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Review article

Fermented and ripened fish products in the northern European countries

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ABSTRACT

In northern Europe a number of fish products are prepared in such a way that biochemical and microbial action can take place. These are complex processes for which there are few available scientific studies. This article covers the origin, manufacturing, characteristics, and consumption of traditional fermented fish products, including *surströmming* from Sweden, *rakfisk* from Norway, *hákarl* from Iceland, and the barrel-salted herring that was commonly produced in most of northern Europe.

1. Introduction

Fish has always been staple food for people in the Nordic countries but, as the fishing is seasonal, there was a need to store and preserve fish through the winter months. Drying is the oldest form of food preservation and dried white fish (mainly cod) was historically the most important food commodity in Norway, both as staple food and for trade, especially in the coastal regions. More fatty fish species, however, such as salmon, trout, charr, and herring, are not very suitable for drying [1].

Use of salt for preservative purposes was known before the Christian era in well-developed societies, such as China and ancient Egypt [2]. The knowledge spread gradually from south to north in Europe; how fast is uncertain, but probably it did not reach the north to any large extent until the Viking Age, along with the extensive trade during this period. Due to long and difficult transportation, salt was expensive and generally scarce, especially in remote inland areas. Instead of using full-salt preservation (15–20% w/w), people therefore probably experimented using lower salt concentrations when preparing caught fish for storing and found that the procedure sometimes resulted in edible, even tasteful (although smelly!), and lasting products. The techniques varied somewhat with regard to salt concentrations, storage temperatures, storage containers, fish species, and handling. In this regard, the cured fish products in mildly salted brine have the same roots, but the different technologies have resulted in quite different processes and products.

Fermentation plays an important role in many parts of the world for the production of traditional fish products. In Southeast Asia, fermented fish products have a long history and they are of great nutritional importance. Fermented fish is an old staple food in European cuisines; for instance, the ancient Greeks and Romans made a famous sauce from fermented fish called *garum* [3]. In northern Europe, only a few traditional fermented fish products are still produced. This production relies both on naturally occurring enzymes (in the muscle or the intestinal tract) as well as bacteria. In general, the former is most significant with respect to changing texture as well as producing some of the flavor, and the latter aids the development of aroma and flavor [4]. Unlike the fully fermented Asian products, in northern Europe some degree of processing, such as removal of gills and some of the intestinal tract is

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often used and additionally the processing temperature (ambient) is considerably lower.

There is also good reason to believe that the general sensory acceptance of aroma and taste was quite different in former times; many people found it hard to accept salt during the Middle Ages. The occurrence of rancid and putrid aroma was a much more natural part of the daily food, which can explain the occurrence of a number of dried and fermented fish products in the Nordic countries.

From the 19th century, the modern fishery and fish industry, with industrial preservation, long-distance food distribution and the chain of chilling and freezing, with refrigerators and freezers in every home, has totally changed the handling of all food including fish products. The old technologies of drying, fermenting and smoking fish catches have more or less disappeared, and few have survived into the modern supermarkets.

This article will cover four main traditional products: Icelandic *hákarl*; Norwegian *rakfisk*; Swedish *surströmming*; and barrel-salted ripened herring, which is quite common in all of northern Europe. With the exception of *hákarl*, all the northern European fermented fish products are salted. (See Supplimentary Photographs.)

Gravlax will not be covered in detail. The word *gravlax*, referenced many times in Swedish writing from the Middle Ages, literally meaning *buried salmon*, probably reflects the use of the relatively low but frost-free temperature in the ground [1]. At that time *gravlax* was essentially synonymous with *rakfisk*, but the meaning has since changed. *Graving* of fish (or meat) now means a short-time (few days) marination or curing using a salt–sugar–spice mix, giving a much more perishable product than *rakfisk*.

The canning procedure, introduced in the 19th century, enabled some of these products to be distributed and marketed in shops and stored at home, while traditionally they were stored in large wooden barrels or smaller 1-L kegs. The food safety and storage stability of these traditional products can be seen as illustrative of the so-called *hurdle principle*, where not one, but a combination of a number of hurdles for microbial growth, such as pH, salt concentration, and *Lactobacilli*, render the final product safe and stable by inhibiting the growth of microbial pathogens and spoilage flora.

Common to all these products is the fact that scientific research on the process and products is scarce and available literature is hard to find, especially in the English language.

2. Hákarl

2.1. Origin

Fermenting or curing of *hákarl*—Greenland shark—(*Somniosus microcephalus*) has been practiced in Iceland for centuries. Although there was knowledge from neighboring countries on the common use of salt for preservation, the production of salt was difficult in Iceland as there was shortage of firewood. Other means had to be found and the traditional food preservation methods in Iceland were acidifying using lactic acid (milk whey), fermentation (*kæsing*) and drying.

Shark is mentioned in the Icelandic sagas, but the references are not clear on whether the fish were specifically caught for consumption or had simply drifted ashore [5]. Shark fishing had become common in Iceland during the 14th century and at that time fermented *hákarl* was an important part of the diet of Icelanders and continued to be so for centuries.

