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THE EVALUATION OF FUNCTIONAL PROPERTIES OF FISH MEAL

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ABSTRACT

The raw material freshness and drying methods are determining factors of fish meal quality. The aim of this experiment was to study the effect of the drying method and raw material freshness as for its functional properties in fish meal. Blue whiting, herring and capelin meals produced in commercial fish meal processing plants in Iceland were obtained. The samples were categorized (according to the freshness of raw fish and processing technique) into three grades (low temperature (LT), Norsea Mink (NSM) and standard). Freshness of raw material was assessed through the total volatile nitrogen content in fish before process. Fish meals were dried using air dryers (Dyno and Hetland) and steam dryers. Samples were tested for proximate composition, including salt content, unbound ammonia, water activity, bulk density, flow characteristics, particle size and some functional properties (viscosity, water holding capacity and solubility). Sub samples of all samples were stored at 35°C for four weeks and tested for moisture content, water activity and unbound ammonia content.
The results obtained indicated that the salt content of LT meal of blue whiting was comparatively higher than all the others and it was significantly higher ($p=0.001$ and 0.0004) in LT meal of herring than in NSM and standard meal. Unbound ammonia content in LT meal of all three species were significantly lower ($p<0.05$) than in NSM and standard grade. Viscosity was significantly higher in LT meal of herring ($p=0.02$) and capelin ($p=0.04$) than in the other two grades while it was different in blue whiting. Viscosity was significantly higher in meals dried in Dyno air dryer than in Hetland air dryer and steam dryer ($p=0.01$ and 0.007) respectively. Water holding capacity was significantly higher ($p=0.04$) in LT meal of herring than in NSM and standard meals. Solubility was significantly lower in LT meal of herring ($p=0.001$) and capelin ($p=0.02$) than in other meals and in herring meals which was dried in Dyno air dryer ($p=0.001$) than meals dried in Hetland air and steam drier.

These results suggest that the usage of fresh raw materials, low temperature and low retention time (during drying) for fish meal processing retains functional properties to a greater extent which is useful in the fish feed industry.

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1. INTRODUCTION

The annual world fish catch has been over 90 million metric tons since 1986 and reached a total of 100 million metric tons in 1989 (Ruiter 1995). Many of the most valuable and accessible fish stocks are exploited at or above sustainable levels. Pollution, damming of rivers and clear-cutting of mangrove-swaps are examples of acts of man that are likely to further reduce reproductive success of many species of fish and shellfish. Clearly the importance of aquaculture will continue to increase. As environmental problems of the fish processing industry are directly linked to the amount of fish being wasted, improved utilisation will lead to an improved environment. The classic saying "pollution is a resource in the wrong place" is particularly true for the fish processing industry (UNIDO 1991). In the last 10-15 years fish meal and fish oil has increasingly been used as the main ingredients in the diet of farmed fish and shrimps (Ruiter 1995).
In Sri Lanka, aquaculture has been increasing steadily in the past few years and the demand for fishmeal has increased. Fish meal is imported for around 5 million US$ every year (FAO statistics).
Raw material freshness is important if a producer wants to make premium quality fish meal. Enzymatic and bacteriologic activity in the fish can rapidly decrease the content and quality of the protein and oil. Protein decomposes into amines and ammonia, and both reduce the protein value and recovery of protein (Keller 1990b).
Drying is one of the key processes in fish meal production. The dryer used can affect many of the important attributes of fish meal quality.
Information regarding functional properties of fish meal is not readily available. The term "functionality" as applied to food ingredients, is defined as any property, aside from nutritional attributes, that influences the ingredient's usefulness in food. Most functional properties play a major role in the physical behaviour of foods or food ingredients during their preparation, processing, or storage (Fennema 1985).
Functional properties mainly depend on protein in fish. Demand for high quality fish meal is increasing and behaviour of functional properties in fish meal is important. Viscosity and water holding capacity are important properties when making pellets from fish meal which contribute to increasing the yield of pellets. Less solubility will increase the availability of feed for fish.

The objectives of this study are:

1. To become familiar with the process of fish meal production.

2. To evaluate the influence of the drying method and the freshness of the raw material on fish meal quality.

3. To study the behaviour of some functional properties in fish meal.

2. LITERATURE REVIEW

2.1 History of fish meal industry

The fish meal and oil industry started in northern Europe and North America at the beginning of the 19th century. It was based on surplus catches of herring from seasonal coastal fisheries. It was essentially an oil production activity. The residue was originally used as a fertiliser, but since the beginning of the 20th century it has been dried and ground into fishmeal for animal feeding. In fact, one definition of fish meal is that it is a ground solid product that has been obtained by removing most of the water and some or all of the oil from fish or fish waste (Ruiter 1995).

2.2 Importance in aquaculture

Seafood processing wastes can be used as food for fish either in the form of bait or in the form of meal or pellets in aquaculture operations. The use of wastes for bait is perhaps the oldest of all methods for profitable disposal of processing wastes. Fish wastes can also be used in aquaculture. Aquaculture is expanding rapidly world-wide. Its traditional centre is in Asia where new species such as milk fish, yellowtail, eel and shrimps have been added to the traditional carp species. While milk fish depend on algae growth in shallow ponds, yellowtail, eel and shrimp culture can utilise fish wastes. As these species are highly priced, protein and fat of low economic value can be converted to highly valued products (UNIDO 1991).
In future, environmental problems caused by nitrogen and phosphorus from fish farming will put demands on the fish farmers and feed producers to minimize this problem. The need for highly digestible fish meal will then increase (Keller 1990a).

2.3 Importance of fish meal

Fish meal has been used as a livestock feed for many years. It is popular because of its high nutritional value. It has high levels of essential amino acids such as lysine ($C_6H_{14}N_2O_2$), which is often deficient in grain products that are the typical base for most animal feeds (Hall 1992). It also has a high methionine and cysteine content and a high digestibility and biological value (Keller 1990c). It also contains vitamins such as B12 ($C_{63}H_{88}CoN_{14}O_{14}P$), choline ($C_5H_{14}NO$), niacin ($C_6H_5NO_2$), pantothenic acid ($C_9H_{17}NO_5$) and riboflavin ($C_{17}H_{20}N_4O_6$) and is a good source of calcium (Ca), copper (Cu), iron (Fe), phosphorous (P) and other trace minerals. Fish meal is low in fibre and easy to produce (Hall 1992).

2.4 Raw materials

Fish used for meal production may be divided into three categories:

(a) Fish caught for the sole purpose of fishmeal production (e.g. Peru, Norway, Denmark, South Africa, and U.S.A.).

