# Fish Processing Sustainability and New Opportunities

## 7 Sustainability of Fermented Fish Products

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### 7.1 INTRODUCTION

Fermented fish is a broad term for different kinds of fish products. Traditionally, preservation of fresh fish was by salting, smoking and sun-drying (see Chapter 3). Salting and drying in a tropical climate can be prolonged due to high humidity and frequent rainfall, which allows fermentation to start, and people gradually acquired a liking for the taste and the aroma of fermented fish. Another attraction of fermented fish was as a cheap process for underdeveloped countries as an alternative to heavily salted fish products. The ability of fermentation to enhance the flavour (or to mask the taste of tainted fish products) increased its production and consumption even in developed countries (Saisithi, 1994).

Today, the demand for fermented food is so great that more varieties are sought. By partially supplementing ordinary salted fish with carbohydrate sources, such as palm sugar, roasted rice or cooked rice, traditional fermented fish products with different tastes and aromas are obtained. Nowadays, non-traditional fermented fish products are also produced using bacterial starter cultures.

Fermented fish is generally seen as a South-East Asian product through prime examples such as fish sauce. However, studies showed that such products are commonly found in other parts of the world, especially in Africa. Fermented fish production and consumption are also reported to occur in European countries such as Denmark, Norway and Sweden. However, most studies on fermented fish are of either African or Asian origin (Adams et al., 1985; Essuman, 1992; Saisithi, 1994).

## 7.2 PRINCIPLES OF THE FERMENTATION PROCESS

The complex ripening process consists of chemical and biochemical reactions that change the characteristics of the fish tissue and thus the sensory properties of the fish. Ripening is believed to be caused mainly by enzymic actions which split macromolecules such as protein and fat in the fish musculature into low molecular weight compounds, e.g. peptides, amino acids and free fatty acids. The texture of the salted fish becomes softer and tenderer during the ripening phase and a pleasant, typical taste is formed (Schubring and Oehlenschläger, 1997). The enzymes responsible for ripening are reported to be endogenous proteolytic enzymes from the internal organs and muscle tissue of the fish. The other source of enzymes is known to be bacterial, mainly lactic acid bacteria (LAB) (Østergaard et al., 1998) derived either from fish, salt or other ingredients used in the process.

The use of salt in fresh fish preservation as selective microbial agent has been reported by various researchers (Anihouvi et al., 2007). LAB are found as the dominant micro-organisms in many fermented fish products where their primary role is to ferment available carbohydrates and thereby cause a decrease in pH. The combination of low pH and organic acids (mainly lactic acid) is the main preservation factor in fermented fish products. Generally, pH should be below 5–4.5 in order to inhibit pathogenic and spoilage bacteria (Østergaard et al., 1998; Paludan-Müller et al., 1999). In addition, salt and spices (such as garlic, pepper or ginger) may add to the safety of products and, in some products, garlic may serve as a carbohydrate source for the fermentation. The salt concentration may range from 1% to 20% (w/w) in different forms of fermented fish having a pronounced influence on the microbial growth and the rate of fermentation, and thereby on the sensory quality and safety of the product. It is therefore of interest to identify the optimal salt concentration, which does not inhibit the growth of the fermenting microorganisms, and in addition contributes positively to the flavour and texture of the product (Achinewhu and Oboh, 2002; Paludan-Müller et al., 2002; Komatsuzaki et al., 2005). Sustainability is enhanced here by the exploitation of a native enzyme system, native bacterial flora and ambient temperature controlled and directed to human benefit.

### 7.2.1 Metabolic activity of LAB

The production of lactic acid by LAB can be described as homolactic (only lactic acid produced) or heterolactic (produces carbon dioxide, lactate, acetate and sometimes ethanol). The starting point is a hexose sugar, usually glucose, and lactic acid is the end product of the well-known Embden-Meyerhof-Parnas (EMP) glycolytic pathway and it might be necessary to promote the homolactic route if lactic acid is to be the only end product. However, lactose (a disaccharide) and pentose sugars can also be metabolized, yielding varying amounts of lactic acid. The provision of fermentable sugars in a food to be preserved by the action of LAB is an essential prerequisite for a successful fermentation (Hall, 2002). Some LAB are able to catabolize amino acids, by deamination or decarboxylation, yielding carbon dioxide, ammonia and volatile fatty acids and thus contributing to the flavour of the product. Arginine is common in fish tissues and is metabolized, but any amino acid can be utilized. Decarboxylation can give rise to toxic amines and sulphur-containing amino acids can give rise to hydrogen sulphide (Han-Ching et al., 1992; Hall, 2002).

