Properties of South African fish meal: a review

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THE SOUTH AFRICAN FISHING INDUSTRY converts pelagic fish unsuitable for human consumption into animal feed with high nutritional value. Nine factories along the west and southeast coasts of South Africa produce fish meal and fish oil. Fishermen, acting independently from factory managers, catch the fish at night and bring it ashore the next morning for processing. The meal produced is largely added to chicken feed at levels of 3–10%, where it forms an almost irreplaceable component due to its unique essential amino acid composition and the presence of polyunsaturated fatty acids (PUFA) in the residual lipids. The production process uses only steam (in the cooker) and heat (in the dryer) to make the two final products — fish meal and fish oil. No additional chemicals are used with the exception of the antioxidant ethoxyquin (1,2-dihydro-6-ethoxy-2,2,4-trimethylquinoline, EQ), that is added at a level of 400 mg/kg to protect the PUFA in the meal. It is therefore an environmentally clean process and waste products

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are biodegradable. Drying of fish meal is a vulnerable part of the process as the PUFA are liable to be oxidized if drying is not properly managed. Addition of EQ immediately after drying protects the PUFA from subsequent aerobic oxidation. Spoilage of fish in the delay between catching and processing remains a problem, as icing the fish aboard ship is not economically viable. Processing spoiled fish inevitably leads to a reduction in the quality of meal and oil and also contributes to air pollution. Efforts are continually being made to improve the manufacture and quality of fish meal and this review highlights these endeavours. The South African fish meal industry is responsible for only about 1.5% of the world's fish meal production but it has yielded original research out of all proportion to the industry's size.[1] Fish meal factory managers worldwide have been able to improve their production process, their analytical methods and their quality controls as a result of work carried out over more than 50 years at the Fishing Industry Research Institute in Cape Town, now part of the CSIR in South Africa.

Introduction

Dictionary definitions of fish meal invariably state that it is made from sun-dried fish that is ground into meal and fed to chickens or used as fertilizer. This may have been so in the early days of fish meal production but it is most certainly incorrect for the modern South African fish meal industry. Fish meal production in this country, which started soon after the Second World War, has over the years been transformed into a sophisticated multimillion-rand industry. Fish unsuitable for human consumption, together with cannery waste (heads, tails and guts) are converted into valuable fish meal at nine factories along the west and southeast coasts of South Africa. The predominant species used are anchovy (*Engraulis capensis*), pilchard (*Sardinops ocellata*), red eye (*Etrumeus whiteheadi*), maasbanker (*Trachurus trachurus*) and lantern fish (*Lampanyctodes hectoris*). Pilchards are mostly canned but the other species are almost all converted into fish meal. On average, the conversion factor of fish to fish meal is 23%. In other words, to produce one ton of fish meal, 4.35 tons of fish is required. The annual production of fish meal in global terms is small, averag-

ing about 70 000 tons but this fluctuates widely from approximately 40 000 to 100 000 tons. The industry is dependent on the annual availability of species, but on average 60% is produced from anchovy, 20% from red eye, 10% from pilchard by-catch and 10% from maasbanker plus lantern fish and cannery offal.[2] Most of the South African fish meal is used by the local poultry industry in contrast to other nations, such as Norway and Chile, where aquaculture is the predominant consumer. The largest fish meal producers and exporters are Peru, Chile and Denmark, whereas China is the largest importer and here aquaculture is also the predominant consumer.[3]

Fish meal: its production, components and their properties

Production

To produce fish meal, fish is treated with boiling water or steam in 'cookers', resulting in rupturing cell walls, releasing oil, and denaturing proteins. Recent experiments have shown that these reactions occur at 75°C, substantially below the 'cooker' temperature of 95–100°C.[4] Thus, some countries, such as Norway, produce low-temperature meals for use in aquaculture where both 'cookers' and dryers operate at a maximum of 80°C.[3] The resulting broth is then subjected to pressure to yield presscake and a mixture of oil and water. The oil is separated from the water phase (stickwater) in large centrifuges and the presscake, after being broken into small pieces in a hammer mill, is dried in a flame (direct) or steam (indirect) dryer. The stickwater is subsequently concentrated to a viscous liquid *in vacuo* and added back to the presscake prior to the final drying process. In the past, stickwater was simply discarded and run into the sea but at present all South African fish meal factories have a stickwater plant, resulting in the production of a 'full meal.' This distinguishes it from an old-fashioned 'normal meal' that has no stickwater concentrate added to it. The meal is dried in either steam or flame dryers. The maximum temperature of the meal at the outlet of the dryer is about 80°C, whereas the temperature of both steam and flame dryers is as much as 400–600°C. Evaporation of water from the presscake serves to keep the meal temperature down; it rises only slowly to approximately 80°C at the outlet.[4]

