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SUMMARY - The development of Mediterranean aquaculture from the early eighties has set up a new industry which is planned to produce around 50,000 tons of fish in 1996. According to present technical ratios, this represents roughly 100,000 tons/year of aquafeed shared among over 20 fish feed manufacturers. Pressed or extruded pellets, lipid/protein content, vitamin levels, essential amino and fatty acids, floating or sinking pellets ... are still questions frequently asked to fish feed manufacturers who use a wide range of raw materials and techniques to adapt their products to the fish needs in a highly competitive environment. Traditionally situated in northern countries for historical reasons, all large fishfeed manufacturers usually include a southern development in their strategy. Other more recent manufacturers have directly started their activity in Mediterranean countries. Although many feeds on the seabass and seabream market come directly from the salmon and trout industry, some noticeable R&D have been made to produce specific feeds for these species, formulated to better cover the needs of these fish and so help the fish farming industry to achieve better performance and minimize pollution discharge to the environment.

Key words: Raw materials, extruded, pressed, fish feed, Mediterranean sea.

RESUME *- "Fabrication et production d'un aliment commercial pour poisson". Le développement de l'aquaculture méditerranéenne depuis le début des années 80 a permis l'émergence d'une industrie nouvelle qui produira environ 50.000 tonnes de poisson en 1996. Avec les ratios techniques actuels, cela représente plus de 100.000 tonnes d'aliments par an, produits par plus de vingt fabricants. Aliments pressés ou extrudés, rapport lipides/protéines, niveaux vitaminiques, acides aminés et acides gras essentiels, granulés flottants ou plongeants, ... sont autant de questions auxquelles les fabricants d'aliments composés doivent souvent répondre. Ils utilisent pour cela un large éventail de matières premières et de techniques de façon à adapter au mieux leurs produits aux besoins des poissons, dans un environnement hautement compétitif. Traditionnellement originaires des pays nordiques pour des raisons historiques, tous les grands provendiers incluent une composante méditerranéenne dans leurs plans de développement. D'autres plus récents, ont directement émergé dans les pays méditerranéens. Bien que beaucoup d'aliments loup et daurade présents sur le marché dérivent directement des formules saumon ou truite, des efforts notables de R&D sont faits pour obtenir des produits spécifiques, formulés pour mieux couvrir les besoins des poissons méditerranéens et permettre aux aquaculteurs d'améliorer leurs ratios technico-économiques tout en réduisant les effluents polluants rejetés dans le milieu.*

Mots-clés *: Matières premières, extrudé, pressé, aliment poisson, Méditerranée.*

FISH FEED MARKET IN THE MEDITERRANEAN

Fish production

Farmed fish production in the Mediterranean at industrial level actually began in the early eighties (Italy 1975, France 1984, Greece 1983, Tunisia 1986). The first industrially integrated projects (hatchery and ongrowing) derived from results of laboratory research, were soon followed by small family projects in the most suitable locations (Greece). This move, supported at first by high prices (100 to 120 FF/kg), together with high EC subsidies for investment, led to the creation of a genuine industry which presently encompasses between 300 to 400 farms all around the Mediterranean region, and even beyond (Kuwait, Saudi Arabia). Most of these farms are found in Greece where, according to the European Federation of Aquaculture (F.E.A.P.), 225 firms exploit this source, of which three are quoted on the second Athens stockmarket. However, a sharp fall in fish prices at the end of 1992 and the devaluation of the Italian lira, have brought about many restructurings in this field, which are still going on today.

Table 1 shows the estimates for sales of farmed sea bass *(Dicentrarchus labrax)* and sea bream *(Sparus aurata)* in different countries within the Mediterranean region:

Table 1. Annual estimated sales of sea bass and sea bream by country-within the Mediterranean region (values given in metric tons)

Country	1994	1995	1996	1997
Greece	12000	16000	20000	23000
Italy	4000	6000	7000	8000
Spain	3200	4000	5400	6000
Turkey	2000	2500	3500	4000
France	2400	3700	3900	3800
Morocco	1000	1300	1500	1600
Tunisia	700	400	500	550
Malta	550	1300	1400	1500
Cyprus	550	600	700	750
Croatia	1000	1000	1100	1150
Israel	500	800	1000	1300
Egypt	50	100	150	200
Portugal	700	1000	1000	1500
Kuwait	50	200	300	500
TOTAL	29250	38900	47450	53850

This soaring production will probably be slowed down by market saturation (Italy), unless new marketing strategies, new species *(Pagrus pagrus, Puntazzo puntazzo, Dentex dentex...)*, new markets (North of Europe, Greece) or accidental losses of production (diseases) boost demand.

Feed production

Feedstuffs necessary for the production of such quantities of fish, are most often dry, pressed or extruded feed, and are currently produced by some twenty industrial companies, of which only three major firms exclusively produce only fish feed.

Given the production estimates mentioned in Table 1, the estimated total feed production (based on the feed conversion ratios usually found in Mediterranean species) in the region is currently believed to be between 105 to 120,000 tons a year.

Table 2. Estimates of fish feed produced within the Mediterranean region for

sea bass and sea bream in tons	1994	1995	1996	1997
Fish production	29250	38900	47450	53850
Average FCR	2.6	2.5	2.4	2.2
Feed	76,050	97,250	113,880	118,470

RAW MATERIALS

Depending on the manufacturers, feed formulation more or less approximates to the nutrient requirements of the farmed species. However, most formulations usually include a certain number of raw materials which account for, depending on their quality and the manufacturing organization, between two thirds to three quarters of the feed final selling price.

Scientific research on the specific nutrient requirements of fish is much more recent than research on other animal species where scientific research only really commenced after World War II, during the emergence of the first aquaculture experiences in western Europe. Lately, however, this research effort has speeded up considerably along with the development of new aquaculture enterprises.

Considering what a living organism needs to feed on, the first thing which comes to our minds is to cover the energy requirements in order to ensure the living bodily functions (i.e. moving, growth, reproduction, metabolism). The energy is provided by the intake and metabolism of proteins, lipids and carbohydrates. In addition the animal also needs a certain number of micro-nutrients to be able to grow, such as vitamins and minerals. In the present paper we will deal with the main macro-nutrients which make up the composition of industrial fish feeds. The vitamins and minerals whose biological role is highly important but whose technological role is minimal will not be discussed here.

When a feed formulation is required, a wide range of raw materials are available, and can be classified according to their major components, namely proteins, lipids or carbohydrates (Nitrogen Free Extract = N.F.E.).

The aim to be achieved is the production of feeds which are easy to handle and economically acceptable, which allows us to regularly produce high-quality fish for consumption.

Regulation in force

The regulation on feed products states which products can be used for each animal species. Some threshold values are defined for a group of undesirable substances (for instance, heavy metals and pesticides) and additives (certain vitamins, antioxidants, pigments,...) which can be contained in raw materials.

The raw materials and additives are arranged in positive lists, that is, only the substances quoted in the list can be used within the limits of the prescribed values. These rules have been set up in order to protect farm animals and human beings who consume them.