(b) By- catches

(c) Fish off cuts and offal from the consumption industry (FAO 1971).

Most fish species may be converted into fishmeal and oil. Table 1 shows the composition of some species commonly used for fish meal production. The main constituents of the fish vary little as regards to protein and inorganic matter. Fat (oil) and water contents, which make up 72-78% of the fish are highly variable (Ruiter 1995).

Table 1: Approximate average composition of some species (whole fish) (Winder and Barlow 1981)

Species	Scientific name	% Protein(N x 6.25)	% Fat	% Water
Anchoveta	*Engraulis ringens*	18	6	78
Herring (winter)	*Clupea harengus*	18	11	70
Herring (spring)	*Clupea harengus*	18	8	73
Pilchard	*Sardinops ocellata*	18	9	69
Mackerel (autumn)	*Scomber scombrus*	15	27	56
Mackerel (spring)	*Scomber scombrus*	18	6	74
Horse mackerel	*Trachurus trachurus*	16	17	63
Capelin	*Mallotus villosus*	14	10	75
Blue whiting	*Micromesistius poutassou*	15	2	79
Sand eel	*Ammodytes sp.*	18	7	73
Sprat	*Sprattus sprattus*	15	8	75

2.5 Handling of raw materials

Handling of raw material is a very important step in preserving freshness. Cooling and icing of raw material will normally slow down the biological decomposition. Handling of fish and fish offal with seawater and refrigerated sea water storage will increase the salt content in the raw material going to the fish meal plants (FAO 1971). Table 2 shows some specifications for low temperature (LT) meal. As shown in table 2 the maximum limit for salt is 2.5%.

Table 2: Specification for LT fish meal (Ruiter 1995)

Crude protein	Min. 72%
Crude fat	Max. 12%
Water	Max. 10%, min. 6%
Salt (NaCl)	Max. 2.5%
Ash (salt free)	Max. 14%
Ammonia (NH_3-N)	Max. 0.18%
TVN in raw material	Max. 50 mgN $100g^{-1}$ fish

In a number of fish species used for fish meal production particularly small pelagic fish species such as sardines, anchovies, herring etc. the digestive enzymes may cause heavy autolysis leading to softening of the meat, rupture of the belly wall and formation of considerable amounts of blood water containing both protein and oil. This causes difficulties in handling and processing and may lead to serious losses of both protein and oil (FAO 1971).

Fat deterioration (lipolysis) caused by different fat splitting enzymes (lipases) is a general feature in fatty fish. Fish oils are largely composed of glycerol combined with fatty acids to form glycerides. Splitting of the glycerides of the oil and formation of free fatty acids (FFA) result in reduced quality of the oil with economic consequences. The anaerobic conditions of bulk storage of whole fish create a complex medium for microbes with formation of a variety of chemical spoilage products. One predominant end product is ammonia, which is generally used as a measure of deterioration. Ammonia is formed by bacterial breakdown of amino acids and protein and the heavy

production of ammonia in a load of deteriorating fish may result in significant loss of protein (FAO 1971).
The volatile bases (TVN) analysis is traditionally used in the fish meal industry to evaluate the freshness of raw material (Olafsdottir et al. 2000). Premium quality fish meal requires raw material less than 40 mg TVN per 100 g (Keller 1990b). In some countries fisherman are paid for their catch on a scale relating to TVN content (Pike 1989).

2.6 Grades of fish meal

In general there are three grades of fish meal; LT, NSM and standard and those are categorized according to the freshness of raw fish and processing techniques (Arason personal communication). The production of LT meal implies reduced heating (70°C or lower in the dryer instead of 90°C) (Ruiter 1995). The price difference between the three grades of fish meal used in fish feeds is about 12% for each increase in quality. The highest grade of fish meal used in fish feeds, LT costs about 25% more than standard fish meal, and about 12% more than NSM. The types of fish meal used by the aquaculture industry are expected to change. Demand for high quality marine products in aquaculture feeds is expected to increase (Keller 1990c).

2.7 Fish meal production process

The purpose of the process is to separate the three main components of the raw material, i.e. solids (fat-free dry matter), oil and water. The following processing steps are included.: (i) heating, which coagulates the protein, ruptures the fat depots and liberates oil and water; (ii) pressing (or centrifugation), which removes a large fraction of the liquids from the mass; (iii) separation of the liquid into oil and water (stick water); (iv) evaporation of the stick water into a concentrate (fat solubles); (v) drying of the solid material (press cake) plus added solubles, which removes sufficient water from the wet material to produce a stable meal; (vi) milling and storage (Ruiter 1995).

2.7.1 Heating

Until fairly recently, the general view has been that the best results would be obtained at the highest possible temperatures, which, at atmospheric pressure, would be 100°C. New experiments have shown that the walls of the fat cells are broken down before the temperature reaches 50°C. Another important recent observation is that coagulation of the fish material is completed at much lower temperatures than 100°C depending on pH-level and ionic concentrations. There might be cases where optimal cooking temperatures are 60-75°C, depending on species and other factors. The most common practice of cooking good raw material is to heat to 95-100°C within 15 to 20 minutes. The proof of a good cooking is good pressability of the mass, which leads to proper removal of press liquid and, in particular for fatty fish species, efficient recovery of oil, producing a meal with a low fat content which is one of the criterion of quality (Ruiter 1995).

2.7.2 Pressing

Pressing has the purpose of squeezing out as much liquid from solid fish pulp. This is important not only to improve the oil yield and the quality of the meal, but also to reduce the moisture content of the press cake as far as possible, thereby reducing the fuel consumption of the dryers and increasing their capacity (Ruiter 1995).

The dominant type of press used in the fish meal industry is the double or twin screw press. The performance of the press is largely determined by the profile and the compression ratio of the screws, i.e. the ratio between the flow volumes of the inlet and outlet flows (Ruiter 1995). The twin screw press should be able to produce press cakes with moisture contents somewhat below 50%

2.7.3 Separation

The separation of the three fractions of press liquid coming from the press and pre-strainer, i.e. sludge, oil and water, is based on their different specific gravities. For efficient separation, centrifugation is the method of choice. An important prerequisite is high temperature, implying that the press liquid should be reheated to 90-95°C before entering the centrifuges. This applies to sludge removal as well as separation of oil and water (Ruiter 1995).
The suspended solids are first to be removed. This is done in a horizontal centrifuge (decanter or desludger). Separation of stick water takes place in vertical disc centrifuges, either of the nozzle type, which discharge the stick water and remaining sludge continuously, or of the self-cleaning type, which are often preferred. Stick water with a dry matter content of 6-9% is concentrated in the evaporators. The sludge is pumped to the press cake before drying (Ruiter 1995).
The final refining step of the oil is carried out in special separators. This step called polishing, is facilitated by using hot water, which extracts impurities from the oil and ensures a better stability during storage (Ruiter 1995).