Sometimes overheating occurs in the dryer, resulting in brown, scorched meals with drastically reduced nutritional value; this can be prevented by equipping dryers with automatic controls that adjust the heat input in accordance with the dryer outlet temperature. Meals can also overheat during storage or shipping and can even spontaneously combust. This overheating is due to oxidation of the polyunsaturated fatty acids (PUFAs) present in the residual meal lipids. In the past, meals were 'cured', that is, the PUFA were left to oxidize in air at room temperature and regularly turned over for several months until no more heat generation was noticeable. This treatment, although not fully recognized at the time, reduced the nutritional value of the meal. Surprisingly, the damage done to the protein was not as much as expected because the oxidation leads largely to polymerization of the lipids without involving the protein.[5–8]

All South African fish meal producers now use the antioxidant ethoxyquin (1,2-dihydro-6-ethoxy-2,2,4-trimethylquinoline, EQ) to protect the PUFA to great benefit of the fishing industry. The antioxidant, a brown oily liquid, is added to the meals immediately after drying at levels of about 400 mg/kg. In South American meals, the addition can be as high as 1000 mg/kg. Adding EQ during drying has been tried but most of the antioxidant was lost through evaporation and this therefore had to be abandoned. After cooling and milling, the meal is placed into woven plastic or hessian bags for storage and transportation.

Components

Fish meal consists largely of protein (60–70%) with smaller amounts of residual lipids (5–10%), moisture (5–10%) and inorganic material (ash) from the fish bones (10–25%). The composition of fish meal will immediately tell the expert whether the meal was made from whole fish or from cannery offal as the latter produces meals containing more ash. In addition, high lipid content indicates that either the press was defective or crude fish oil was deliberately added back to the meal. The latter is done either to increase the PUFA content of the meal, in for instance formulations designed for aquaculture, or illegally to rid a factory of low-grade fish oil.

Protein

Protein is by far the largest and most valuable component of a meal. The manufacturing process is therefore designed to protect the protein as much as possible. For instance, addition of excess formalin (40% aqueous solution of formaldehyde) to the raw fish to prevent either decomposition in the delay between catching and processing or to facilitate the pressing operation should be discouraged. Formaldehyde reacts with the ε-amino group of lysine, an essential amino acid, rendering it unavailable to the animal. Addition of 0.2% formaldehyde (based on wet fish) resulted in a drop of available lysine from 7.5 to 6.5 g lysine/100 g protein, while 0.5% formaldehyde decreased it even further to 5.5 g lysine/100 g protein. Addition of 0.05% formaldehyde to the fish had no measurable effect on the available lysine content of the meal.[9] (Reference 4 erroneously mentions 0.05% formalin rather than 0.05% formaldehyde as the 'safe' amount.)

Fish meal is normally blended together with proteins plus carbohydrates of vegetable origin in the feeding of chickens, pigs, lambs and ruminants, where it is considered to be virtually irreplaceable by proteins from other sources. In addition it is also the protein of choice in aquaculture. Its irreplaceability has been variously ascribed to the high available lysine content of the protein, to the unique combination of essential amino acids plus trace metals, to the sulphur-containing amino acid taurine or to unidentified growth factors (UGFs).[7,10] These UGFs are a convenient blanket name for the unexplained nutritional benefits imparted to animals by the meal. It appears to be a typical example of synergism where the whole is more than the sum of the parts.

The quality of a protein is normally indicated by its amino acid composition, or aminogram. The uniqueness of fish meal resides in its high content of the essential amino acid lysine and this is the reason why it enhances the protein of vegetable sources, such as maize (corn) that is deficient in lysine.[11] Fish meal, however, contains no carbohydrates, so these need to be supplied by grains. The aminograms of a South African pilchard meal together with that of maize are recorded in Table 1,[12] which clearly illustrates that the lysine content of fish meal of 8.3 g/100 g protein is markedly higher than the 3.0 g/100 g protein of maize meal.