Energy and nutrients

It is often considered in human nutrition that "energy is like a bottleneck in feeding matters". When the energetic requirements are satisfied, one stops eating, no matter whether one has ingested or not all the essential nutrients. In other words, appetite is regulated through covering all the energetic requirements.

If one has eaten a plate of chips, which contains few proteins, but has fulfilled their basic energetic requirements, one cannot then eat, three plates of fish to make up for the protein deficit. This can be applied generally to most animal species. Under normal circumstances, organism regulating systems are very precise, but one may ingest more energetic substances than necessary, and as a result having malnutrition. It follows therefore that it is necessary to cover at the same time the essential nutritional requirements as well as the energetic requirements in order to have a correct nourishment.

For most living organisms there exists an average optimal rate of the energy supplied by the three groups of nutrient classes (proteins, lipids and carbohydrates). The term "average optimal rate" means that, for certain oganisms, the limits are more restrictive than for others in such a way that, for instance, the lipids can replace partially the carbohydrates and vice versa, or a specific amount of protein can be replaced by lipids, with everything being in agreement with the aims fixed in terms of growth rate and carcass quality.

The fish we are now dealing with are strictly speaking carnivores, or almost carnivores. Their ability to metabolise carbohydrates is therefore very poor. On the contrary, it is possible to replace a part of the costly proteins by lipids in their feed without producing excessively fatty fish. It has been proved true at different levels according to species, whenever we deal with reasonable limits and IF THE FEEDS DISTRIBUTION IS ADEQUATELY CONTROLLED. If the goal is to achieve a good growth rate together with a good conversion rate, the different nutrients must be present in adequate proportions in the feeds and must have a high degree of digestibility.

As an indication, the essential amino acids requirements for different fish species is presented in Table 3:

Table 3. Amino acid requirements and tissue composition of various fish species (values expressed as % of protein Dietary) (adapted from New, 1987)

Amino acid	Requirements Rainbow trout	Gilthead seabream	Composition Seabass flesh	Seabass roe
Arginine	3.5	<2.6	6	6
Histidine	1.6		2.3	2.4
Isoleucine	2.4		3.7	4.2
Leucine	4.4		8.5	9.5
Lysine	5.3	5	10.1	7.7
Methionine	1.8	4	3.7	2.7
Phenylalanine	3.1		6	6.6
Threonine	3.4		4.8	5.2
Tryptophan	0.5	0.6	1.1	
Valine	3.1		4.2	5.3

It follows from the data presented that the feeds used for rearing these species must contain similar dietary amino acid levels. A review of the main raw materials and their quality criteria is given below.

Fish meal

Fish meal is a well-known source of proteins which is strongly demanded by the animal feeds industry. This is due to its balanced amino acid content, which makes it an ideal feed for many domestic animals. Moreover, its use to adjust (improve) the amino acid content of other dietary protein sources also contributes to increase demand.

As its name points out, fish meal is derived from captured fish, including whole fish, fish scraps from fillets, and preserves of industries. Most of the main capture fishery producers devote the main part of this activity to fish meal production.

Table 4. Amino acid composition of low temperature fish meal (quot. Nordsilmel)

Amino acid	Percentage of total protein content
Arginine	5.9
Histidine	2.3
Isoleucine	4.4
Leucine	7.5
Lysine	8.0
Methionine	3.0
Phenylalanine	4.1
Threonine	4.1
Valine	4.9

Raw materials for fish meals

The raw materials used in fish meal manufacture come almost entirely from species which are not often used for human consumption (either due to their size, or because they are very abundant). For example, in Denmark the species are essentially the greater sand eel and the sprat, in Norway and Iceland the capelin and the blue whiting, and in Chile and Peru the anchovy. Other fish species used for the manufactured fishmeal include herring, mackerel and horse mackerel.

Raw fish quality

The quality of raw materials is essential for the final product quality. The same is also true for the fish meal and fish oil.

As all the higher living organisms, fish possess when living a certain number of protection systems against bacteria and also have an enzymatic activity in their body fluids and digestive tract. When a fish is captured and dies, these mechanisms are disrupted and tissue lysis (enzymatic self-decomposition) and decay (bacterial decomposition) start.

This tissue autolysis or enzymatic decomposition occurs in all dead bodies. The higher the temperature, the faster the enzymatic decomposition (maximum at 40 to 50ºC for fish). Similarly, since lysis is mainly activated by proteases, enzymes which hydrolyze proteins, and as proteins generally ensure tissue structure, the proteolysis is usually accompanied by a decrease in flesh water holding capacity, which in turn renders the flesh soft and inconsistent. If this autolysis is allowed to continue, the final result will be a soup consisting of water, amino acids and peptides, and oil. This process is also used commercially in order to produce fish hydrolysate (nuoc-mam). The fish oils will be attacked by lipases (enzymes which hydrolyze fatty acids), concentrated in the liver and in the digestive tract. These oils and lipids are broken down into glycerol and free fatty acids.

In general, fish in a late stage of decomposition is to be avoided for fish meal manufacturing because it leads, apart from manufacturing difficulties, to the production of highly hygroscopic meals which contain high levels of free amino acids and many free fatty acids. In general, fishmeals rich in free fatty acids are usually considered to be of low quality.

However, the enzymatic decomposition of fish does not always result in a reduction of its nutritional value. Actually, the decomposition process may render the fish meal more easily digestible for certain animals. This factor is positively exploited in the fish hydrolysate, provided that hydrolysis is conducted under controlled conditions.

The putrefaction, or bacterial decomposition of fish is more serious and it is often accompanied by a stinking smell and the production of certain noxious substances. Bacterial decomposition is dependent upon temperature, and proceeds twice as fast at 3°C than at 0°C. In general, between freezing point and 15°C, it is usually considered that rotting speed doubles for every 3°C increase.

Certain bacteria specialise in protein and amino acid decomposition, removing the carboxyl group (=COOH) and leaving biogenic amines, some of which are noxious (ptomaine, cadaverine) and spreading bad odours. If bacterial decomposition is allowed to continue to its end, carbon gas (CO_2) and ammonia (NH_3) are liberated. Other bacteria attack more particularly the sulphur amino acids, emitting gasses such as sulphur hydrogen (H_2S) which are very toxic (with a characteristic smell of rotten eggs), and the mercaptanes (produced by skunks).

Bacteria are also responsible for the corruption of nitrogen products that are not proteins (NPN = Non Protein Nitrogen) including the trimethylamine oxide, which, together with ammonia produce the characteristical odour of "rotten fish" (TVN = Total Volatile Nitrogen).

A few years ago, manufacturers set up a fish control quality for raw fish intended for fish meal. This quality is assessed on the basis of TVN content; the higher the TVN content, the lower the price paid. TVN values also depend on fish species. For fish intended for human consumption, it is generally accepted that the TVN value should not be higher than 25 to 35 mg/100 g.

Fishmeal manufacture

The fishmeal processing system consists of preserving initial fish proteins by means of a controlled dehydration, which extracts around 80% of the water and oils contained when fresh from fish. This leads to the production of a dry product, easy to preserve and easier to transport than the initial product.