Shark liver oil played an important role in the economy of Iceland as an export item and the fermented meat was part of the staple diet; often consumed with other foods such as dried fish (stock fish), bread, and rye cakes or simply eaten on its own. The fatty brown meat from the belly flaps (*glerhákarl*) was sliced thinly and used as butter. The cartilage or gristle was also used for food, commonly as hash with some shark flesh, but it needed a lot of fat, mainly tallow. In general, all parts of the shark were utilized largely as food, e.g., the eggs and intestines. The skin was commonly used for making shoes but in tough times it was boiled and eaten [5].

Shark fishing reached its peak in the 17th and 18th centuries, probably due to the strong demand for shark liver oil, which was used for lighting lamps in Europe, but fishing continued well into the 20th century [5].

2.2. Process

For fermenting, the shark was first cut into pieces or chunks, washed with seawater, and placed in gravel pits often close to the sea so the seawater flooded over the fish at high tide; the fish was *buried* by covering the pits with stones, seaweed, or turf and left for several weeks or months [5]. Nowadays the shark chunks are allowed to ferment outdoors in closed containers and the liquid drains off through holes in the bottom of the containers. The fermentation may take 3–6 weeks depending on the temperature and during which season the fish is caught. After the fermentation period, the shark chunks are cut into smaller pieces, washed and dried in drying sheds commonly called *hjallar*. The drying period varies from several weeks to months depending on the weather and time of year but also on which parts of the shark are used. Only after burying and drying is the *hákarl* considered edible.

Although the fermentation is very traditional and the cured meat used to be an important part of the diet of Icelanders, only one study has been carried out on the fermentation of *hákarl* in recent years [6]. The study showed that during the shark fermentation (35 days) the total bacteria count increased greatly with *Moraxella*/*Acinetobacter* groups predominating, along with *Lactobacillus*. The total number of bacteria at the end of the fermentation reached 10^8/g. Urea in the *hákarl* was converted into ammonia by bacterial ureases with consequent increase of pH: from about 6 in the fresh shark to 9 in the fermented/dried ready-to-eat product. Trimethylamine (TMA) N-oxide was also broken down to TMA by the bacteria. The same study showed that during the drying period (70 days) the total number of bacteria decreased and the level of ammonia and TMA diminished somewhat. The dry matter increased during the fermentation from 25.5% to 30.3%, but especially during the drying period and was 64.5% in the final ready-to-eat product [6].

Skate (*Raja batis*: a cartilaginous species) is traditionally processed in Iceland in a similar manner to that of *hákarl* by placing it in a pile and allowing it to cure or ferment for a period of a few days to few weeks. In a recent study on the curing of skate similar microbial and chemical changes to that of shark fermentation were observed [7]; a pH shift from 6.6 to 9.3 and excessive levels of TMA of up to 75.6 mg N/100 g and total volatile nitrogen of 706 mg N/100g during the 9-day curing process. Reynisson et al [7] concluded that curing of skate was controlled by a dynamic bacterial community where the key players belong to *Oceanisphaera, Pseudoalteromonas, Photobacterium, Aliivibrio,* and *Pseudomonas.*

Chemical analyses of various samples of fermented *hákarl* show that the composition varies considerably, depending on the processing, processor, and from which part of the shark the meat originates. White meat originating from body parts of the shark (*skyrhákarl*) in general contains more water and ammonia and less fat than the brown shark meat (*glerhárkarl*), which originates from the belly flaps. The average chemical composition was found to be: 31.6% water, 44% fat, 24.8% protein, 1.4% salt, 1.7% ash, and 0.7% ammonia [8].

2.3. Food safety

Fresh shark meat is considered poisonous although the specific poison(s) have not been identified [8,9]. During the past centuries some incidences were recorded in Iceland, in which people were taken ill (e.g., from dysentery) sometimes fatally, after consuming fresh or too lightly fermented shark [5]. In Greenland, toxic effects have been observed in dogs after ingesting shark flesh [10]. Shark is a cartilaginous species and contains high amounts of urea in its tissues and high levels of TMA N-oxide [11]. *Post mortem*, these compounds are broken down to form ammonia and TMA and they and their precursors, may as such be harmful if consumed in large quantities. Anthoni et al [10] suggested that the poisoning from the flesh of Greenland shark may be due to TMA. The source of shark poisoning in former times in Iceland may also have been caused by consumption of the liver, which contains high levels of vitamin A, overdoses of which can lead to toxic effects. The shark was often the first fresh product available after long, hard winters, when food was scarce, and it is likely that all edible parts of the fish were eaten, including the liver. Neurotoxins should not be ruled out and such toxins have been isolated from shark liver believed to be the cause of mass poisoning in Madagascar following the ingestion of a single bull shark (*Carcharhinus leucas*) [12]. Another concern is related to the level of mercury, which has been found to be high in the fermented products at about 1.6–2.7 ppm [8].

The fermentation of shark renders a potentially harmful raw material (fresh shark) into a nutritious food product; in such a way that the final ready-to-eat product can be stored for long periods (up to several years), without spoilage due to the high pH and low water activity.