2.7.4 Evaporation

Evaporation of stick water is a relatively new process in the fish meal industry. Evaporators did not become standard equipment until the late 1970s (Ruiter 1995). This is done in the fish meal plants by the evaporation system where the press liquid is separated from the lipids and concentrated from 6% dry matter to about 30% dry matter (Hoyem and Kvale 1977).

2.7.5 Drying

The prime reason for drying is to reduce the moisture content of the non-aqueous material to such a level that insufficient water remains to support the growth of the micro-organisms which feed on it. This level is also sufficiently low to stop chemical degradation (Jason 1984). It is necessary to dry the press cake and the concentrate as quickly as possible from 45-60% moisture content to 10% moisture or less (Ruiter 1995).
Drying is the process step that affects the protein quality most. Fish proteins, as other proteins, are affected when exposed to high temperatures for long periods. This affects the nutritional value of meal, especially important when fed to fry and juvenile fish and other animals. When the product temperature is kept below 70°C during the process, long drying time and the heat affects the protein quality very little. Exposure to high temperatures for very short time (1-10 minutes) will have little effect on protein quality

(Keller 1990b). For salmon and mink feeds, special low temperature fish meals have been found to give higher feed intakes and better growth (Pike 1989).

2.7.6 Milling and storage

The ideal in milling is to produce small particles averaging around 40 mesh Tyler screen and of as even a size as possible. In practice there is a great variation in particle sizes ranging from 10 mesh to over 100 mesh. Most specifications require the fish meal to pass through a 10 mesh screen, otherwise it is too coarse for feed mixes. Production of excessive fine particles must be avoided for several reasons. They cause dusting when handled, sift through woven bags resulting in loss and in pollution and cause compacting of bulk meal (Ruiter 1995).
Antioxidants are applied immediately after manufacture to prevent oxidation (Ruiter 1995).

2.8 Properties of fish meal

The microbiological and chemical stability of dry food and feeds depends on the water activity (a_w) of the product. In fishmeal the most important deteriorative reactions are lipid oxidation and microbial growth. Since fishmeal is packaged in permeable plastic materials (e.g. woven polypropylene bags) it tends to equilibrate during storage with the ambient relative humidity. Also fishmeal is subject to temperature shifts during transportation and storage.
Fish meal is highly heterogeneous material, both physically and chemically. It contains particles derived from different fish tissues, pieces of bones, scales and in many cases, soluble and suspended material from stick dry state water and blood water. Knowledge of the relationship between equilibrium, relative humidity and the moisture content of fish meals and hydrolysates is important to design drying operations, conveying and storage equipment and packaging requirements (Bligh 1992).
Raw material, drying method and moisture content affect flow properties. The lower the oil content generally more readily the meal will flow. Moisture content below 8% improves flow characteristics. Flow is improved by pelletising (Pike 1989).

3. MATERIALS AND METHODS

3.1 Materials

3.1.1 Factory visits

One objective of the project was to become familiar with the fish meal production process. Two commercial fish meal processing plants were visited in Iceland (Isfelag Vestmannaeyja Hf in Akureyri and Faxamjol in Reykjavik).

3.1.2 Samples for analysis

All fish meal samples were obtained from commercial fish meal plants in Iceland. Fish meal samples were categorized into three grades according to the freshness of raw materials used based on TVN content. Table 3 shows the major characteristics of the samples used.

Table 3: Characteristics of the selected fish meals

Type of meal	Method of drying	Grade	TVN mgN/100g
Blue whiting	Hetland, air	Low temperature	<50
Blue whiting	Hetland, air	Norsea Mink	50-90
Blue whiting	Hetland, air	Standard	>90
Herring	Hetland, air	Low temperature	<50
Herring	Hetland, air	Norsea Mink	50-90
Herring	Hetland, air	Standard	>90
Herring	Dyno, air	Standard	>90
Herring	Steam	Standard	>90
Capelin	Dyno, air	Low temperature	<50
Capelin	Steam	Norsea Mink	50-90

Blue whiting , herring and capelin fish meals which were prepared at low temperature (LT) and at normal temperature (Norsea Mink (NSM) and standard) were compared. One sample of herring standard meal and capelin LT meal were dried in Dyno air dyers. Drying is done in two stages in Dyno air dryers. In the first stage the temperature of the drier is 365°C and meal is dried for 10-15 seconds. In the second stage meal is dried for 15-20 minutes at 365°C. All blue whiting and three herring samples were prepared in Hetland air dryers. The meal was dried for 25 minutes and the temperature of the dryer can be adjusted. Samples of herring and capelin were dried with the use of steam dryers and the fish meal was dried for about 100 minutes. Fresh fish (low TVN content) can be processed at low temperatures resulting in high quality fish meal. Air dryers are used for the production of high quality low temperature (LT) fish meal and air temperature will not go above 365°C with the product temperature below 80°C. When the raw material freshness is poor the producer has to produce fish meal under the elevated temperatures within a short period to overcome further deterioration of raw material and produce NSM or standard grade fish meal.

3.1.3 Sample preparation

All fish meal samples as mentioned in Table 3 were divided into two parts. One part was stored at room temperature (around 25°C) and the other part at 35°C in (300g) plastic containers. Samples stored at 35°C were taken out of the incubator once a week and kept open for two hours for evaporation of water. After four weeks storage at 35°C samples were analysed for the parameters shown in Table 4. Samples were stored at 35°C for four weeks to compare the situation in elevated temperature storage conditions.

Table 4: Parameters tested in fish meals

Parameters tested at room temperature	Parameters tested at 35°C
Unbound ammonia content	Moisture content
Salt content	Water activity
Protein content	Unbound ammonia
Moisture content	
Fat content	
Water activity	
Water holding capacity	
Solubility	
Bulk density	
Viscosity	
Flow characteristics	
Particle size	

3.2 Methods

3.2.1 Unbound ammonia content

About 5.0 g of fish meal, 3.0 g of magnesium oxide and about 200 ml distilled water was weighed into the distillation bottle. It was attached to a pre-heated steam distillator. About 50 ml of 1% boric acid was measured into an Erlenmeyer flask. Distillation was done for 30 minutes. After the distillation the boric acid solution containing the volatiles, was titrated with the standardized sulphuric solution (0.1M) (Helrich 1990a).