Fresh fish entering the manufacturing plant is first ground and then cooked in a continuous heating oven at 90-95 ºC, which in-turn coagulates proteins and lose their water-holding capacity. The hot mash is then transported to an endless screw that presses it and squeezes out most of the remaining water and oils.

Some manufactures have recently been equipped with dryers operating at "low temperature", at approximately 70 to 80 ºC, that produce the famous low temperature fish meal (LT fish meal).

Drying by gas flame or by any other means at excessively high temperature involves the risk of denaturing proteins which become non-digestive, and the risk of forming nitrosamines which are extremely toxic and carcinogenic. In regular drying conditions, these compounds are not generated, except when nitrites have been used to preserve raw fish initially. This is definitely forbidden in all the Northern Atlantic area.

Pressed fish coming out of the press (press cake) is then cut into smaller portions and placed into a dryer on a steam heated surface. During the drying period, the mash is in constant motion and subject to an air jet which removes all the steam emitted.

The dried mash obtained is now called ‘fish meal’ and contains from 8 to 10% of water. However, if the moisture level is more than 11-12%, there is a risk of the fish meal developing moulds. Generally, antioxidants are added when fish meal is introduced and taken out of the dryer, and by so doing ensuring the stability of the oils remaining within the fish meal.

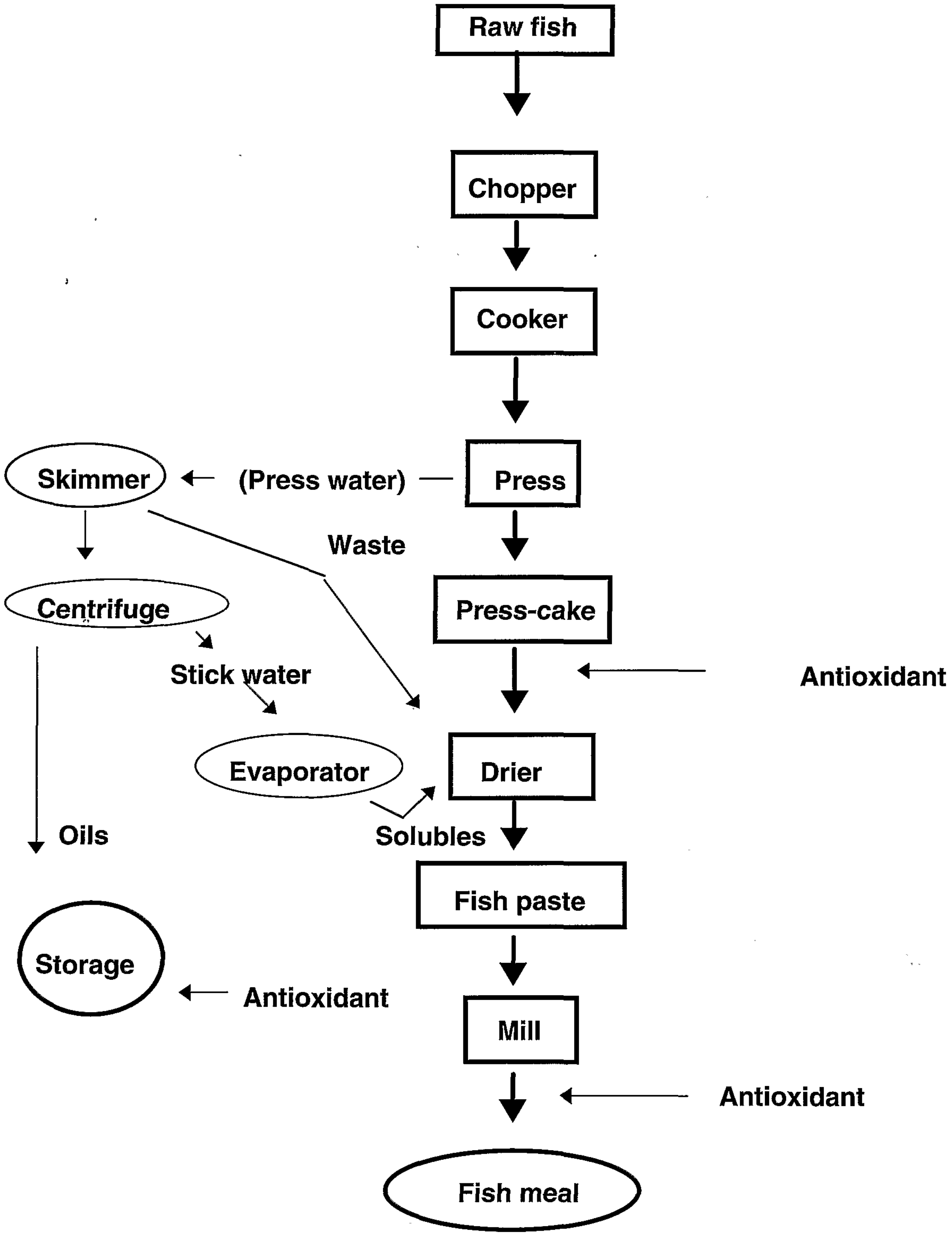

Fig. 1. Fishmeal manufacturing cycle.

The mixture of water and oils squeezed out from the fish in the press (press water), contains considerable amounts of protein, salts, and hydrosoluble vitamins, is removed and centrifuged so as to release particles in suspension and to separate out the oils. The aqueous protein solution resulting from centrifugation (stick water) is then evaporated until it has reached 40 to 50% moisture, thus making up the fish solubles which are usually added to the press cake and then dried.

The oils are centrifuged again to take out the final remaining water traces and impurities, and then stored. In most instances, antioxidants are added to the oil so as to prevent it growing stale.

Fishmeal quality

High quality fishmeal should have the following characteristics:

High protein content (> 70%)
Highly digestible proteins
Low lipid content
Low amount of ash
Low amount of salts
Very low TVN value (Total Volatile Nitrogen)
Few biogenic amines
No DMN content (Dimethylnitrosamine)

A high content of highly digestible proteins is generally a good indication that fresh fish has been used, and that drying temperature has been reasonable.

A low lipid content indicates that either an initial good quality of fish (fresh fish) or that gadoid fishes have been used, or both.

A low ash content is generally a sign that the fishmeal has been made from whole fish, and not from fillet waste.

It is difficult to obtain salt values below 2.5 to 3% in fish meal, except when raw materials are of very high quality are used. In general, a salt content above 2.5% indicates that marine water has been introduced along with the initial fish, which is almost unavoidable.

Feedstuffs can release a large part of indesirable total volatile nitrogen compounds by strongly drying fishmeal. However, a high residual TVN rate may indicate traces of low quality raw materials.

Finally, biogenic amines have been particularly followed during recent years, since many farmed animals, including fish, are very sensitive to them and biogenic amines constituting antinutritional factors.

Criteria for fishmeal quality

Fishmeal manufacturers provide different quality products, which depend, among other things, on the fish and drying methods used.

For various reasons, aquafeed manufacturers (as well as feed manufacturers for minks) demand the regular high quality fishmeal. However, 'low temperature' fishmeal is usually considered to be the best. In general, regular fishmeal quality standards are much less defined than LT fishmeal standards.