2.4. Consumption traditions

The fermented *hákarl* was in former times an important source of protein, energy, and nutrition for Icelanders but is now consumed as a delicacy, mainly by the older population, and as an important part of the traditional food mainly eaten during Thorri (late January until latter part of February). It is also an item of curiosity for visiting tourists. The final ready-to-eat product has a soft texture, whitish, almost cheese-like appearance, a pungent ammonia smell, and a strong fishy taste, which many people unfamiliar with the product dislike. Today the product is often served in small cubes accompanied with a shot of caraway-flavored schnapps (*Brennivín*). In 2014 the landed catch of shark in Iceland was 60 tons, about 6 tons in 2013 and 19 tons in 2012 [13]. The annual consumption is believed to be about 20 tons.

3. Rakfisk

3.1. Origin

The term *rakfisk* was first mentioned in writing in 1348, but this technique of preserving fish was most probably known long time before that. The word *rak* is most probably derived from the Old Norse word *rakr*, meaning moist or wet, reflecting the way of storage/preservation, which is wet, as opposed to dry. *Fisk* of course means fish.

The core geographic area for *rakfisk* is a belt in inland Norway, stretching in a south-west direction from western mid-Sweden [14]. Although some kind of *rakfisk* production may have been used throughout Norway, it was perhaps in these inland areas that the preservation of food through the winter season was most important and where salt availability tended to be low. Hence, the tradition grew strongest here and among the important sources of food in this area were freshwater salmonid fish such as trout or charr. A product reminiscent of Swedish *surströmming*, half-salted herring, more common in coastal areas, almost disappeared in the 19th century, probably due to a misdirected suspicion that it could cause leprosy [14]. This also contributed to *rakfisk* developing into a typical inland tradition.

The temperature used for *rakfisk* production, 3–7°C, reflects the way controlled temperature storage of food was obtained before the advent of refrigeration, i.e., using the relatively stable and low (but frost-free) temperature in the ground. The maturation of *rakfisk* was done by storing wooden kegs or barrels in dug holes in the ground, or in properly dug cellars.

3.2. Process

Rakfisk is currently produced from salmonid freshwater fish, mainly lake trout and some arctic charr. The production is based on mild salting of the gutted fish and layering the fish (belly up), preferably under pressure, in tight containers, stored at low temperatures (3–7°C) for 3–12 months. During storage a fermentation/ripening takes place. Spontaneous brining occurs after dry salting or the salting may be performed using premade brine. In both cases, the fish is totally submerged in the salt brine during the storage/maturation period. Salt concentration in the brine (and in the fish after equilibration) is 4–6% (w/w).

Two Norwegian researchers, Schmidt-Nilsen and Bøhmer [15] described some of the microbiological and chemical characteristics of *rakfisk* production. Based on pH measurements, salt content, and some microbiological, chemical, and sensory analyses, carried out in samples from a few producers in the *rakfisk* heartland, they conclude that the process is dual in its nature. It is a combination of *autolytic* processes by fish enzymes (proteolytic and lipolytic) and microbiological activity, especially acid producing bacteria. The autolytic process is active at temperatures down to 0°C, when the bacterial activity is rather limited. However, at higher temperatures, 5–10°C, fermentation by bacteria is a dominant feature of the process. The authors also state that it is possible to control the process by salt concentration and temperature, which is still assumed to be the case.

Further research on the product was not performed until the 1980s, when the focus shifted to hygienic and food safety aspects, since *rakfisk* had fallen into disrepute due to cases of botulism. Kjos-Hansen [16] described the process with respect to the risk of contamination and growth of *Clostridium botulinum* concluding that as long as strict hygienic practice is used, e.g., no contact with soil, proper gutting and cleaning practice, clean equipment, and control of salt (not lower than 5%) and temperature (not above 10°C), *rakfisk* is safe with regard to botulism. This study also showed that *Lactobacilli* are the dominant microorganisms in a standard *rakfisk* process (i.e., trout as raw material, temperature 5–10°C and 5–6% salt), and that the pH initially drops from around 6.5 to 4.5 in the brine, but rises again towards the end of the process. In *rakfisk* production with relatively high temperatures (7–8°C), and low salt concentrations (4–5%), Axelsson [17] determined that lactic acid bacteria (LAB) are few in numbers in the raw material, but start growing after brining occurs and quickly becomes the dominating bacterial group. The lactic fermentation is finished after approximately 4 weeks and the numbers in the brine reach 10^8–10^9 bacteria/mL at that point and stay almost at this level further through the process. Few LAB are able to grow under these quite selective conditions (high salt, low temperature). One of them is *Lactobacillus sakei*, which is the most common LAB in standard *rakfisk* production. *L. sakei* produces lactic acid and may produce minor amounts of certain aroma compounds, but is not known to secrete protein or lipid degrading enzymes. Since the product needs at least 9–10 weeks more of ripening before it achieves its characteristic *rak* taste and smell, fermentation probably only *sets the stage* and the final maturation is rather obtained through the autolytic process already suggested by Schmidt-Nilsen and Bøhmer [15], i.e., by enzymatic activities originating from the fish itself, although the details are not clear.