### 7.2.3 Other issues relating to fermentation process

Fermentable carbohydrates: The presence of fermentable carbohydrates (mono- and disaccharides) is essential and is usually provided by the addition of rice (or cassava). However, starchy substrates must be broken down and enzymes with amylolytic activity have been demonstrated (Hall, 2002).

Presence of salt: The presence of salt inhibits spoilage bacteria and promotes LAB and halophiles generally by lowering the water activity (Hall, 2002), although LAB are inhibited by low water activity affecting the fermentation (Adams et al., 1987). The effect varies depending on the phase in which salt is found, being highest in the solid state and less in solution.

Initial pH: The initial pH of the raw material will vary and hence the pH drop due to any specific LAB activity will depend on this value. A rapid drop in pH demands the presence of easily fermentable carbohydrates (Hall, 2002).

Temperature: This has an enormous effect on fermentation and in traditional products ambient temperatures alone, in the range of 25–35°C, promote a vigorous ferment-promoting tissue breakdown and favour sauce production (Hall, 2002).

## 7.3 DEFINITION AND CLASSIFICATION OF FERMENTED FISH PRODUCTS

### 7.3.1 Definition

Essuman (1992) defined fermented fish as any fishery product which has undergone degradative changes through enzymatic or microbiological activity either in the presence or absence of salt. Traditionally the term 'fermented fish' covered both enzyme-hydrolysed and microbial fermented fish products, and a clear distinction has not been made between these products (Huss et al., 2003).

Most of the traditional products involve salting and occasionally smoking, marinating and drying; therefore, although some products are only involved in one type of processing method (either salted, marinated or smoked) some involve combinations and can also be called fermented fish products. Some products may be called semi-fermented products such as Icelandic fermented shark or Norwegian rakfisk (URL-1; Amilien and Hegnes 2004).

Another definition of fermented fish products is 'products which contain a carbohydrate source and in which the level of salt is less than 8% water phase salt (WPS)'. This level of salt (8%) allows the fermentative growth of LAB and a concomitant decrease in pH to less than 4.5. In contrast, enzyme-hydrolysed fish has a WPS greater than 8% and a final pH between 5 and 7 is found (Paludan-Müller, 2002 cited in Huss et al., 2003). In Africa salting and drying of fish for preservation is accompanied by fermentation, but the period is short (a few days) and the product is not transformed into a paste or sauce.

### 7.3.2 Classification

Several authors have tried to classify fermented fish products according to various rules or characteristics of the ferments as reported by Hall (2002). Thus, Subba Rao (1967) recognized three groups according to the final appearance of the product whilst Amano (1962) divided fermented fish products into three categories according to the mechanism of protein breakdown as follows:

(i) Traditional salted products mainly fermented by the action of enzymes normally present in fish flesh and entrails to which salt has been added.

(ii) Traditional products fermented by the combined effects of fish enzymes supplemented with microbial enzymes supplied in the form of starter cultures on fish flesh and entrails with added salt.

(iii) Non-traditional products manufactured by accelerated fermentation, acid ensilage and chemical hydrolysis.

However, not all types of fermented fish products fit into this classification (Huss et al., 2003). Adams et al. (1985) divided traditional fermented fish products of South-East Asia according to the substrates used in the fermentation processes as follows:

(i) Products made from fish and salt.

(ii) Products made from fish, salt and carbohydrate.

Here again, considering the added ingredients as substrates does not represent a true classification of traditionally fermented fish products. The addition of carbohydrates to a mixture of fish and salt is usually intended for different purposes. For example, roasted rice, which is added in the late fermentation period, not only provides flavour to the products but also absorbs excess moisture and prevents the fermented fish from sticking together. The roasted rice is sometimes replaced by rice bran. Sugar is often provided as an energy source for LAB, thus hastening the bacterial growth rate. Cooked rice sometimes replaces the sugar and can be a substrate for moulds and yeasts.

Saisithi (1987) made a different classification based on both substrate used and source of enzymes during the LAB fermentation of traditional fish products.