Antioxidants

Although they are not necessarily mentioned in fishmeal purchase contracts, antioxidants are nearly always added to fishmeal during the manufacturing process. This is particularly compulsory when they are to be transported by sea in order to prevent the oils from going stale which, under certain conditions, can lead to the spontaneous combustion of fishmeal.

The lipid fraction of a good quality fishmeal usually consists of around 25 to 30% free fatty acids, 25 to 30% glycerides, 25 to 30% phospholipids, and contains some traces of cholesterol and waxes. The main characteristic of these fatty acids is that the degree of unsaturation is higher in fishmeal than within the oil extracted from the fish during the fishmeal manufacturing process. As a consequence, the lipid fraction contained in fishmeal will generally tend to oxidize more readily on exposure with air, than extracted fish oil.

The most commonly used antioxidants are ethoxyquin and vitamin E.

Phosphorus in fish meal

Phosphorus within industrial feedstuffs comes mainly from fishmeal, and in particular from the mineral fraction (i.e. bones, salts of interstitial tissues) and tissue phospholipids. For each fish species, the mineral salt content (and phosphorus content in consequence) varies throughout the season and the physiological condition of the animal; being higher just after reproduction and lower when animals are in fairly good health.

A direct relationship between fishmeal ash and phosphorus contents has been discovered. When needed, a low phosphorus fishmeal can be obtained by using only fish flesh for making fishmeal (bones and skin are chemically or mechanically removed). However, even in this instance, the phosphorus content of fish meal will not be less than 1.5%, and it will of course be much more expensive.

Soya proteins

Soya proteins are obtained from soya beans grown mainly in the hot-climate areas of the U.S.A., South America and Asia and is one of the most important protein sources for animal and human nutrition.

Its importance is further enhanced because soya bean serves as a reference point in the world market of protein raw materials. Even rumours about harvest size in the U.S.A. for example could influence the world prices for a large range of other raw materials.

Manufacture of soya proteins

Soya beans can be processed in many different ways, and contain the following basic nutrients:

Proteins	....	35 - 40%
Lipids	....	17 - 20%
N.F.E.	....	30 - 35%
Cellulose	....	5 - 6%
Ash	....	5 - 6 %

Bean processing consists essentially of extracting the oil so as to concentrate the proteins. This process provides a very important by-product, namely soya oil, which is widely used as a raw material and oil for human consumption. This process also contributes to the elimination of certain anti-nutritional factors present in the raw bean.

The first step in processing involves the removal of the shell (cellulose) from the grain. The "bare" beans are then heated, on the one hand to reduce the activity of certain enzymes, and on the other to break the cellulose strands and facilitate the following steps. The heated beans are then mashed to form thin paste-like slices, which further facilitates the destruction of the cellulose structure and oil extraction.

The product, now termed 'whole soya cake', still contains its oil and has around 40% protein, and as such is sold directly for animal feeding.

Next, the oil can be extracted from the whole cake by means of a solvent (i.e. such as hexane). After total evaporation of the solvent, there remains the solvent-extracted soya cake, which in turn is widely used for animal feeding, and contains 45 to 50% protein.

Table 5. Compared amino acid contents of a fishmeal, soya meal and catfish flesh (values expressed as % total protein)

Amino acid	Fishmeal	Soya meal	Catfish flesh
Threonine	3.6	3.8	4.8
Valine	3.9	5.1	4.2
Methionine	2.5	1.3	3.7
Leucine	5.6	7.7	3.7
Isoleucine	3.4	4.6	3.7
Lysine	6.4	6.1	10.1
Arginine	6.4	7.4	6
Phenylalanine	3.2	5.0	6
Tryptophan	1.2	1.5	1.1
Histidine	1.7	2.4	2.4

During recent years, manufacturers have developed techniques for the further extraction of soya cake in order to increase its protein content. These extracts (water / alcohol) that remove a large part of N.F.E., result in the production of soya protein concentrates which contain around 60 to 70% protein. Moreover, through other extractions with acids & bases, a large part of the cellulose fraction can be removed, so as to obtain a soya protein isolate containing approximately 70% protein.

Figure 2 summarizes the major steps involved during the processing and manufacture of soya-based industrial products.

Soya proteins in animal feeding

Soya proteins are widely used in formulations for animal. It is generally accepted that the amino acid profile of soya meal resembles that of fishmeal and covers a substantial part of the nutritional requirements of fish.

As a good fish feed should present an amino acid profile suitable for the animal's needs, it is apparent that soya meal protein is deficient in sulphur amino acids, and as such the dietary methionine content must be adjusted within soybean-based rations.

As a general rule fish farmers do not generally consider the incorporation of soya protein in feed formulae to have good prospects. This is because of the fact that soya meal may contain an anti-trypsic factor which inhibits trypsin (digestive proteolytic enzyme), although this factor can be easily eliminated by heating or refining soya meals.

The carbohydrates contained in soya meal are not particularly nutritious for carnivore fish; the cellulose and oligosaccharides present are particularly non-digestible, and may reduce the digestibility of the whole feed. However, water/alcohol extraction of soya cake may remove a considerable proportion of the oligosaccharides present, and acid/base extraction (soya protein isolate) removes both oligosaccharides and cellulose, and by so doing transforms the product into an excellent source of protein for fish.

Bloodmeal

Abattoirs or slaughterhouses produce many important by-products, such as blood and bones, etc. which are often difficult to commercialize. Nowadays however, these by-products constitute the basic raw material of the bone and bloodmeals widely used in industry for animal feeding.

Considerable amounts of blood are produced by abattoirs, and this product is usually transported to drying ovens and converted into bloodmeal. Blood from different origins such as bovine, sheep, porcine, and poultry are usually stored and processed separately. However, so as to comply with basic sanitary measures, it is generally compulsory to store blood within cooling chambers and to ensure that the level of bacteria is kept within prescribed maximum limits.