A more recent project includes a more thorough study at the microbiota in rakfisk brine using culture-independent methods and using a more diverse selection of products [18]. This study confirms that LAB, most often *L. sakei*, tend to be the dominating bacteria in the *rakfisk* process when production is done using relatively high temperatures (5–7°C) and the salt concentration is around 4–5 %. The pH drop was less dramatic than described by Kjos-Hanssen [16], unless small amounts of sugar (0.2–0.4%) were used. Some producers use temperatures of 3–4°C and higher salt concentrations, approximately 6%, in which the growth of bacteria generally is slower and LAB, although present, tend not to be dominating. Instead, other psychrotrophs and salt-tolerant groups of bacteria dominate, e.g., species of the genus *Psychrobacter*. The fact that the product anyway eventually matures into a product with typical *rak* attributes, may suggest that the autolytic activities over time are the major contributors to these attributes, rather than the bacterial fermentation, which partly confirm the notions of Schmidt-Nielsen and Bøhmer [15]. As with most of these traditional fermented products, however, it is very difficult to ascertain the actual quantitative roles of bacterial aroma and acid production, bacterial enzymatic activity, and fish enzymatic activity for the final characteristics of the product.

3.3. Food safety

The earliest documented outbreak of botulism in *rakfisk* was in 1831 [19]. Since 1970 there have been four documented outbreaks affecting some 20 persons, with the last reported outbreak in 2003. As observed by Kjos-Hansen [16], only *rakfisk* produced in private homes and with clear breaches of accepted principles (e.g., too high temperatures) has been the source.

Most food safety concerns with regard to *rakfisk* have recently been directed towards avoiding *Listeria monocytogenes* and although it has been detected from time to time, only one documented outbreak of listeriosis illness has occurred. Rigorous hygiene and correct handling of the raw material are essential for avoiding *L. monocytogenes* and studies also indicate that using low ripening temperatures (< 5°C) results in essentially no growth, although conditions are not inhibitory in theory [20].

3.4. Consumption traditions

Rakfisk is regarded as a Norwegian specialty, commonly eaten from late fall and through the Christmas season. The seasonal tradition for consuming the product stems from the fishing of the trout or charr, which traditionally takes place during the late summer. The caught fish was prepared for *rakfisk* and was thus ready in the late fall and for Christmas. Although at present, most producers use farmed fish and are somewhat independent of this seasonal fishing, the seasonal tradition for consumption prevails.

Rakfisk is manufactured in a traditional, artisanal and localized manner and is known for its characteristic taste, odor and somewhat spreadable texture. The taste, smell, and spreadability increase with the ripening time. *Rakfisk* is usually served uncooked as fillet pieces with *lefse* (Norwegian soft flatbread), butter, onions and/or leek, sour cream, and potatoes as well as beer and *akvavit* (Scandinavian flavored spirit). *Rakfisk* is in a trend of increasing popularity in Norway as a delicatessen food and the annual production is approximately 400 tons.

4. Surströmming

4.1. Origin

The name *surströmming* originates from the combination of *sur* (in English: sour or acidic), which can be related to the lactic acid formation, and *strømming*, which is the local name for Baltic herring caught in the northern regions of the Baltic Sea. The process may have been developed in order to keep relatively large catches, for as long as possible, with as little salt as possible. The process was already known, but became increasingly popular in periods with trade embargos and limited salt supply (first 1520–1530). In some regions of Sweden, *surströmming* was a staple food and it was supplied as army rations in the 17th century.

4.2. Process

The raw material is freshly caught Baltic herring (*Clupea harengus* var. membras) caught just prior to spawning from May until the first week of July [21]. The fat content of the herring at this time is rather low. The process starts with presalting of the herring for 1–2 days in saturated salt solution with continuous stirring for the first 4 hours. After the presalting, the herring is deheaded and gutted (gonads and pyloric ceca are not removed), put into barrels with a weaker brine (17% salt). After sealing, the barrels are rotated occasionally for the first 3 days and then put into storage. The barrels are stored at 15–18°C for 3–4 weeks. This process is accompanied by formation of gases that escape from between the barrel staves. When the fermentation is ended, the herring is transferred to cans together with brine from the fermentation barrels.

Chemically, the fermentation process starts with the normal *post mortem* processes in the fish, formation of lactic acid due to anaerobic situation in the muscle tissue, continued by autolysis of proteins and lipids, followed by establishment of a fermentative microbial flora; many autolytic enzymes are found in the muscle tissue (calpains, cathepsins, proteasomes with caspase, etc.); another important source of autocatalytic enzymes is the pyloric ceca in the gut [22,23]; together with bacteria, pungent smelling acids are formed in the fish such as propionic acid, butyric acid, and acetic acid. Hydrogen sulfide is also produced. The salt increases the osmotic pressure of the brine above the zone where bacteria responsible for rotting (decomposition of proteins) can thrive and prevents decomposition of fish proteins into oligopeptides and amino acids. Neither indole, skatole, putrescine, nor cadaverine—otherwise typical for rotting processes—have been detected [21].