Drying fish meal at elevated temperatures is risky and gives rise to an undesirable side reaction of the protein that caused much concern in the 1980s and 1990s. Under certain conditions, especially at high temperatures, the ε-amino group of lysine reacts with the amino group of free histidine or histamine, forming a secondary amine and releasing ammonia. The substance thus formed causes erosion of the gizzard in chickens and in severe cases can lead to death. The systematic name of the compound generated is 2-amino-9-(4-imidazolyl)-7-azanonanoic

Table 1. Amino acid composition of a South African pilchard and maize meal.

	Pilchard	Maize
	(g/100 g protein)	
Aspartic acid	10.0	6.6
Threonine	5.0	3.7
Serine	3.9	4.8
Glutamic acid	13.7	20.8
Proline	4.8	8.3
Glycine	5.8	4.1
Alanine	6.4	7.7
Cystine	4.2	1.8
Valine	6.4	5.0
Methionine	2.2	2.1
Isoleucine	5.2	3.7
Leucine	7.5	12.8
Tyrosine	4.4	5.1
Phenylalamine	4.6	5.1
Lysine	8.3	3.0
Histidine	2.7	2.8
Arginine	6.6	5.7
Tryptophane	1.0	0.6
Protein (%N × 6.25)	66.3	9.4

acid (gizzerosine). Its dihydrochoride is a white crystalline powder with a melting point of 253–256°C (decomposition). The structure of gizzerosine is shown in Fig. 1.
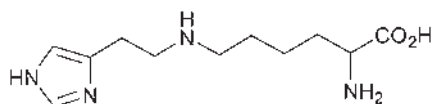

Fig. 1. Gizzerosine.

In a remarkable investigation, Japanese workers isolated traces (2 mg) of gizzerosine from 10 kg of mackerel (*Scombridae* species) meal and subsequently also synthesized it.[13–15] Synthetic gizzerosine added in minute amounts (2 mg/kg) to chicken feed caused severe erosion of the gizzards of chickens. Attempts to detect gizzerosine in South African meals were unsuccessful, but some imported meals from South America were responsible for gizzard erosion.[16] The isolation of gizzerosine from fish meal has never been reproduced in South Africa or anywhere else in the world, although fish meals liable to induce gizzard erosion in chickens were prepared by subjecting local meals to high temperatures.[17] The gizzard erosion saga, which received high prominence in the 1980s and 1990s in both South Africa and Chile, remains an incompletely resolved problem, but now that high drying temperatures of the meals are avoided, its occurrence has almost wholly disappeared in South Africa.

Residual lipids

Fish meal is not entirely free of lipids as not all of them, in particular the phospholipids, can be pressed out. These residual lipids, although present only in small amounts, play an important role in the behaviour of fish meal as they are highly unsaturated and therefore liable to oxidation. This may cause heating and sometimes even spontaneous combustion when not protected by an antioxidant. At the same time, these lipids are a unique source of PUFA that greatly enhance the nutritional value of the meal. All meals in South Africa are therefore treated with the antioxidant EQ.

While protecting the PUFA in the meal the antioxidant itself is sacrificed and increasingly less will be detectable. Maritime shipping regulations demand that 100 mg/kg of antioxidant (it does not state EQ) is present in the meal prior to shipping[18] and a dosage of 400 mg/kg to South African meals seems adequate to meet this criterion. Upon oxidation, EQ yields various products, notably a dimeric oxidation coupling compound 1,8-di(1,2-dihydro-6-ethoxy-2,2,4-trimethylquinoline) (EQ-dimer) and a quinolone 2,6-dihydro-2,2,4-trimethyl-6-quinolone, which are also antioxidants.[19] To date, these two oxidation products of EQ do not qualify as antioxidants under maritime shipping regulations. The toxicity of EQ remains an area of debate and controversy, and countries have their own legislation for the maximum permissible levels of it in foodstuffs.[18] For instance, in Belgium, Denmark, Greece, Italy, Luxembourg, the Netherlands and Spain, EQ is not allowed in any food for human consumption. Sweden, like the U.S.A., however allows it at levels of as much as 100 mg/kg in spice blends and spice extracts, while in the U.K. only 3 mg/kg is allowed on apples and pears. Legislation on animal foodstuffs is more relaxed. In the United States, for instance, levels of 150 mg/kg are allowed in food for animal consumption. It appears therefore that the dosage level of 400 mg/kg used in South African fish meals is low enough to ensure that no, or only minute, amounts of it are recovered in the flesh and eggs of chickens and in the muscle of salmon reared on a fish meal diet. Tissues of broilers fed a diet containing 125 mg/kg EQ contained less than 0.005 mg/kg EQ, while eggs from hens in the U.K. gave an average value of 0.011 mg/kg.[18] Owing to the reactive nature of South American meals, a dosage of 1000 mg/kg seems required to meet the International Maritime Organisation's demand of having at least 100 mg/kg EQ in the meal prior to shipment.