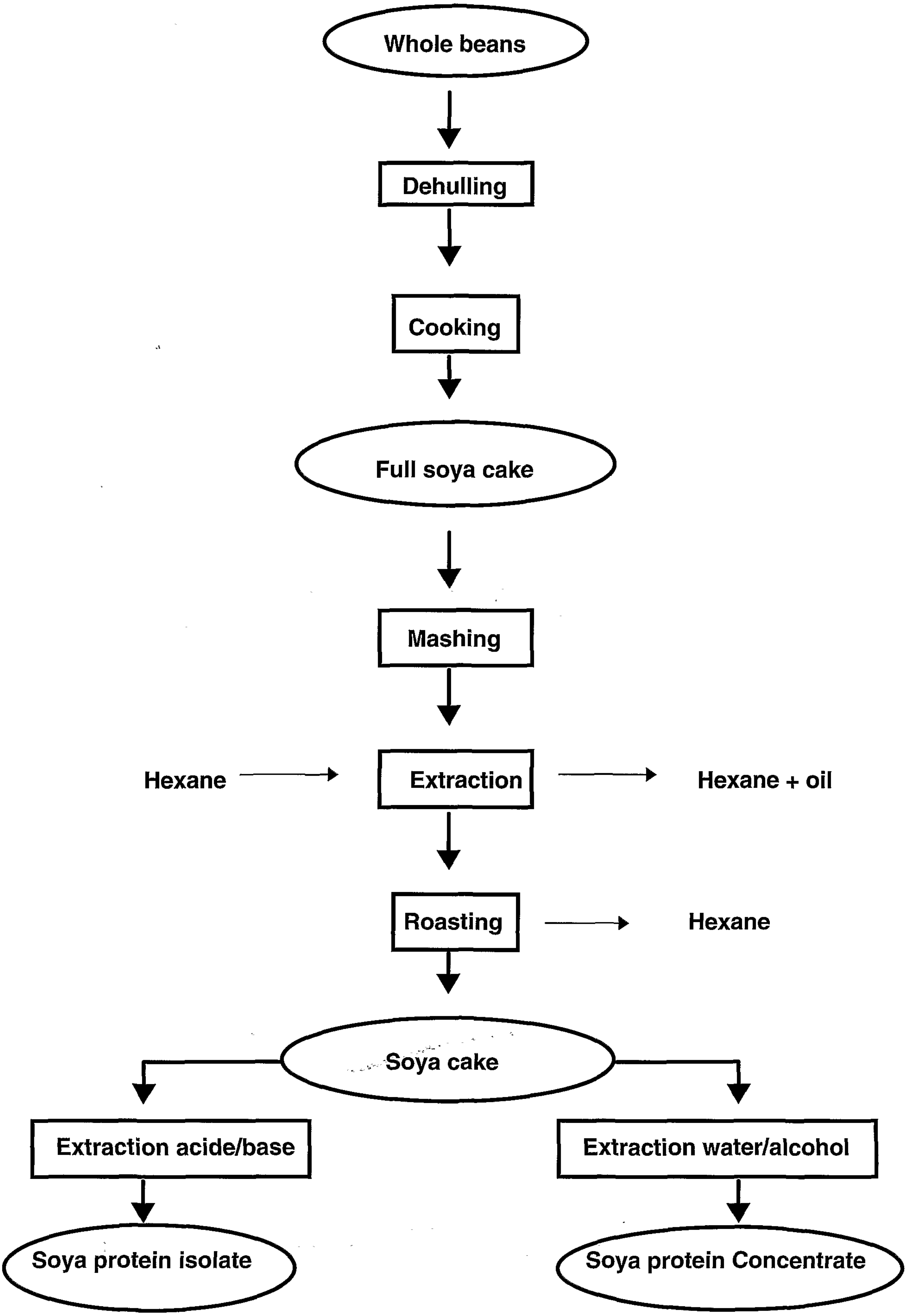

Fig. 2. Soya protein manufacturing principles.

Blood as a source of protein

Bloodmeal has a very high protein content, usually containing around 85 to 90% protein, and compared with fishmeal protein is deficient in the sulphur amino acid methionine (Table 6).

Apart from its high protein content, bloodmeal also possesses the following characteristics:

Lipids: 0.5%
Ash: 5.0%
Water: 8.0%
Iron: 0.23%
Phosphorus: 0.25%

The poor phosphorus content of bloodmeal is interesting for fish feed manufacture because this element must be reduced to a minimum level within the faeces. On the other hand, the high iron content of bloodmeal may become a constraint for certain fish species for whom excess iron may reduce the immune response capacities of fish, making them more sensitive toward infections.

Table 6. Essential amino acid content of fishmeal, blood meal and catfish flesh (values expressed as % protein)

Amino acid	Fishmeal	Blood meal	Catfish flesh
Threonine	3.6	3.9	4.8
Valine	3.9	9.6	4.2
Methionine	2.5	0.9	3.7
Leucine	5.6	13.4	3.7
Isoleucine	3.4	1.3	3.7
Lysine	6.4	9.2	10.1
Arginine	6.4	4.7	6
Phenylalanine	3.2	7.8	6
Tryptophan	1.2	0.4	1.1
Histidine	1.7	7.0	2.4

The manufacture of bloodmeal

Fresh blood is kept cool at the factory, and sizeable particles filtered and the blood mass stirred so as to separate the fibrillar phase from the liquid mass. The fibrine is then heated up to coagulation and the coagulated mass divided and dried through a hot air stream (i.e. by spray drying). This method is particularly gentle (spraying a product in a hot airstream) and does not denature the proteins because the water evaporation cools down the hot air very quickly, thereby preventing overheating.

Bloodmeal quality

Bloodmeal as a raw material should satisfy certain basic quality criteria, some of which are imposed by veterinary authorities. For example, the presence of pathogens and in particular Salmonelles is forbidden. This in turn imposes a high enough heating period for quite a long period of time.

The factory should be equally divided into two sections between the place where the fresh blood arrives and the area where the final products are stored. The single physical bond between these two areas should be the processing unit.

Due to certain market requirements, some factories keep the blood coming from different animal species within different storage areas.

Similarly, in the United Kingdom, due to the recent occurrence of "mad cow" disease (bovine spongiform encephalitis) fishfarmers require written certification that the feedstuffs delivered to them do not contain any constituent of cattle or sheep origin.

Fish oil

Fish oils are a co-product of the fish meal industry. Their nutritional characteristics regarding fatty acids make them indispensable for fish feed manufacture, and in particular their characteristic high content of n-3 unsaturated fatty acids (first double bond linkage in position 3), which are essential for a well-balanced food formula for carnivorous fish species.

Fish oil composition

For the past fifteen years many fish meal manufacturers have found that aquafeeds for farmed fish constitute a new and important market for fish oils. These fish oils are mainly derived from great sand eels *(Hyperoplus lanceolatus)* and capelans *(Mallotus villosus)*, which are especially rich in n-3 polyunsaturated fatty acids.

Table 7 presents the fatty acid content of two different types of fish oil used in aquafeeds.

The designation used for fatty acids takes into account the norms applied in biochemistry: the first figure indicating the number of carbon atoms, the second figure the number of double bond linkages, and n-3 meaning that the first double bond linkage occurs between the third and fourth carbon atom starting from the farthest end of the carboxyl radical (-COOH).

Lipids in fish meal

The fatty acid profile of farmed fish flesh is largely dependent upon the fatty acid profile of its food. For example, ilf fish are fed a feedstuff containing fish oil, the content of fillets will be rich in n-3 fatty acids. By contrast, if the fish are fed oils of plant origin their flesh will be rich in n-6 lipids, and if saturated animal fat (lard) is used the flesh will be rich in saturated fatty acids.