Canning takes place at the beginning of July and for 5 weeks thereafter. Ten days prior to the premiere (in August), the final (canned) product is distributed to wholesalers. Fermentation continues in the can and within half a year or so, gases have built up sufficiently for the once flat tops of the cylindrical tins to bulge into a more rounded shape. Kobayashi et al [24] identified the effective microbes in *surströmming* fermentation to be species of strictly anaerobic halophile bacteria, *Haloanaerobium,* being responsible for the in-can ripening. These bacteria produce carbon dioxide and a number of compounds that account for the unique odor: pungent (propionic acid), rotten-egg (hydrogen sulfide), rancid-butter (butyric acid), and vinegary (acetic acid).

These unusual containers of *surströmming* can be found today in supermarkets all over Sweden. *Surströmming* typically contains 11.8% protein, 8.8% salt, and 3.8% fat [25]. The current annual production is approximately 600 tons.

4.3. Food safety

Due to the fermentation process, the microbial flora is controlled by lactobacilli. The origin of these is most probably the barrels. When using sterilized vessels there is no development of the typical *surströmming* flavor. The Swedish national Food Agency conducted trials in the 1970s by adding known food pathogens such as *Staphylococcus aureus*, *Bacillus cereus*, and *Clostridium perfringens* to *surströmming*, but none of these microorganisms could be shown to grow in *surströmming*, thus indicating that there is an efficient barrier towards growth of unwanted bacteria in *surströmming*. *Clostridium botulinum* and *Listeria monocytogenes* have not been tested, but the salt content of *surströmming* makes it very unlikely that they should be able to grow [26]. Model experiments with various strains of *Lactobacilli*, indicate that they establish a stable and safe microbial situation, due to inhibition of both pathogens and spoilage flora. They also seemed to contribute to lipid stability by inhibiting development of rancidity, which otherwise is a great cause of rapid quality deterioration in fatty fish products.

A recent investigation of quality parameters of salted and fermented fish products in relation to food safety [27], found levels of histamine 25–80 ppm in *surströmming*, but no pathogenic bacteria. The TMA level was approximately 35 mg/100 g, the pH 7.1–7.4 and the water activity 0.90–0.91.

Currently, however, there are issues related to dioxin content in Baltic Herring [28,29] and hence also in *surströmming*. The Swedish National Food agency recommends pregnant women to consume *surströmming* only 2–3 times per year [30].

4.4. Consumption traditions

Surströmming is often eaten with a kind of bread known as *tunnbröd* (thin bread). This thin, either soft or crispy bread (not to be confused with crisp bread) comes in big square sheets when crisp or as rounds of almost a meter in diameter when soft.

The custom in Höga Kusten (The High Coast), the area of northern Sweden where this tradition originates, is to make a sandwich, commonly known as a *surströmmings-klämma*, using two pieces of the crispy kind of *tunnbröd* with butter, boiled and sliced or mashed potatoes topped with fillets of the fish together with finely diced onions. *Surströmming* is usually served as the focus of a traditional festivity, a *surströmmingsskiva* (*surströmming* party), accompanied by schnapps and light beers.

5. Barrel-salted ripened herring and sprats

5.1. Origin

The use of herring (*Clupea harengus*) in the Norwegian diet can be traced back more than 1,000 years. From excavations, remains of herring bones indicate its importance as a food source. Legislation from the 12th century describes the legality of herring fishery on every day of the week—including Sundays—a dispensation given by Pope Alexander III (1159–1181) [31]. This could be attributed to seasons and irregularity; herring would be absent for long periods (years), and reoccur, as it is also described in the early sagas. During catch seasons it would be available in vast amounts, which led to a need for preservation, not only on shore but also at sea [32].

Due to the lack of salt sources, the initial preservation approach in northern Europe was drying. However, with emerging trade salt became available. The salting of herring was probably first practiced in Scotland in the 8th century [32]. Salting of herring in barrels is a traditional preservation process that has been a common practice in Norway since the 15th century [31]. In the 16th century, the Dutch took over the trading of fish in Norway from the Hanseatic League, who also lost their monopoly on the salt trade in Norway [33]. The addition of brine to the barrels was a lesson learned from the Dutch as was the development of less salted products, which started in the 19th century.

Traditionally ripened herring (*Gammeldags modnede sild*) is now a protected product in Denmark, and the food authorities check that the rules of preparation are kept. The alternative to the traditional process with intact intestines, is salting of fillets which can be produced either in barrels, similar to the traditional process, or in tubs with acetic acid. The latter takes less time to *ripen* and both are cheaper to produce, but differ from the traditionally ripened both in taste and texture.

5.2. Process

Traditionally, the raw material for spice-salted herring has been different stocks of herring: Icelandic summer spawning; Norwegian spring spawning; local stocks (Fjord herring); and Baltic herring. In addition sprats (*Clupea sprattus*) have been, and still are used for some special products called *anchovies*. Currently, however, the raw material is mainly small size Norwegian spring-spawning herring, caught in October and November.