It is interesting to note that fish meal needs an antioxidant while crude fish oil does not, implying that natural antioxidants present in fish end up largely in the oil. Polar substances such as phospholipids, cholesterol and chlorophyll are mostly retained by the meal, while natural antioxidants remain largely in the oil. This indicates that these natural antioxidants are non-polar compounds, some or all of them belonging to the tocopherol (vitamin E) family. Apart from vitamin E, little is known about the nature and concentrations of natural antioxidants in fish oils and their corresponding meals. One report describes the vitamin E content of a dozen fish oils and their corresponding meal lipids. It was found that its content in the oils varied from 1 to 239 mg/kg and 10 of the meal lipids had no vitamin E while the other two had 17 and 99 mg/kg, the latter corresponding to the oil with the highest vitamin E content.[20] It seems clear that more work is required to answer such questions as: is vitamin E the only antioxidant in fish, is there a seasonal variation in antioxidant level, and what is the effect of drying on the natural antioxidant content of a meal?

The residual lipids of fish meal consist largely of PUFA esterified to glycerol either as triacylglycerols or as phospholipids in an approximate ratio of 2:1, respectively. These fatty acids, in particular docosahexaenoic acid (DHA, C22:6n-3) and eicosapentaenoic acid (EPA, C20:5n-3), are very vulnerable to oxidation. This is illustrated in Table 2, where the fatty acid compositions of a pair of anchovy meal lipids, stabilized and non-stabilized with 400 mg/kg EQ, were compared about 1 hour after production in the factory. It shows that the PUFA content of the non-stabilized meal was only 33.0% (as a

Table 2. Fatty acid composition of EQ-stabilized and non-stabilized anchovy meals shortly after production (each fatty acid as g methyl ester per 100 g methyl esters).

	400 mg/kg EQ	No EQ
C14:0	7.9	10.0
C15:0	0.5	0.6
C16:0	20.0	23.3
C17:0	0.6	0.7
C18:0	4.2	4.8
C20:O	0.6	0.6
C24:0	0.4	0.4
Total saturated	34.2	40.4
C16:1	9.1	11.7
C18:1 n-9	8.8	8.7
C18:1 n-7	3.9	4.5
C20:1	1.5	1.2
C22:1 n-11	0.9	0.8
C24:1	0.5	
Total monoenes	24.7	26.9
C16:4	1.5	1.4
C16:3	0.9	0.9
C18:4 n-3	1.4	1.2
C18:2	1.3	1.3
C20:4 n-6	1.3	1.4
C20:5 n-3	17.5	13.8
C20:4 n-3	0.6	0.7
C21:5	0.6	0.5
C22:6 n-3	14.4	10.5
C22:5 n-3	1.8	1.3
Total polyunsaturated	41.3	33.0

percentage of methyl esters) compared to 41.3% of the meal dosed with EQ.[8] The effect of oxidation on PUFA is also clearly illustrated in the manufacture of an unstabilized pilchard meal produced in the laboratory and analysed at different stages of production. The average unsaturation of the phospholipids decreased from 3.2 double bonds per molecule in the fresh fish to 2.8 in the fresh meal and to 0.9 in the cured meal.[21]

