	78	24	118	134	103	99	163	118	66	33	69	123	139
Rhodotorula pilimanae	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]	
Fishery products	**Range of use**	**Mean use**	**Range of use**	**Mean use**
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 B_{12} 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 monogastic 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

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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

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I1142E/1/10.09/1800