For the traditional process, deheaded herring (100 kg) are put in plastic barrels (typically 120 L) with salt (15 kg), sugar (6–7 kg) and sometimes spices (2 kg) [34,35] and kept for 3–6 months at refrigeration temperatures. During the first days a brine is formed, and some kind of mechanical movement is required during the 1st week in order to redistribute this brine in the barrel to avoid dry zones and oxidation. Nowadays the salting/ripening process is important not so much to preserve the fish but to produce a well-ripened product with a tender consistency and a pleasant taste and odor.

Although salting of herring is traditional, knowledge about the changes that take place in the fish during the ripening stage is still limited. The initial stage is the salting, characterized by salt uptake, water and weight changes [36–38], ends when the concentration of the salt in the tissues equals that of the surrounding brine. The subsequent ripening stage consists of (bio)chemical and physical changes that alter the characteristics of the muscle tissue and thus the sensory properties of the fish. Muscle proteins are broken down thus producing low molecular weight compounds, e.g., peptides and amino acids [39,40]. The texture of the fish becomes softer and more tender during the ripening and a pleasant (ripened) taste is formed [41].

The role of microorganisms in the ripening has been investigated. The original psychrophilic and proteolytic flora [42,43] is changed with the addition of salt, and the obligatory or facultative halophilic bacteria [44] micrococci, Gram-positive rods and yeasts develop to become dominant, although at low number, until the fish is ripe. Experiments with added antibiotics, formaldehyde, and gamma irradiation have been made to establish the significance of the bacteria to the ripening of anchovies. The effects of removing the bacteria seemed minor [21], leading to the conclusion that the ripening is caused mainly by enzymes. The origin of the enzymes that are important for the ripening is still not clear. Endogenous proteolytic enzymes from the internal organs of the herring are considered to be of prime importance but enzymes from muscle tissue may also be important [32,35,39]. Studies have shown that herring that has been thoroughly cleaned of intestines ripens slowly and does not acquire the characteristic taste [32,45].

After the barrel ripening, the herring is filleted and packed in vacuum packages or in sweet brine glass jars or they can be sliced into thin slices (tidbits) and packaged in metal cans. The production of canned herring products dates back to 1841, when the first canning factory was established, principally for the manufacture of anchovies [44]. In slightly acidic brine with added preservation agents, these products are shelf stable for a number of months at refrigeration temperature, but the ripening process continues even after packaging, and affects both taste and texture.

5.3. Food safety

Scombroid poisoning (scombrotoxicosis) is a worldwide problem of food borne intoxication caused by the consumption of seafood containing large quantities of histamine [46]. Historically the formation of histamine has been associated with salted herring. Langmyhr and Tertnes [34] studied the formation of histamine as function of raw material freshness and salt content. These authors found low levels of histamine in salted, fresh herring. In spoiled herring, however, levels of histamine were high already 1 day after salting. Furthermore it was seen that less histamine was formed in heavily salted herring (> 20 kg salt per 100 kg herring) than in sugar salted and spice salted (less salt).

5.4. Consumption traditions

The northern European production of ripened herring is mainly used for herring delicacies. The main market for the traditionally ripened product is currently Denmark, with the main consumption related to holidays (Christmas, Easter, and Midsummer). The traditionally ripened products are served with eggs and in different sauces as condiments for sandwiches, often as part of a herring feast, which also includes beer and schnapps. Or they can be served with boiled potatoes, dill, raw onions, sour cream, and beets, as a lunch or dinner. The combination with potatoes is believed to have been a very important staple food for the population in northern Europe for centuries. With increasing wealth, however, different preferences developed. The tradition of using herring for a main meal has almost disappeared and the herring consumption is currently rather low.

6. Market aspects and future trends

The current situation in the northern European market for fish products is dominated by two main phenomena; the authorities recommend and the market demands less salt. Furthermore, the younger generations prefer less taste and Japanese-style raw fish such as sushi and sashimi is becoming increasingly popular. Combined, these do not favor the traditional fermented products. They are both salty and/or strong tasting. Most of the fermented products are highly seasonal and the production/consumption is quite low.

In northern Europe, both salted fish products as well as traditional fermented products are generally popular with adults (age > 40 years). There is, however, an increasing interest in locally produced traditional food, so production volumes of the traditional fermented products have remained stable or slightly increased during the last few years. Aspects that may further help this development could be related to the documentation of potential health benefits of these products, e.g., related to their contents of biologically active peptides.

Although the process control has improved, there have been few efforts to further develop products based on the traditionally fermented ones, similar to that presented by Burgess [47]. The use of technology and bacterial cultures from the meat sausage industry has been explored by Nordvi et al [48,49] to produce a fermented and dried saithe and salmon product. However, this approach has not been commercialized.