Table 7. Fatty acid composition of two fish oils

Fatty acid	Regular oil	Red oil of greater sand eel
C 14:0	7 - 10%	6.6%
C 16:0	12 - 18 %	17.1 %
C 16:1	6 - 9 %	8.5 %
C 18:0	1 - 3 %	2.4 %
C 18:1	8 - 16 %	10.2 %
C 18:2	1 - 3 %	1.7 %
C 18:4 n-3	1 - 4 %	4.3 %
C 20:4 n-3	-	1.0 %
C 20:5 n-3	5 - 15 %	12 %
C 22:1	12 - 24 %	10 %
C 22:5 n-3	0.5 - 2 %	0.8 %
C 22:6 n-3	6 - 12 %	11.5 %

Table 8. Fatty acid composition of fillets from trout fed different dietary lipid sources

Fatty acid	Fillet (fed herring oil)	Fillet (fed lard)
Saturated	24.4 %	31 %
n-3	9.2 %	1.3 %
n-6	2.9 %	6.3 %
Polyunsaturated	12.1 %	8.1 %
Stearic acid	4.0 %	11.1 %
Oleic acid	25.1 %	35.7 %
Linoleic acid	2.5 %	6.3 %

Fish oil utilization

A large amount of fish oil arising from fish meal manufactures is re-processed in specialized facilities for diverse purposes; part of it being hydrogenated and mixed with other lipids, and transformed into margarine, mayonnaise and bakery compounds, and the other part used directly by the feed industry.

Fish oil quality

Quality standards for oils vary largely according to their use. For example, for aquafeeds the content of n-3 unsaturated fatty acids for instance will be closely scrutinized. However, in general the criteria applied are as follows:

Colour: Fish oil must be pale and transparent. A brownish colour indicates the presence of impurities, staleness or overheating. A reddish oil contains carotenoids (capelin oil) and will be especially appreciated for salmonids.

Free fatty acids (F.F.A): The presence of free fatty acids, that is molecules which are not polymerised into glycerides, indicates that the oil has been either subjected to the hydrolytic action of lipases or that it has been made from raw materials of poor quality. It could also mean that the oil contained impurities (water, bacteria, enzymes, etc.) during storage.

Non-saponifiable residue: Marine and plant oils, and fats, contain different compounds which, for diverse reasons, are undesirable in the food industry (cholesterol, wax, etc.). The concentration of these substances is estimated by saponifying the fatty matter to be analyzed, removing the soap obtained and analyzing the part that has not saponified.

Iodine value: As iodine can bind to double linkages of unsaturated lipids, the quantity of iodine absorbed by one particular oil indicates its degree of unsaturation.

Peroxide value: It is used to measure the rancidity of an oil.

Contracts regarding fish oil quality for use within aquafeeds generally mention the above listed specifications.

Wheat flour

Wheat is one of the most important cereals worldwide, and is used for making bread and for many other produces. It is also an essential raw material for livestock feeding, including fish.

Wheat composition

The proximate composition of wheat grain is as follows:

Dry matter:	....	85%
Protein:	....	12% (of dry matter)
Starch:	....	65% (of dry matter)
Lipid:	....	2% (of dry matter)
Ash:	....	2% (of dry matter)

However, these nutrient proportions vary according to the wheat varieties used and the growing practices employed. For example, protein content can vary from 7 to 16% for the same wheat according to fertilizers used. Similarly, a high protein content normally implies a low starch content and vice versa.

The physical properties of one particular wheat flour (i.e. capacity to bind with water and to gelatinize, bread-making, etc.) largely depend upon its protein and starch content. However, analyzing these two compounds in one wheat flour consignment does not usually provide sufficient information to deduce its industrial properties for a particular process. For this reason a more detailed analysis regarding starch as well as other physico-chemical tests are routinely made for wheat flours used for industrial purposes.

Proteins in wheat flour

Wheat proteins, commonly known as gluten, have remarkable properties. For instance, it precipitates and forms an insoluble rubber-like mass when the wheat flour is mixed with water. This precipitation is speeded up in hot water, and the precipitated gluten mass can be inflated as a balloon. It is this property of inflation that makes gluten-rich flours so suitable for bread-making, whereas the low protein flours are more easily used in biscuit-making. Moreover, in the food industry, wheat gluten is often used to improve the properties of other flours, for bread-making or as a thickening agent.

However, since wheat gluten is lysine-deficient, when used at high levels in animal feed it should be complemented with lysine-rich protein sources such as fishmeal.

Wheat in fish feeding

Starch products, especially wheat, are frequently used as binders for the manufacture of pellets; the gelatinizing property of starch when water-heated being useful for this purpose as the starch absorbs water and forms a gel. Moreover, when starch is gelatinized its digestibility improves considerably. Various starch types (wheat, barley, rice, maize or potatoes) can gelatinize but each one will have its own characteristics. In addition, all three starch types generally have the capacity to form a stable structure when subjected from high to low pressure during the extrusion process. It is this property which is used for feeds that must have a high lipid content, during the extrusion process the starch forms a cell structure with alveoli that can then be filled with oil instead of air and/or steam.

For carnivorous fish feeding purposes the starch must be considered as a supporting structure that gives the pellets their texture and together with the other dietary ingredients allows the formation of a binded diet. However, since the natural feeding habits and foods of seabass and/or seabream usually contain very small proportions of carbohydrates (ca. 3% glycogen, animal starch - glucose polymer). If excessive quantities of digestible starch are provided in the feed this may result in the accumulation of excess liver glycogen, which in turn may trigger a liver dysfunction.

PRODUCTION TECHNIQUES

Two main types of feeds are available on the market, namely pressed feeds and extruded feeds. There still remains many farmers in favour of using pressed feeds for marine aquaculture because many farmers use floating cages in areas with active currents which require a fast sinking feed to as to prevent the feed from getting out of the cages without being swallowed. Pressed feeds, being denser, meet fairly well this condition. However, there is now a general trend towards the use of extruded feeds which have much better physical and "digestive" properties.

Formulation

As we have seen, feed formulators can resort to a wide assortment of raw materials to make up a food mixture so as to meet the nutritional requirements of the fish for energy, amino acids, fatty acids, carbohydrates, vitamins and minerals.

These raw materials are generally used in flour or liquid form, and will have to undergo binding by means of a technological process to obtain a food mixture in the form of dry pellets, which are easy to use and preserve.

The first factor to be considered for feed formulation is the total energy and protein/energy ratio of the final product. After this, the protein content must be calculated according to the amino acid balance desired, and the lipids included to satisfy the best fatty acid profile for the species concerned and the energy level desired. All this must be considered taking into account the vitamin and mineral requirements of the cultured species.

This formulation is not easily reached and so computerized linear programming techniques must be used. Furthermore, it is also necessary, after covering all the nutritional requirements of the species within the formula, to also produce a range of tasty feeds of different pellet sizes for the different age classes.

Various feed types are produced depending upon the developmental status of the fish species in question:

WEANING	powder or flake products
ADVANCED-FRY STAGE	crumbs
PRE-FATTENING	crumbs or small pellets
FATTENING	pellets
BROODSTOCK	pellets (generally complemented with fresh fish or a moist food mixture)

Manufacturing stages

Storage

The raw materials coming into the feed manufacturing plant are generally stored in silos with an ideal height calculated so as to allow the raw material flow to be conveyed downwards, during the manufacturing process, until the final product is produced. This is in order to avoid having to pull the products up by vertical conveyors that usually cause breaks and dust in the final product.

Grinding

Grinding raw materials reduces particle size and increases ingredient surface area, thus facilitating mixing, pelleting and digestibility. The most commonly used grinders are hammer-mills, for fish feed manufacture, as plate-grinders do not generally produce fine enough ground materials.