3.2.2 Salt content

About 0.5 g of fish meal was weighed into 250 ml extraction flask. A known volume of 0.1N silver nitrate which was sufficient to precipitate all chloride as silver chloride (AgCl) was added. 25 ml of distilled water and 20 ml of nitric acid were added and boiled on hot plate until all solids, except AgCl, was dissolved (usually for 20 minutes). It was titrated with ammonium thayocianate (NH_4SCN) and ammonium iron disulfate ($Fe(NH_4)(SO_4)_2$) (Helrich 1990b).

3.2.3 Protein content (Protein automatic method)

The method is a version of the original Kjeldahl method. About 0.5 g of fishmeal was mixed with potassium sulphate (K_2SO_4) and a little of copper sulphate ($CuSO_4$) as a catalyst and digested in a long necked Kjeldhal bottles with concentrated sulphuric acid for approximately 2 hours (one hour after contents are clear). Distilled water was then added. The Kjeldahl bottle was placed in Kjeltec auto sampler 1035/30 system where the ammonia is distilled into boric acid and the acid is simultaneously titrated with diluted sulphuric acid. The nitrogen content was multiplied by 6.25 to get the protein (Animal feeding stuff-determination of nitrogen content and calculation of crude protein 1979).

3.2.4 Moisture content

About 5 g of ground and well mixed fish meal was weighed accurately in a clean and dry (pre weighed) metal dish, with a lid. The sample was heated in a heating oven at 102°-105°C for 4 hours. Then the lid was placed on the dish which was cooled in a desiccator and weighed. Water corresponded to the weight loss (Animal feeding stuff-determination of moisture content 1983).

3.2.5 Fat content (Soxtec method)

About 5 g of fish meal sample was weighed into a small porcelain bowl and heated in an oven at 102°C-105°C for one hour. After cooling, the dry fish meal sample was transferred into a soxlet thimble. The meal in the thimble was covered with cotton wool and placed into a soxlet apparatus (fat extraction unit). A dry and clean fat extraction flask which pre-weighed was placed into the extraction unit together with 80 ml of petroleum ether (boiling point 30-40°C). Then the extraction was carried out. Finally the ether was evaporated off and the flask dried in an oven at 102-105°C for 30 minutes. The weight increase of the flask corresponded to the fat content (AOCS 1989).

3.2.6 Water activity(a_w)

Novasina water activity meter was used. The sample bowl was filled to 2/3 (approximately) with fish meal and inserted into the measuring bowl. The measuring bowl was placed underneath. Display in the standby mode was read at 25°C.

3.2.7 Water holding capacity and solubility

Centrifuge bottle was weighed. 10 g of fish meal was put into the bottle and 40 g of distilled water (at room temperature) was added. Bottle was placed in a shaker and shaken for 5 minutes at 330 motions/minute. The centrifugal force was set at 3000 and centrifuged for 20 minutes. The supernatant was decanted and the bottle weighed. Percent water holding capacity of fish meal was calculated. For solubility the dry matter was determined in the supernatant as follows. A crucible with sea sands was weighed. About 5 g of supernatant was poured into that and mixed well. The sample was heated in a heating oven at 102°-105°C for 4-6 hours. It was cooled in a desiccator and weighed. Dry matter corresponded to the weight increase.

3.2.8 Bulk density

A container was taken which the volume was exactly known. Fish meal was filled to the top of the container and smooth surface was taken. Container weight and weight to volume ratio was taken.

3.2.9 Viscosity

Brabender viscometer was used. The control device was turned on 30 minutes before starting measurement. 110 g of fish meal and 190 g of distilled water was weighed into a beaker and mixed thoroughly. The sample was placed in the measuring cup of the viscometer and then the measuring arm was lowered into the cup. Viscosity measurements were taken following approximately 25 minutes of spindle rotation (rotation speed was 75 revolutions per minute). Tested temperature ranged between 65°C and 70°C.

3.2.10 Flow characteristics

A cylinder was placed on a table (diameter of cylinder- 4.3 cm). 50 g of fish meal was weighed and spread over a sieve so that fish meal fell onto the cylinder. This was done until a cone formed on the cylinder. The height of the cone was measured in mm (Figure 1).

3.2.11 Particle size

50.0 g of well mixed fish meal sample was weighed. The sample was transferred into the top sieve of set of sieves (sieve numbers 18, 30, 45 and 50, and aperture sizes are 1000µ, 590µ, 350µ and 297µ respectively) with pan. Sieves were fixed in a sieve shaker and shaken for 5 minutes. The particles remaining on and adhering to each of sieves was measured. Each sieve fraction and pan fraction was calculated as percentage of sample weight.

3.3 Analysis of data

The results from the experiment were analysed in Microsoft Excel 97. For analysis single factor ANOVA and two sample t-test were used. Averages and standard deviations were calculated using Microsoft Excel 97.

Figure 1: Measuring flow characteristics of fish meal

4. RESULTS

4.1 Process of fish meal production

The steps involved in the production of fish meal are shown schematically in Figure 2 and described below. Production processes are slightly different in the two plants.

Storage of raw materials: Raw materials are stored in tanks until the operation starts.
Cooking: Fish or fish by-product is cooked at 90-95°C for 20-25 minutes in steam cookers. This is done to coagulate or denature the proteins. The fats and water are thereby released and the digestibility of the protein is somewhat improved.
Pressing: Mechanical liquid-solid separation by twin screw pressing. The oil and water phases (containing water-soluble proteins as well) are separated from the solid phase (press cake). The press cake contains 40-50% of the solids.
Separation: Separating the oil and the particles from the liquid phase by subsequent treatment in decanter centrifuges and centrifuge separators. The water phase is now called stick water and contains 6-10% soluble proteins, minerals, salt etc. After concentration in a multi-stage evaporator it is mixed with the press cake before drying.
Drying: In one of two factories (Faxamjol) a Dyno air dryer is used and it consists of two drying steps. At the first stage, the press cake is dried at 365°C for 10-15 seconds which removes 60% of water. At the second stage the press cake is dried for 15-20 minutes which leads to a 32% water reduction. In the other factory Hetland air dryer which consists of one drying step (at 365°C for 25 minutes) is used. Antioxidant (ethoxyquin) is added after drying. Fish meal is cooled and ground at the mill.