Although the production of the traditionally fermented fish products in northern Europe has been standardized and is currently handled by only a few produces, it is still based on a limited scientific knowledge of the processes. The interactions between enzymes in muscle and intestines, as well as a complex microflora have proven difficult to characterize in detail. Modern analytical tools for characterizing protein degradation and bacterial cultures as well as texture and taste development could be used to substantially improve this knowledge. Furthermore, the use of nondestructive spectroscopic techniques could be used for process monitoring [50]. A deeper knowledge of the autolysis and fermentation might give basis for better control and eventually an introduction of bacterial starter cultures for controlled fermentation, and also new product types.

Conflicts of interest

The authors have no conflicts of interest.

Appendix A. Supplementary data

Supplementary data related to this article can be found online at http://dx.doi.org/10.1016/j.jef.2015.02.004.

References

[1] Hagen H, Vestad G. Tre sterke fra innlandet—om rakefisk, akevitt og pultost. Brummunddal (Norway): Gutu Forlag; 2012.
[2] Kurlansky M. Salt. London (UK): Vintage Books; 2003.
[3] Aquerreta Y, Astiasaran I, Bello J. Use of exogenous enzymes to elaborate the Roman fish sauce 'garum'. J Sci Food Agric 2002;82:107–12.
[4] Beddows CG. Fermented fish and fish products. In: Wood BJB, editor. Microbiology of fermented foodsvol. 2. London (UK): Elsevier; 1985. p. 1–39.
[5] Kristjánsson L. Íslenskir sjávarhættir (Icelandic marine and fish processing methods). Reykjavik (Iceland): Bókaútgáfa Menningarsjóðs; 1983. p. 316–95.
[6] Magnússon H, Gudbjörnsdóttir B. Örveru—og efnabreytingar við verkun hákarls. Reykjavik (Iceland): Icelandic Fisheries Laboratories; 1984.
[7] Reynisson E, Thornór Marteinsson V, Jónsdóttir R, Magnússon SH, Hreggvidsson GO. Bacterial succession during curing process of a skate (*Dipturus batis*) and isolation of novel strains. J Appl Microbiol 2012;113:329–38.
[8] Kristinsson Ö. Efnagreining á verkuðum hákarli. Reykjavik (Iceland): Icelandic Fisheries Laboratories; 1993.
[9] Halsted BW. Biotoxications, allergies and other disorders. In: Borgstrom G, editor. Fish as food. New York (USA): Academic Press; 1962. p. 521–40.
[10] Anthoni U, Christophersen C, Gram L, Nielsen NH, Nielsen P. Poisonings from flesh of the Greenland shark *Somniosus microcephalus* may be due to trimethylamine. Toxicon 1991;29:1205–12.
[11] Simidu W. Nonprotein nitrogenous compounds. In: Borgstrom G, editor. Fish as food: production, biochemistry, and microbiology. New York (USA): Academic Press; 1961. p. 353–84.
[12] Boisier P, Ranaivoson G, Rasolofonirina N, Andriamahefazafy B, Roux J, Chanteau S, et al. Fatal mass poisoning in Madagascar following ingestion of a shark (*Carcharhinus leucas*): Clinical and epidemiological aspects and isolation of toxins. Toxicon 1995;33:1359–64.
[13] Anon. Fiskistofa. Uppsala (Sweden): The National Food Agency (SE); 2015.
[14] Riddervold A, Heuch H. Rakfisk—en vidunderlig spise. Oslo (Norway): Teknologisk Forlag; 1999. p. 16.
[15] Schmidt-Nilsen S, Bøhmer T. Zur Kenntnis der wenig gezalzenen Forellen, 'Rakörret'. Kongelige Norske Videnskaps Forhandlinger 1935;8:83–6.
[16] Kjos-Hansen B. Rakørret—hygiene. Norsk Veterinærtidskrift 1986;98:121–5.
[17] Axelsson L. Rakfisk—trygg mat? Toxikologen 2008;18:10–3.
[18] Bjerke GA, Rudi K, Axelsson L, Blom H. Characterization of the bacterial community during ripening of Norwegian fermented fish, Global issues in food microbiology: 23rd International ICFMH Symposium FoodMicro 2012. Istanbul (Turkey): ITU; 2012. p. 680.
[19] Schjønsby HP. Botulisme i Østerdalen i. Tidsskrift for den Norske Legeforening 1831;122:2860–2.
[20] Bjerke GA, Blom H, Axelsson L. Growth of *Listeria monocytogenes* in Norwegian fermented fish and effect of an anti-*Listeria* bacteriophage. Eighteenth International Symposium on Problems of Listeriosis – Isopol XVIII. Belgium: Impressions; 2013. p. 211.
[21] Alm F. Scandinavian anchovies and herring tidbits. In: Borgstrøm G, editor. Fish as food. London (UK): Academic Press; 1965. p. 195–216.
[22] Battle H. Digestion and digestive enzymes in the herring (*Clupea harengus* L.). J Biol Board Canada 1935;1:145–57.
[23] Ghaly AE, Dave D, Budge S, Brooks MS. Fish spoilage mechanisms and preservation techniques: review. Am J Appl Sci 2010;7:859–77.