Group 1: This group consists of fish paste and fish sauce products from South-East Asia. They are usually prepared from whole fish, which is the only available substrate in lactic acid fermentation. The addition of salt to fish reduces the water activity to prevent microbial spoilage. The enzymes for the fermentation process come partly from the fish digestive system and partly from the bacteria naturally present in the fish and in the salt. Examples are fish sauces such as nuoc-mam from

Vietnam and fish pastes like trassi from Indonesia. Figure 7.1 shows a production line for G1 type of fermented fish product.

Group 2: There are more varieties in this group compared to Group 1. Either marine or freshwater fish can be used, prepared in different forms such as whole dressed fish, pieces and minced. Carbohydrates are usually added in the form of cooked rice (palm sugar is sometimes used). The ratio of salt to fish is approximately 1:3 or 1:4. Salting and fermenting times vary from 1 to 3 days (occasionally up to 2 mo). After the first fermenting process, more carbohydrate source is added and allowed to ferment again for another 3–4 days. The main characteristics of the products in this group are that carbohydrate is the principle substrate, and the acid thus produced is the main preservative. This is in contrast to the products in Group 1, where the main substrate and the preservative action is the high salt concentration. However, microorganisms that are responsible for the fermentation of the products in both groups are naturally occurring microorganisms. Figure 7.2 shows a production line for G2 fermented fish product. Table 7.3 shows the microorganisms found in products of Groups 1 and 2.

Group 3: The fermented fish products in this group are similar to the products of Group 2 as far as the nature of substrates is concerned. The only difference is that the causative microorganisms are added as a starter culture. However, the microorganisms are not inhibited. Salted fish is fermented by the naturally occurring microorganisms found with the fish and/or present in the salt. Added steamed rice, however, is fermented by the starter microorganisms. Medium- to large-sized freshwater fish are commonly used and dressed by scaling, eviscerating and cutting off the head of the fish. The dressed fish is slit transversely on both sides to facilitate salt penetration. Figure 7.3 shows an example of the processing methods for Group 3.

Although the production of fish sauces and pastes is described as 'fermentation', some researchers argue that they are really the result of endogenous fish enzymes with little or no impact from microbial (LAB) activity (Adnam and Owens, 1984). The enzymes involved are active at acid-pH and are thought toinclude pepsins (from viscera) and cathepsins (released from cells); these enzymes being most active at the start of the fermentation and bacterial enzymes become involved at a later time.

According to all the above, it is obvious that fermented fish classification depends on the region (Asian, African or European) where those traditional products are produced. In Africa, several methodologies are applied to fermented fish products, such as fermented fish either dried or smoked after fermentation. In Europe, there are some fermented fish products which have no salt applications in their methodology such as Hakarl.

## 7.4 TYPES OF FERMENTED FISH PRODUCTS

As already mentioned, fermented fish have been considered as South-East Asian products although there are traditional products from Europe and from Africa. The following description indicates some characteristics of these regional products.

### 7.4.1 European products

In Europe the fermentation of fish has a long history, now mainly associated with the Scandinavian countries where Gaffelbitar, Tidbits and Surströmming are fermented products made from the Atlantic herring (Clupea harengus) whilst Rakfisk is made from trout (Salmo trutta). Gaffelbitar and Tidbits are fermented for 12–18 months with a mixture of salt, sugar and spices present. Flavour development is due mainly to endogenous enzyme activity but the contribution of LAB such as Pediococcus, Lactobacillus and Leuconostoc spp. is important. These days, Rakfisk is usually processed by Norwegian and Swedish companies, while various types of Surströmming are of Swedish origin. One Icelandic product is Hakarl, produced from semi-fermented shark (URL-1).

Other European fermented fish products include gravad lacks from Germany although it is said to be of Swedish, Danish and Norwegian origin (Bopp, personal communication).

Many European fish-processing companies and authorities are not aware that certain products are really fermented. One such is spiced herring from Denmark, produced from whole herring, firstly treated with salt, sugar and spiced mix. Fermentation is carried out in big barrels for several months facilitated by enzymes from naturally occurring bacteria in the salt and fish, intestinal enzymes and possibly tissue enzymes. After maturing, the fish is filleted and packed in vinegar.