It should be mentioned that fish meal is normally added as a protein source to the chicken diet in amounts varying from 3% to 10%. When the proportion of fish meal exceeds 10%, a fishy taint develops in the flesh and eggs of chickens. This taint is, however, less pronounced when using oxidized meals compared to meals stabilized with EQ, implicating PUFA in the fishy flavour.[22] This is a consequence of protecting PUFAs in fish meal. Another consequence is the need to add vitamin E to the diet to assist the chickens to cope with the extra unsaturation of the diet. These early studies, however, assessed only the growth of chickens and the quality of meat produced. The value of PUFAs in the well being of the live animal was at that stage largely unknown. Recent research has shown that PUFA markedly improve egg production, immunity towards infectious diseases, bone structure and fertility of the chicken.[23] These benefits are destroyed when the lipids are oxidized — PUFA might well be the UGFs that eluded past researchers.

Ash

The mineral (ash) content of fish meal varies considerably from about 10% to 25%, depending on the amount of cannery offal used in its production.[24] The ash, determined by combustion at 550°C, consists largely of calcium, phosphorus, sodium, potassium and magnesium, but it also contains essential trace elements such as strontium, vanadium, molybdenum, iron, selenium, manganese, fluorine and iodine.[25–27] The level of mercury in fish and therefore in fish meal is a matter of concern, although its concentration in meal prepared from pelagic fish is extremely low. For instance, anchovy meals have levels of 0.07–0.14 mg/kg that correspond to about 0.02–0.04 mg/kg in the fish.[26] Fish that have a greater longevity than anchovy such as shark (*Selachii* species), tuna (*Thunnidae* species) and swordfish (*Xiphidae* species) accumulate mercury in their muscle; the maximum permissible level in these fish destined for export from South Africa is 1.0 mg/kg.[28] It has been shown recently that the health hazard associated with eating such fish is

not as severe as originally thought, as the mercury occurs in a relatively harmless form linked to a cysteine residue of the protein rather than as methylmercury.[29] Calcium is, not surprisingly, the most abundant mineral in the meal with levels of 2.2–8.7% and a mean of 4.0%.[30] The addition of small amounts (0.5% of the weight of the fish) of calcium hydroxide (slaked lime) to fish prior to processing considerably reduces the free fatty acid (FFA) content of the resulting oil, thus improving its quality and assisting the pressing operation. This practice, which has been adopted by several fish meal and oil factories in South Africa, inevitably leads to an increase in the calcium content of meal. However, addition of 0.5% lime to the fish increases the calcium content of the meal only by 1%, which seems acceptable, as it has no effect on the growth of chickens,[31] but it markedly improves fish oil quality.

Moisture

The moisture content of fish meal ranges from 5% to 10%. If the moisture content exceeds 10%, the meal turns greenish-white as moulds grow on it and it becomes rock hard.[32] At the other end of the scale, if the moisture content drops below 5% the meal becomes dusty and hygroscopic, which in turn may lead to spontaneous combustion.

Determination of the quality of fish meal

Since fish meals are made from fish in various stages of spoilage, determination of their quality has stimulated much research. The final consumer is the animal and therefore numerous feeding trials on poultry, cattle, pigs, sheep, mink and even fish have been carried out. Mink seems to be the only animal that survives on a diet largely consisting of fish meal and thus the performance of mink fed a particular meal is the ultimate criterion of the quality of that meal. Feeding trials are, however, costly and lengthy, so that chemical tests for measuring quality are preferred.

It must be realized that the quality of a meal depends on two totally independent factors; first, the quality of the fish (expressed as a spoilage index) and, second, the temperature of the dryer (expressed as a heat abuse index).

Spoilage indices most frequently used are the total volatile basic nitrogen (TVBN) and the free fatty acid content of the meal. The former measures volatile nitrogenous bases formed on spoilage of the fish and remaining in the meal after processing, while the latter measures free

fatty acids liberated by enzymatic breakdown of fish lipids and retained by the meal. These spoilage indicators are readily determined and are useful but must be used with caution. The TVBN content of a meal also depends on the temperature of the dryer and the time spent in it because some nitrogenous bases are volatilized during drying. Valid comparisons therefore can be made only on meals dried under identical conditions. FFA contents are also unreliable as the acids remaining in the meal depend on the efficiency of the press. In addition, FFAs generated enzymatically increase to a maximum and then decrease because, on spoilage, long-chain fatty acids break down into water-soluble, short-chain fatty acids that are not part of the lipid fraction of the meal and therefore escape measurement.