4.2 Proximate composition of fish

Mean values of percentage of protein, fat, moisture and salt as determined by standard methods are shown in Table 5. Protein content in herring meal ranged from 70.5% to 73.1% and in blue whiting and capelin from 68.0% to 70.8% and 69.6% to 72.7% respectively. As fish meals are obtained by separating protein and ash from water and oil, meals with very similar composition can be expected irrespective of the species being processed (Burt et al. 1992b). LT meal of blue whiting had higher concentration of salt than NSM and standard meal while it was significantly higher ($p=0.001$ and 0.0004) in LT meal of herring than in NSM and standard grades. Moisture content of all samples for all methods ranged from 6.0% to 8.5%.

Table 5: Composition of the experimental fish meals (at room temperature)

Note: Values are mean ± standard deviation of 2 replicates
^{LT}Low Temperature ^{NSM} Norsea Mink ST Standard

Type of meal	% protein(N x 6.25)	% Fat	% Moisture	% Salt
Blue whiting^{LT}	69.4 ± 0.02	8.3 ± 0.05	6.1 ± 0.22	4.05 ± 0.01
Blue whiting^{NSM}	70.8 ± 0.20	6.7 ± 0.18	6.0 ±0.01	3.08 ± 0.00
Blue whitingST	68.0 ± 0.01	9.5 ±0.17	7.0 ± 0.01	3.11 ± 0.04
Herring^{LT}	70.5 ± 0.16	10.5 ± 0.04	6.8 ± 0.02	3.92 ± 0.04
Herring^{NSM}	73.1 ± 0.27	8.0 ± 0.06	7.0 ± 0.06	2.03 ± 0.02
HerringST	72.2 ± 0.06	8.9 ± 0.13	7.2 ± 0.06	2.05 ± 0.03
HerringST	71.1 ± 0.12	8.1 ± 0.15	8.5 ± 0.11	1.80 ± 0.02
HerringST	72.7 ± 0.02	9.0 ± 0.02	6.4 ± 0.08	2.03 ± 0.02
Capelin^{LT}	69.6 ± 0.01	11.6 ± 0.04	7.0 ± 0.27	2.70 ± 0.10
Capelin^{NSM}	71.1 ± 0.02	12.2 ± 0.27	7.3 ± 0.04	2.71 ± 0.03

There were no significant differences in mean values of unbound ammonia in samples stored at room temperature and 35°C (Figure 3). However differences were observed for LT meal of herring and capelin meals. Unbound ammonia for LT meal of blue

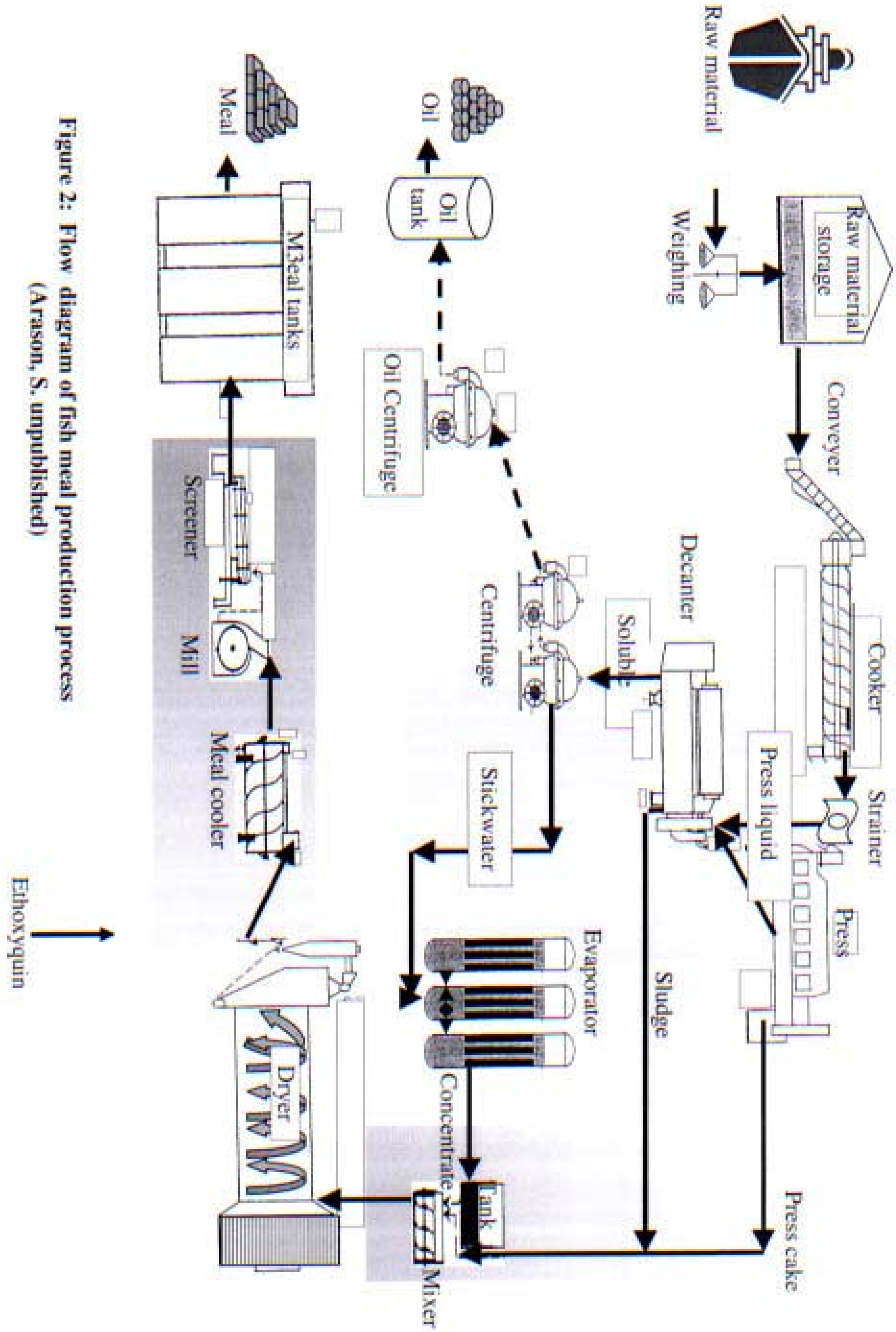

Figure 2: Flow diagram of fish meal production process (Arason, S. unpublished)

whiting, herring and capelin were significantly lower (p=0.001, 0.002, 0.003) than for other grades of fish meal of the same species. This clearly demonstrates the importance of use of fresh raw material with less amount of TVN for the fish meal production.