In hammer-mills, the grinding chamber consists of a series of mobile hammers on a rotor. The hammers, by centrifugal force, position themselves forming a star on the rotor and split the incoming feedstuff apart, which is then forced by depression through a metal grid composed of fitted appropriately sized meshes.

Mixing

The ground ingredients must be mixed according to the desired proportions to obtain a homogeneous mixture. If the grinding process is correctly developed, the particles are homogeneous in size and the mixture produces pellets which statistically have the same formulation.

Generally, the dry ingredients (flours) are first mixed, followed by the liquid components. Continuous mixers are designed so that the feedstuff moves along the mixer as it mixes. There are many different types of mixers, including horizontal band-mixers, vertical mixers, conical screw-mixers, and turbine mixers, etc.

During this mixing process, the vitamin "premix", the binding agents and other additives are added; they must in turn contribute to one or other particular desired quality of the pellets during the pelleting process.

Pelleting

Two different types of pellets are generally prepared for aquafeeds, namely pressed and extruded pellets. A third type, designed as 'expanded feed', is also marketed by some manufacturers.

The main difference between a pressed and an extruded feed is the cooking of the feedstuff in the case of extrusion, with the added mechanical and biological advantages previously described, especially with regard to starch gelatinization

Drying

After the pelleting process, the pellets usually have a high moisture content (15 to 20%) that must be quickly reduced to avoid spoilage. This is usually achieved by using a hot-air drier, which lowers the moisture level to between 8 and 10% depending upon the manufacturing process.

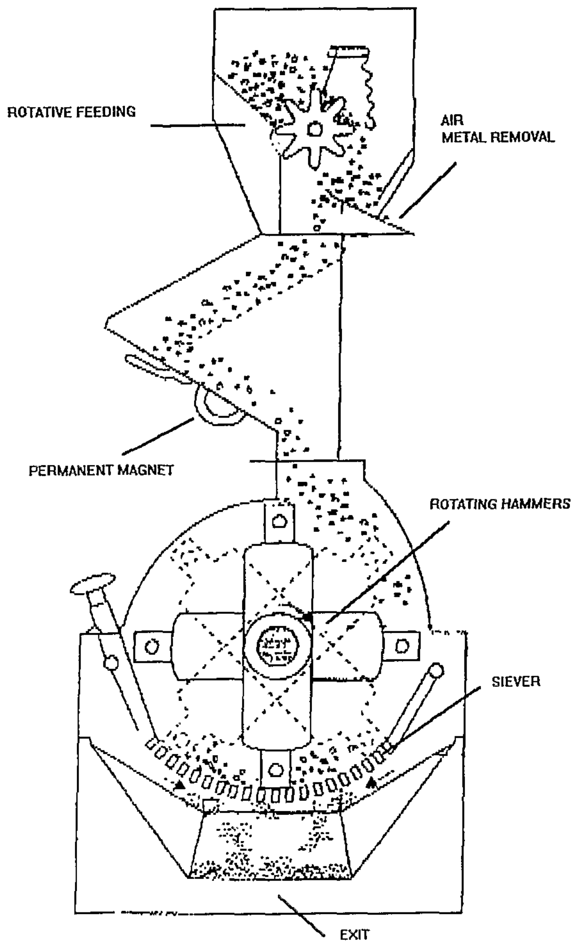

Fig. 3. Sketch of a hammer-mill (from New, 1987).

Sifting

The mechanical manufacturing processes inevitably results in shocks and scorchings that partially crumble the pellets at their surface and cause various breaks and dust that must be eliminated. This is achieved by sifting, a process that is generally applied at least twice before the final conditioning (sifting after drying and after coating/cooling).

Coating

The pellets emerging from the pelleting presses or extruders do not generally contain more than 7 to 10% lipid. To achieve higher dietary lipid levels, coating is necessary with the appropriate oils, generally using heat. In the same manner, certain heat sensitive vitamins and/or drugs that would not normally withstand the pelleting processes (thermolabile products) can also be added later during the coating process.

Cooling

On completion of the coating process (generally undertaken with heated material) the pellets are then cooled and sieved before the final conditioning; cooling occurring in a cool-air flow generated by a cooling-machine or another cooling source (river or seawater, for instance).

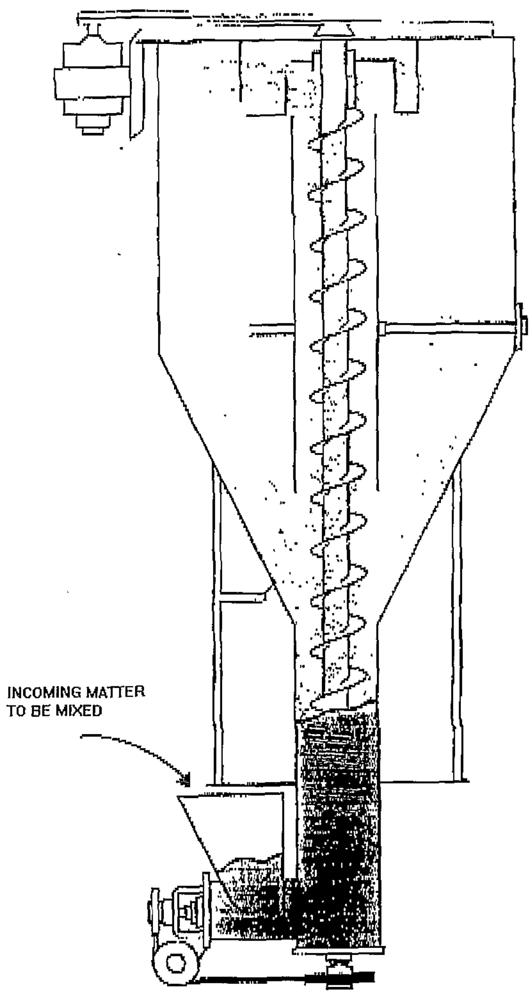

Fig. 4. An example of a vertical mixer.

Baging

Baging usually produces different types of feed presentations within the same factory, namely either small bags (20 or 25 kg) on pallets covered with a plastic film, or big-bags (500 or 1000 kg) in bulk.

Pressed feeds

Pressed feeds are obtained by press-agglutinating the different ingredients that make up the formula.

The pre-mixing of the fishfeed mash prepared according to the instructions provided by the formulator is subjected to steam for 5 to 20 seconds, where the moisture level reaches 16% and temperature rises to approximately 85°C. The pasty mixture is then pressed by cylinders against a drawplate. When emerging from the drawplate, a scraper-blade then cuts the pellets to the desired length; the diameter of the drawplate holes determining pellet size. The pellets are generally very dense and their compactness is influenced by moisture and lipid content.

The formulae used must be appropriate for the manufacture of pressed pellets, in that the formula should contain binding agents so that the pellets do not crumble too quickly. These binding agents can be extruded (pre-gelatinized starch) before their inclusion into the feed mash and then later pressed so as to improve its compactness.

However, this technique that scarcely textures raw materials is limited by lipid inclusion, the content of which should not exceed 14 or 15% because pellets could crumble very easily causing excessive dust and pellet breaks. The quantity of lipid energy which can be added or included in the pellets is therefore technologically limited.