One Swedish company that produces several types of fermented herring (Surströmming also known as sour herring) sold in cans informed the author that they use headed and gutted fish except gonads and small parts of guts left in the fish. First, they pre-salt fish, at around 24% salt, but with only 12% at the end. Fermentation takes place over 5–8 weeks, at 15–18°C (with no other additives), and is mainly effected by bacterial enzymes and partly by intestinal and tissue enzymes. The product is sold in cans (R. Madsen, personal communication). Figure 7.4 shows fermented fish products from Sweden (Surströmming) and Denmark. The same company also produces Rakfisk from trout by using salt and sugar and fermentation is carried out under pressure for 3–12 months at 4–6°C.

#### 7.4.2.2 Patis

This is a fish sauce produced from fish–solar salt mixtures and often produced alongside a fish paste called bagoong (which unlike balao-balao has no added rice). The raw material can be any fish or shrimp species, although Stolephorus, Decapterus and Sardinella are preferred. The amount of salt added varies but is commonly 3:1 salt/fish, with the proportion added controlling the fermentation. On the home scale the fish and salt are mixed and left for a long fermentation (6–12 mo), which is encouraged by mixing at intervals. Once completed, the clear patis is decanted off; more sauce can be produced by pressing the solid remains, with the final residue being bagoong. The colour (light brown to yellow) and clarity of patis varies with fermentation practice. On the commercial scale essentially the same process is followed but care is taken to press the fish–salt mixture because as liquor is released fish can float to the surface and spoil. Liquor can be removed (by scooping or tapping) at various times giving different quality patis, and lowerquality patis can be produced by washing the final solids with salt-water (remaining solid is bagoong) (Hall, 2002).

## 7.5 QUALITY AND STANDARDS OF FERMENTED FISH PRODUCTS

The quality of fermented fish is assessed subjectively by visual and/or organoleptic inspection of parameters such as texture, colour, odour and fragility (Essuman, 1992). Differences in consumer preferences in different regions mean that similar products made in different locations may be considered to be of different quality (Hall, 2002). Since the majority of fermented fish products are consumed either locally or within the country of origin, quality standards will reflect local preferences. Recent research showed that Surstromming from Sweden and fermented fish from Denmark are well liked by Scandinavians but described as 'stink' fish product in other countries like Turkey and topquality products are deemed unacceptable due to their distinctive smell (Köse et al., 2008).

Export markets have been limited but are growing mainly due to immigration and an interest in 'ethnic' foods. Thus, the application of legal food standards relating to quality, composition and toxicology has developed only in recent years for products such as nam-pla from Thailand (Virulhakul, 2000) and includes parameters such as sodium chloride content, percentage of amino acid nitrogen, glutamic acid/total nitrogen, pH and relative density (Hall, 2002).

Quality issues relating to fermented fish products have been described in detail by Saisithi (1994) for traditional fermented fish sauce from South-East Asia, and by Essuman (1992) for fermented fish from Africa. The main factors affecting the quality of fermented fish products are detailed below.

### 7.5.1 Salting procedures

In fermented fish production, addition of salt has different effects on the end product. One of these effects is through the salting technique employed, which must be carried out uniformly around the fish in the vat, tank or barrel to ensure that the salt remains evenly distributed around the fish. The proper distribution of salt over the fish is most important, because diffusion is slow, and if one small part is deprived of salt, the fish will spoil.

As soon as salt comes into contact with the fresh fish natural brine will form fairly quickly. If the salting process is slow, the natural brine can be expected to cover the fish at the end of 1–2 days. In this case, fish in the top layer will start to spoil (Saisithi, 1994). Salting by hand is very slow to make sure that all fish is salted uniformly and fish may be spoilt before salting is complete. The autolysis of fish tissues begins almost immediately after the fish is dead and bacterial spoilage will soon follow, so the salting process should be completed while the fish is still fresh. Salting and mixing machines (cascade or drum mixers) can speed up the process (Saisithi, 1994).

The second effect comes from the ratio of fish/salt used, which is very important in determining the fermented product produced (see Section 7.2).

Thirdly, the quality of salt also affects the product quality. Common salt (sodium chloride) is the most widely used chemical in fish curing in many African and South Asian countries. Some product types require specific types of salt, such as solar salt, in the production of African fermented products.