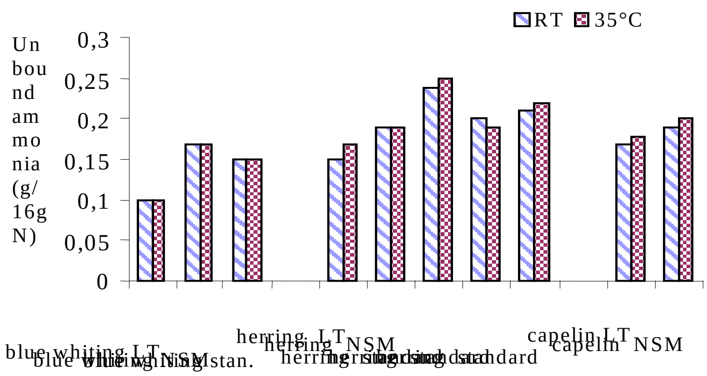

Figure 1: Unbound ammonia content of fish meal at room temperature and at 35°C

4.3 Functional properties

High quality (LT) fish meal of herring (p=0.02) and capelin (p=0.04) showed significantly higher viscosities than in NSM and standard meal except in blue whiting (Figure 4). The Dyno air dryer produced significantly higher viscous meals than Hetland (p=0.01) and steam dryer (p=0.007) whereas the difference was significantly higher (p=0.03) in herring meals of Hetland than meals dried in steam dryer.

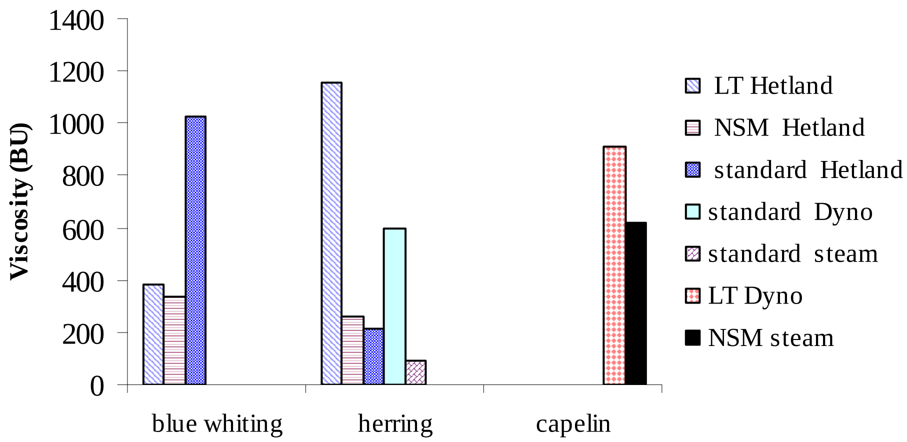

Figure 4: Viscosity of fish meals

Solubility was significantly lower in LT meal of herring (p= 0.001) and capelin (p = 0.02) than in other meals and in herring meals which was dried in Dyno air dryer (p=0.001) than meals dried in Hetland air and steam drier (Figure 5).

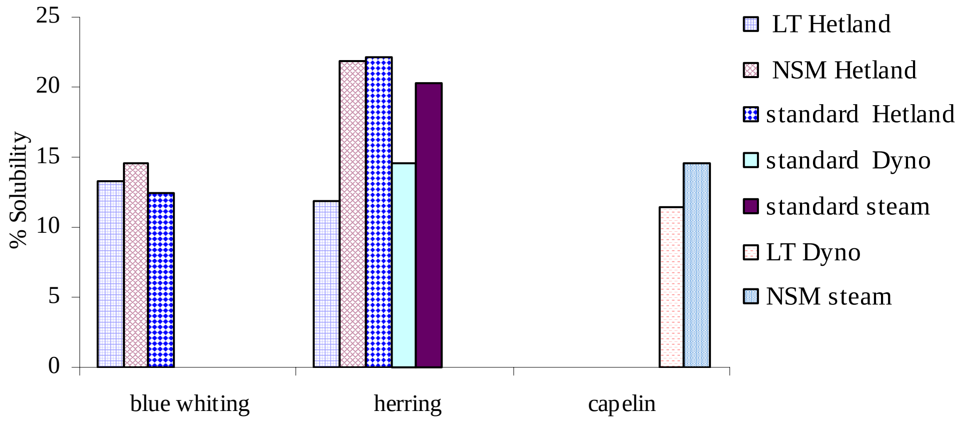

Figure 5: Solubility of fish meals

Figure 6 shows the water holding capacity of fish meals. Water holding capacity of LT meal was significantly higher (p= 0.04) in herring meal than in standard meal. It was significantly higher (p=0.01 and 0.006) in herring meal dried in Dyno dryer than in Hetland air dryer and steam dryer. Water holding capacity was higher in LT meal of capelin (dried in Dyno drier) than in NSM meal dried in steam dryer. The water holding capacity of blue whiting was quite different.

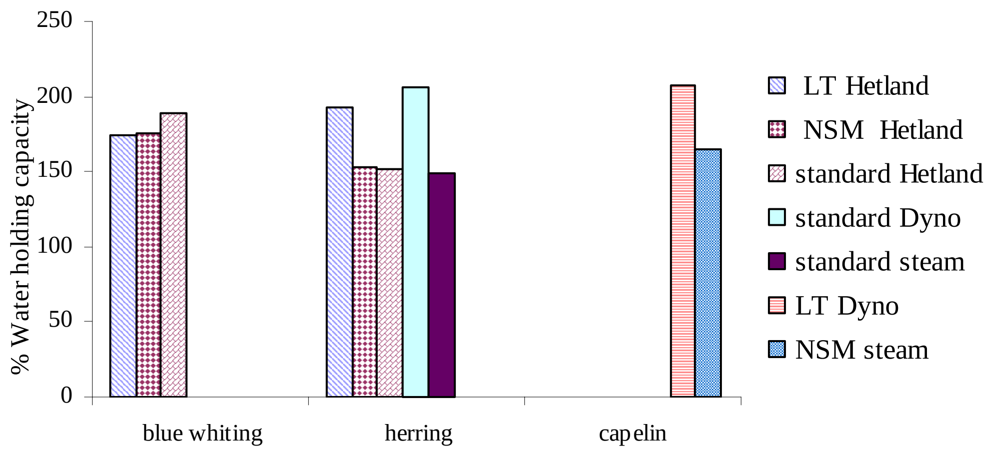

Figure 6: Water holding capacity of fish meals

4.4 Physical properties

Water activity of samples which were stored at room temperature and at 35°C varied from 0.23 to 0.33 (Table 6 and 7). Moisture content was below 8.5% in all samples (Table 5 and 7).