[24] Kobayashi T, Kimura B, Fujii T. Strictly anaerobic halophiles isolated from canned Swedish fermented herrings (*surströmming*). Int J Food Microbiol 2000;54:81–9.
[25] Anon. Livsmedeldatabasen. Uppsala (Sweden): The National Food Agency (SE); 2015.
[26] Lindberg AM, Stenström IM, Trenström A. Patogena bakterier i livsmedel och vatten. Lund (Sweden): Embreco; 2012.
[27] Köse S, Koral S, Yasar A, Yayli N, Tufan B, Üsen F, et al. Investigating some quality parameters of salted and fermented fish products of EU and Turkish origin in relation to food safety. 2007. Proceedings of Fish Fermentation, Norway.
[28] Bignert A, Nyberg E, Sundqvist KL, Wiberg K. Spatial variation in concentrations and patterns of the PCDD/F and dioxin-like-PCB content in herring from the northern Baltic Sea. J Environ Monit 2007;9:550–6.
[29] Miller A, Hedman JE, Nyberg E, Haglund P, Cousins IT, Wiberg K, et al. Temporal trends in dioxins (polychlorinated dibenzo-p-dioxin and dibenzofurans) and dioxin-like polychlorinated biphenyls in Baltic herring (*Clupea harengus*). Mar Pollut Bull 2013;73:220–30.
[30] Anon. Smarta tjejer håller sig till surströmmingssäsongen. Uppsala (Sweden): The National Food Agency (SE); 2014.
[31] Strømstad A. Sild til hverdag og fest. Oslo (Norway): Boksenteret; 1997.
[32] Voskresensky NA. Salting of herring. In: Borgstrøm G, editor. Fish as food. London (UK): Academic Press; 1965. p. 107–31.
[33] Kristiansen S. Sild. Havets sølv, bordet gull. Tromsø (Norway): Grafisk Produksjon; 1983.
[34] Langmyhr E, Tertnes G. Formation of histamine in salted herring. Bergen (Norway): Directorate of Fisheries; 1984.
[35] Nielsen HH. Proteolytic enzyme activities in salted herring during cold storage. Lyngby (Denmark): Department of Biotechnology, Technical University of Denmark; 1995. p. 1–131.
[36] Del Valle FR, Nickerson JTR. Studies on salting and drying fish. 1. Equilibrium considerations in salting. J Food Sci 1967;32:173–9.
[37] Del Valle FR, Nickerson JTR. Studies on salting and drying fish. 2. Dynamic aspects of the salting of fish. J Food Sci 1967;32:218–24.
[38] Zugarramurdi A, Lupin HM. A model to explain observed behavior on fish salting. J Food Sci 1980;45:1305–11.
[39] Kiesvaara M. On the soluble nitrogen fraction of barrel-salted herring and semi-preserves during ripening. Helsinki (Finland): Food Research Centre. Technical Research Centre of Finland; 1975. p. 99.
[40] Olsen SO, Skara T. Chemical changes during ripening of North Sea herring. In: Luten J, Børresen T, Oehlenschläger J, editors. Seafood from producer to consumer, integrated approach to quality. Noorwijkerhout (Netherlands): Elsevier; 1997. p. 305–18.
[41] Stefansson G, Nielsen HH, Skåra T, Schubring R, Oehlenschläger J, Luten J, et al. Frozen herring as raw material for spice-salting. J Sci Food Agric 2000;80: 1319–24.
[42] Austin B. The bacterial microflora of fish, revised. ScientificWorldJournal 2006;6:931–45.
[43] Cahill MM. Bacterial flora of fishes—a review. Microb Ecol 1990;19:21–41.
[44] Aschehoug V. The bacteriology of semi-sterile fish preserves, especially “gaffelbiter” and “anchovies”. Tidsskrift for hermetikkindustri 1952;38:30–41.
[45] Luijpen AFMG. The influence of gibbing on the ripening of Maatjes cured herrings. Utrecht (Neherlands): Univeristy of Utrecht; 1959.
[46] Shetty N, Tang JW. Gastroenteritis. In: Shetty N, Tang JW, Andrews J, editors. Infectious disease: pathogenesis, prevention and case studies. Chichester (UK): Wiley-Blackwell; 2009.
[47] Burgess PJ. Modification of a traditional Korean food product (*Gochujang*) to enhance its consumer acceptability as an ethnic food. J Ethnic Foods 2014;1: 13–8.
[48] Nordvi B, Egelandsdal B, Langsrud Ø, Ofstad R, Slinde E. Development of a novel, fermented and dried saithe and salmon product. Innov Food Sci Emerg Technol 2007;8:163–71.
[49] Nordvi B, Langsrud Ø, Egelandsdal B, Slinde E, Vogt G, Gutierrez M, et al. Characterization of volatile compounds in a fermented and dried fish product during cold storage. J Food Sci 2007;72:S373–80.
[50] Svensson VT, Nielsen HH, Bro R. Determination of the protein content in brine from salted herring using near-infrared spectroscopy. Lebensmittel-Wissenschaft Und-Technologie-Food Sci Technol 2007;37:803–9.