Extruded feeds

Developed and tested during the early eighties for the manufacture of fish feeds, the extrusion process consists of subjecting the raw feed mash to very high pressures and heat (steam injection), followed by a quick lowering of pressure. This process leads, as we have seen, to starch texturing with nets capturing other elements. When emerging from the drawplate, a brutal depression occurs in the pellets, resulting in a kind of expansion producing their specific rounded shape within extruded feeds.

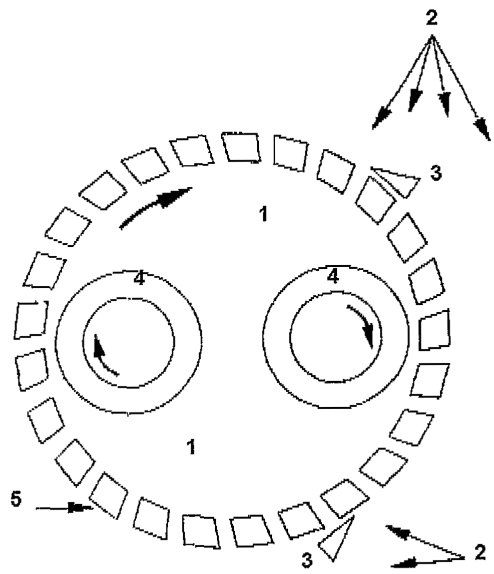

Fig. 5. Conventional roll-press. 1-Mixing, 2-Pellets, 3-Blades, 4-Rolls, 5-Drawplate.

Within the extruder, the pre-mixture is introduced into a steel sheath with one or two endless screws with a particular profile twisting tightly inside it. The thread of these screws can vary, and can even shift its direction many times on the same section of the screw. The pre-mixture, pushed by the rotation of the screw in the sheath, is subjected to very high pressures and temperatures (80 to 120 bars, 110 to 150 °C), and is sometimes also subjected to steam injection along the course. This process ends up in the cooking and extrusion of the product. When emerging from the sheath, a drawplate behind which a blade rotates, allows one to obtain pellets of the desired size.

From the extruder the pellets are dried, sieved and cooled down, and then conveyed towards a coating machine that coats the pellets with additional lipids according to the demands of the formulator. The physical structure of the extruded pellets, which contains around 7 to 8% lipids after coming out of the drier and numerous vacuoles filled up with water or air steam (similar to the bread crumb), allows an additional incorporation of lipids much higher than the pressed formulae. Therefore the extruder provides an important advantage for nutritionists in terms of energy input and with respect to the manipulation of proteins/lipid/energy levels.

On the other hand, the expanded texture of the starch and of the feed mixture improves feed for digestibility, by delaying gut transit time and thereby improving nutrient digestion, the net result being better growth, a lower feed conversion efficiency, reduced oxygen demand, and reduced polluting faecal wastes.

It follows from the higher temperatures and pressures used during extrusion processing that investment and energy costs will be higher than those of conventional pressed feeds. Despite this however, the use of extruded feeds may be more profitable.

Table 9 summarizes the theoretical results obtained with fish fed a pressed (A) or extruded (B) feed.

Table 9. Theoretical valorization of growth

	FEED A	FEED B	B / A Difference
(1) Growth	1	1.1	+10%
(2) Conversion rate	2	2	0%
(3) Feed price / kg	5	6	+20%
(4) Selling price of fish	50	50	0%
(5) Feed expenditure for 1 kg of fish produced (2) x (3)	10	12	+20%
(6) Profit from fish sales (1) x (4)	50	55	+10%
(7) Gross margin for feed item (6) - (5)	40	43	+7.5%

It is clear from the example given that despite the fact that the price of the extruded feed is 20% higher, the feed which provides 10% additional growth provides a 7,5% additional gross margin.

CONCLUSIONS

Since intensive marine aquaculture started long after salmonid farming, the specific nutritional requirements of marine fish (seabass, seabream, turbot) have been less studied and reported in the literature than those of trouts and salmons.

However, being strict carnivorous, the basic nutritional principles remain the same and the values for the different parameters have been filled after laboratory tests conduced by the fish feed manufacturers.

In general the energetic levels required for the growth of marine fish are higher than those of salmonids. If it is considered that 17 to 18 MJ digested by a trout could produce 1 kg of growth, around 33 to 35 MJ would be required to achieve the same growth for the seabass and the seabream, and 26 to 30 MJ for the turbot under the current conditions of feed development, the nutritional techniques used by the fish farmers and the zootechnical performances of the varieties of farmed fish.

Furthermore, the sexual maturation phenomena which occurs in seabass and seabream (sometimes when the fish are 300 g or more) significantly delay growth. However, whenever these processes are controlled (through genetics or photoperiod), the farming performances of these species may well approach those of the trout.

Modern feeds for salmonids currently contain 26 to 30% lipid. The principle is to make use of the energy contained in the proteins (costly and polluting) for growth and use lipids to a maximum to cover the other metabolic requirements. This same principle of protein-saving by using lipids has also been used for marine fish more or less successfully. It is certain that the introduction of high levels of lipids (more than 20%) in extruded feeds may lead to more rapid growth and lower feed conversion efficiency in marine fish. Nevertheless, the use of such expensive feeds has to be complemented by the control of other parameters of the farming operation including farm biomass, distribution systems, rationing calculations, level of oxygen, overall quality of water, etc.

The nutrient levels currently found in modern feeds for seabass and seabream range from 45 to 48% protein and 12 to 22% lipid. An evolution of the ratio of proteins/lipids in rations is necessary over the life cycle and probably during seasons of the year; the most protein-rich feeds being supplied during the young stages of fish life and the rations being strongly reduced during the winter months. Moreover, since proteins are the cause of the main source of nitrogenous discharge to the environment, any decrease in dietary protein levels must therefore lead to a reduction of nitrogenous discharges.

The feed conversion ratios commonly found for marine fish range from 1.7 to 2.7 depending on the feeds used and farming conditions employed. Such levels, together with the use of high protein feeds, result in considerable nitrogen waste (ammonia) and phosphorus waste discharge to the environment. These levels are equivalent to approximately 120 kg of nitrogen and 25 kg of phosphorus per ton of fish (seabass) produced with a feed containing 46% protein / 14% lipid. However, using higher lipid levels with highly digestible proteins (45% protein / 20% lipid) markedly reduces waste output (80 kg nitrogen and 8 kg phosphorus per ton of fish produced). Extruded feeds are the only feeds that allow the use of such high lipid levels. Undoubtedly, the evolution of marine fish feeding must follow this path, although the reduction of waste is not currently the main concern of fishfarmers, who have to struggle in a fiercely competitive environment.

There is still much work to be done in order to accomplish an ideal industrial feed for each fish species. Nevertheless, along with the economic development of aquaculture, each type of exploitation, and species, will be subject to important research efforts so as to obtain, under acceptable economic conditions, efficient feeds delivered at the right time, which are non-polluting and which care for the health of the fish health as well as the consumers'. It is the aim and role of fish feed manufacturers to fulfill this purpose.