Bulk density, flow characteristics and particle sizes of samples were tested and results are indicated in Table 6 and Figure 7. Bulk density ranged from 0.38 to 0.65 g/ml while flow characteristics varied from 25 to 47 mm in meals.

Table 6: Average figures for bulk density, water activity and flow characteristics of fish meals at room temperature
Note: Values are mean of 2 replicates

Type of meal	Water activity	Bulk density (g/ml)	Flow characteristics (mm)
Blue whiting^{LT}	0.24±0.00	0.46±0.00	36±1.41
Blue whiting^{NSM}	0.25±0.00	0.52±0.00	36±0.00
Blue whitingST	0.31±0.00	0.44±0.01	40±0.00
Herring^{LT}	0.30±0.00	0.43±0.00	46±1.41
Herring^{NSM}	0.24±0.01	0.65±0.00	25±0.35
HerringST	0.25±0.01	0.64±0.00	26±0.71
HerringST	0.33±0.00	0.51±0.00	26±1.41
HerringST	0.30±0.01	0.43±0.00	38±0.00
Capelin^{LT}	0.28±0.00	0.46±0.00	35±0.71
Capelin^{NSM}	0.29±0.01	0.38±0.00	47±0.71

Table 7: Average moisture content and water activity of fish meals stored at 35°C
Note: Values are mean ± standard deviation of 2 replicates

Type of meal	% Moisture	Water activity
Blue whiting^{LT}	5.4 ± 0.03	0.23 ± 0.01
Blue whiting^{NSM}	5.8 ± 0.04	0.25 ± 0.01
Blue whitingST	6.4 ± 0.03	0.29 ± 0.01
Herring^{LT}	6.1 ± 0.03	0.27 ± 0.00
Herring^{NSM}	6.4 ± 0.04	0.23 ± 0.01
HerringST	6.8 ± 0.01	0.24 ± 0.01
HerringST	7.2 ± 0.00	0.30 ± 0.01
HerringST	6.1 ± 0.02	0.27 ± 0.00
Capelin^{LT}	6.8 ± 0.01	0.27 ± 0.00

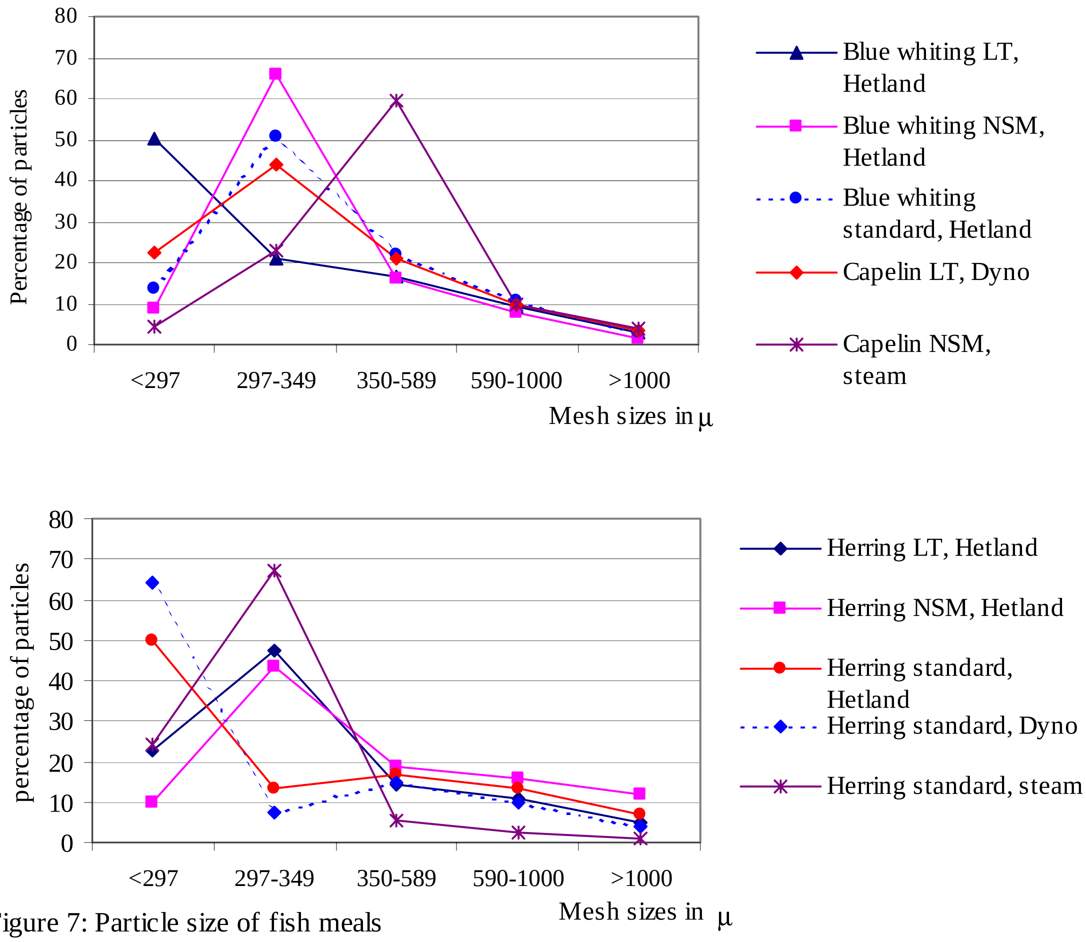

Figure 7: Particle size of fish meals

5. DISCUSSION

The fat content of the fish meal normally indicates the species used. Fluctuations in oil and moisture levels are seasonal and occur within species (Burt et al. 1992b). Herring and capelin are fatty fish while blue whiting is considered a lean fish. Fish meals from white fish are naturally low in fat (Pike 1989).
Moisture contents between 5% and 10% are quite normal (Burt et al. 1992a).
According to Burt et al. (1992a) the salt content in the body fluids of all fish is nearly the same. Increased effort has been put into maintaining the freshness of the raw material on board fishing vessel by cooling directly after catch. Various types of refrigerated sea water (RSW) and chilled sea water (CSW) systems have been used on board fishing vessels (Dagbjartsson et al. 1982). LT meal of blue whiting and herring contained very high amounts of salt 4.05% and 3.92% respectively. This may be because of a long storage time of raw fish in RSW tank before processing on shore.
Unbound ammonia content in fish meal reflects the TVN content of the raw material used. Since cultured aquatic species are more sensitive to the quality of raw feed ingredients than other livestock and have higher nutritional requirements, only high quality raw materials are needed in aqua feeds (Michael et al. 1995a).
Functional properties of fish meal depend mainly on proteins (Michael et al. 1995b) and protein is the main component in fish meal. Functional properties such as viscosity, solubility and water holding capacity depend on protein-water and protein-protein interactions (Fennema 1985). In LT fish meals of herring and capelin water