### 7.5.2 Microorganisms

As mentioned earlier, microorganisms in the fish greatly contribute to the fermentation process as well as the distinct flavour of the products (Table 7.3). Such specific microorganisms originate from fish and salt are used in the processing. Since the isolation of specific microorganisms that have a leading role in the fermentation, starter cultures have been widely used in commercial fish fermentation. Contamination of the salt and unsanitary environmental conditions can alter the microbial flora during fermentation, which will change the flavour and texture of the product and also bring in health issues. The presence of spoilage bacteria is very important in affecting the quality of fermented fish products, especially for African products where processes such as drying and smoking are applied prior to fermentation. The fish-processing infrastructure is invariably of a low hygienic standard at the artisanal level. A reduction in bacterial numbers can be carried out by salting (most of the spoilage bacteria originally present on fish will die off quickly after contact with salt), leaving only the high salt-tolerant bacteria to grow slowly in the medium (Saisithi, 1994).

In situations where brine is reused a number of times, the chemical composition of the salt solution is altered. Significant amounts of organic material areintroduced and the bacterial load of the brine becomes extremely high, especially the red halophiles and the osmophilic moulds, causing two common defects of salted fermented fishery products called pink and dun.

### 7.5.3 Fish enzymes

It is well known that proteolysis of fish protein derives mainly from the fish gut enzymes and the more enzymes present in the gut, the quicker the fish tissues become liquefied. Usually fish will have the highest amount of gut enzymes during the feeding season (Saisithi, 1994) and the tissue protein of actively swimming fish will be hydrolysed faster than that of slow-moving fish (Fuji et al., 1951 cited in Saisithi, 1994). The proper use of salt and fish with strong, enzymic activity helps to cut down the fermentation time appreciably.

Fish sauce is the hydrolysed product of the fish tissues which consist mainly of protein and lipid. The degradation pathways of the lipid component during the fermentation process are not fully understood. Saisithi (1967) found that the amount of total volatile acids (TVA) increased as the fermentation time increased and reached a maximum at approximately 9 months of fermentation. These volatile acids have been established as major flavour components of the fish sauce and are the by-products of lactic acid fermentation by LAB present in the fish sauce Saisithi (1967).

The total amino acid content in fish sauce is approximately the same as that found in the protein of fish tissues. Taurine, a non-protein component, found in nam-pla, could be derived from the amino acids cysteine or cystine (Meister, 1965) which would account for their disappearance from the fish sauce. The application of fish enzymes in fermented products is a good example of applied biochemistry and indicates the presence of many potentially valuable components which need investigation. Chapter 10 describes some examples of the extraction and application of bio-active compounds from fish-processing by-products.

### 7.5.4 Temperature during fermentation

The preferred temperature of fish fermentation varies according to types of product to be produced. It is well known that higher the temperature increases the speed of fermentation and low temperature slows down the fermentation process. Therefore, products from South-East Asia require high temperatures in order to produce liquid or paste-like form of end product. On the other hand, products of European origin usually require lower temperatures. It was reported that fermented herring from Denmark was processed under cold storage conditions and kept in cold storage during marketing prior to consumption (Köse et al., 2008). The regional processes have evolved to reflect ambient temperatures and have proved to be sustainable as a result.

## 7.7 CONCLUSIONS

Although the production of traditional fermented fish products is a longstanding industry across the world their role in securing a sustainable fish processing industry (FPI) is not developed to its fullest potential. This is not due to a lack of interest in the processes themselves which have been studied for many years and fascinate the applied microbiologist and biochemist alike. The intense flavours and aromas associated with the products are probably out of favour nowadays in the United States and EU and are perhaps being superseded in their home regions as Western-style food becomes popular. A sustainable diet in the future might demand a return to less heat-treated products but with stronger flavours as a result and fermented fish products would come into their own. There is a tension here between the need for sustainable processing (less energy-intense) and a healthy diet (e.g. low salt) and between sourcing our protein and fats from a meat-based diet to one based on fish protein and vegetable sources. Sustainability concepts here go beyond an analysis of the processing methods to those reflecting our diet and food intake on a global scale. On several occasions in this chapter mention has been made of the ubiquity of fermented fish products across the world, reflecting the specific combination of raw material, ambient conditions, microbial flora, salt content and dietary traditions which have evolved in each region. There is no doubt that fermented products can contribute to the sustainability of the FPI but this will depend on a massive, rapid change in our perception of these products.