The phospholipid level (PL) of the meal has been suggested as an alternative quality index.[33] Fresh fish contains an almost constant amount of phospholipids,[34] that decreases rapidly on storage through enzymatic hydrolysis, converting them into water-soluble phosphate esters and FFAs without the formation of lysophospholipids.[35] This results in a loss of lipid-phosphorus, so that the remaining meal-phospholipids are an index of its quality as they virtually all end up in the meal.[33] For instance, freshly caught anchovy stored in ice and immediately analysed ashore had a PL content of 1.26% (wet fish), while the same anchovy stored at 17°C for 24 hours had a level of 1.00%, which further decreased to 0.74% after 48 hours at 17°C.[36]

A comparison has been made of the performance of South African factories by ranking them annually for a number of years on the mean PL composition of their meals. The PL content of the meals produced by different factories varied from a mean of 3.88 ± 0.61 to 2.73 ± 0.79 g/100 g (dry basis). The results of this 'peer review' process were made known to all the factories and provided them with trustworthy figures to assess the preprocessing spoilage of their fish and therefore of the quality of their meals.[36]

Heat abuse during drying was also compared in the same study by determining the mean PUFA content of the EQ-treated meals shortly after processing. The average PUFA content of the anchovy, pilchard and red eye meals from the different factories ranged from 42.78 ± 2.99 to 37.44 ± 2.77 (% of methyl esters). Meals contaminated with maasbanker and lantern fish were rigorously excluded from the tests, as their PUFA levels are substantially lower than those of anchovy, pilchard

and red eye. The last three species are capable of producing meals with a PUFA content of 40–45%.[36] The factories that scored low PUFA levels were warned and were able to improve their dryer performance by either overhauling or even renewing their equipment. The PUFA content of the residual lipids in a meal is therefore an excellent guide to detecting heat abuse during drying.

In Iceland, capelin (*Mallotus villosus*) meals are made for human consumption. These products are prepared from extremely fresh capelin and stabilized with vitamin E (approximately 500 mg/kg).[37] The total PUFA content of the meal lipids was found to be 27.5%, similar to that of our lantern fish but much less than that of anchovy, red eye and pilchard, the main species used for South African fish meal.

Conclusions

Fish meals produced in South Africa from pelagic fish unsuitable for human consumption are mainly used in the local poultry industry. The quality of the meals is to a large extent dependent on the freshness of the fish and this varies. In the fishing season, large shoals of fish are swept north by the cold Benguela Current along the west coast of South Africa and Namibia. Because fishermen act independently of the factories, the delay between catching and processing, and therefore the quality of the meals and oils, fluctuates.

Owing to its high lysine content, fish meal is an ideal supplement to enhance the nutritional value of maize in poultry feed, where it is added in amounts of 3–10% of the diet. Globally, it is also considered to be virtually irreplaceable for feeding lambs, pigs, dairy cattle and various species of fish in aquaculture. These farm feeds all require different amounts of fish meal in their diets, ranging from 5% for cattle and sheep to a maximum of 10% for pigs and 30–50% for salmon (*Salmo salar*) and trout (*Oncorhynchus mykiss*).[38–40]

Meal quality is normally assessed by chemical tests such as the total volatile basic nitrogen or free fatty acid content of the meal. These tests must, however, be used with caution and therefore an additional test, the phospholipid content of the meal, has been introduced that accurately measures the freshness of the fish used in making the meal.

Drying is a very vulnerable stage in the production process, especially as the meal is not yet treated with antioxidant and only evaporation of water keeps the temperature below 80°C. Not surprisingly, overheating the meal occasionally occurs due to faulty dryers. Testing the dryers by means of the polyunsaturated fatty acid content of the meals proves to be an excellent guide to detecting defective dryers.

The formation of the toxic substance gizzerosine has been almost totally eliminated from meals, as one of the conditions for its formation is extreme overheating of the meal, which now a rarely happens in South African factories. Gizzerosine has never been isolated from any fish meal except in Japan, where 10 kg of overheated mackerel meal yielded just 2 mg of gizzerosine. Although the gizzerosine problem has not been satisfactorily solved, the urgency for a solution in South Africa has disappeared.

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