holding capacity was higher than in NSM and standard meal while it was reversed in blue whiting. Different properties of fish meal made from blue whiting may be due to differences in composition. Blue whiting is a codfish (white fish, gadidae) and its fat is mainly deposited in the liver, in contrast to fatty fishes like herring and capelin (Burt et al. 1992c). Low temperature fish meals retain more of their functional properties. Water binding capacity may distinguish between LT meal and regular meal (Pike 1989). Water binding capacity is important when making pellets from fish meal. They bind better with either oil or water (Pike 1989). Water holding capacity was significantly higher in fish meal of herring which was dried in Dyno air dryers than in Hetland air dryer and steam dryer (Figure 6). Drying is the process step that most affects the protein quality. When subjected to heating, proteins tend to coagulate or denature (Michael et al. 1995b). In Dyno air dryers the proteins are exposed to lower temperatures for shorter periods and denaturation of protein is low and functional properties of protein are better retained compared to Hetland and steam dryers. It has been found that the drying operation may have a deleterious effect on the proteins, because unfavourable drying conditions may destroy the functional properties. (e.g. swelling, water binding) (Hoyem and Kvale 1977).

According to Figure 4 high quality (LT) fish meal of herring and capelin showed higher viscosities than NSM and standard meal except in meal of blue whiting. High viscous fish meal indicates high binding properties which is an important criteria in feed production since it reduces the requirement of binders for pellatizing. These results are comparable with the results of solubility of fish meals indicated in Figure 5. Solubility was significantly lower in LT meal of herring than in NSM and standard meal. It was significantly lower in standard herring meal which was dried in Dyno air dryer than in Hetland or steam dryer. High quality LT meal with high binding properties resulted in less solubles than in other meals. Solubles are mainly salts and proteins, and fat to a lesser degree. According to the studies of Valle and Aguilera (1991) the press liquid obtained from stale fish has higher levels of dissolved and suspended solids and proteins than that from fresh fish.

Water activity of all samples varied from 0.2 to 0.33 (Table 6 and 7). It resulted in a stable product which was free from mould, yeast and bacterial growth and chemical reactions (Figure 8)which may be due to a low moisture content in samples (<8.5%). Research showed that addition of solubles, shifts in temperature during storage and transport, and cycled dehydration and humidification of fish meals cause major changes in the moisture content and water activity which may lead to severe problems including microbial deterioration and caking (Bligh 1992).

NSM meal of capelin showed the lowest bulk density and highest proportion of large particles. Particle size, bulk density and flow characteristics are important in storage of fish meal. Raw materials with highly degraded protein produce small particles, which are much more susceptible to oxidation and water absorption. Fish spoilage due to autolysis, lipolysis and microbial action will result in soft and degraded flesh, which will coagulate poorly during cooking. This will cause difficulties during processing, leading to lower protein content in the meal (Burt et al. 1992b).

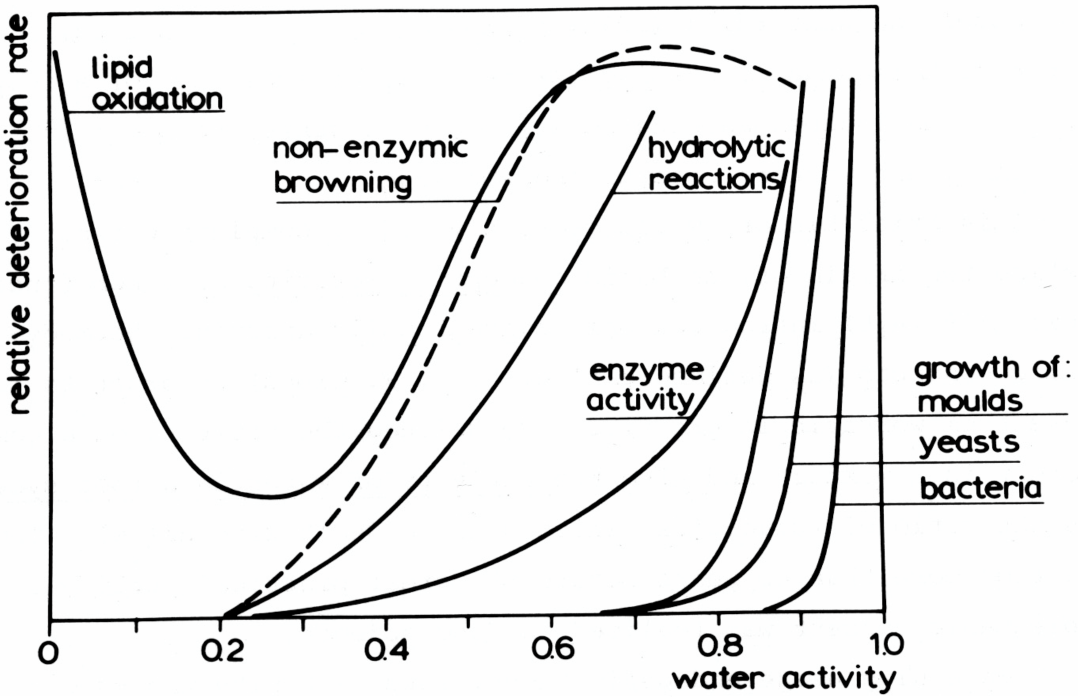

Figure 8: Reaction rates in food as function of water activity
(Rockland and Stewart 1981)

6. CONCLUSIONS

The following conclusions can be drawn concerning the quality of fish meal.

1. The raw material freshness has a significant effect on unbound ammonia content in fish meal, which was irrespective of the fish species used.

2. The use of fresh raw material (TVN less than 50 mgN/100g) and low temperature drying of fish meal for less retention time (Dyno air dryer) has a significant effect on functional properties such as viscosity, solubility and water holding capacity of fish meal.

3. Fish meals with low moisture content and low water activity, produced stable products whose properties were not changed at high temperature.

Suggestions for future work

1. Different behaviour of blue whiting meal as to its functional properties such as viscosity, water holding capacity and solubility need to be studied further.

2. Particle size of fish meals depends mainly on the result of milling operations and other technological parameters of the process. Its behaviour for bulk density and flow characteristics is to be further studied by a proper combination of technological parameters influencing directly the particle size.

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