Review Article
Food Science and Technology

ISSN 0101-2061 (Print)
ISSN 1678-457X (Online)

DOI: https://doi.org/10.1590/fst.77321

CC BY

A review on fermented aquatic food storage quality based on heat treatment and water retention technology

Lawal Adedoyin ISOLA[1]*, Madeeha Hamid MAHMOOD[2], Asraa Yacoob YOUSIF[3], Sarmad Ghazi AL-SHAWI[4], Walid Kamal ABDELBASSET[5,6], Dmitry Olegovich BOKOV[7,8], Lakshmi THANGAVELU[9]

Abstract

Fermentation is a popular food preservation process that improves nutritional and organoleptic qualities, shelf life, and food safety. Fermented fish is produced and consumed in many regions of the world, and it is an integral element of many cuisine traditions. Fermented fish is also a substantial industry in several countries and a rich source of intriguing bacteria. Most of the end product quality of wine and meat, including taste, texture, and nutritional content, is determined by the main and secondary microbial metabolism formed during fermentation. A standard procedure in the food industry is the addition of salt to thermally processed meat and fish products in order to avoid weight loss that may otherwise have occurred due to the decreased water retaining capability caused by heat treatment. This article aims to bring you up-to-date on the different varieties of fermented fish and their production processes around the world. As a result, new methods that focus on limiting or accelerating fish products' heating are essential. Alternative heat transfer technology, such as combi-steamers or water baths, is used in both situations to increase heat transfer, allowing for faster heating and minimizing excessively heavy heat loads on parts of the product.

Keywords: fermentation; nutritional qualities; water-retaining; heat treatment.

Practical Application: Fermented Aquatic Food Storage Quality.

1 Introduction

Due to rising worldwide market for fish and fish-based commodities, preservation technologies have been developed to address issues such as seasonal availability, oxidation, and corruption (Gassem, 2019; Xu et al., 2021). Fermentation, in particular, has been the most extensively utilized preservation process among all the procedures such as smoking, salting, and freezing. It's a low-cost, easy-to-use, and energy-saving way of preserving fish muscle. In a number of nations, fermented fish items have long been a mainstay of the cuisine (Sivamaruthi et al., 2021). Nevertheless, the organoleptic qualities of fermented fish cooked in different nations fluctuate due to differences in geographical location, environmental conditions, culinary preferences, and the supply of fish sources (Choi, 2021). The main product of fermented fish may be the liquid leaked from the fish during salting. Fermented fish products are quite popular across southeast Asia. These goods have distinct qualities, particularly in terms of the fragrance, flavour, and texture that emerge throughout the fermentation process (Beddows, 1998). Different processes are used in fish fermentation and have resulted in three different types of products (Giyatmi & Irianto, 2017):

1) Products in which the fish essentially retains its original form (whole fish)

2) Fermented fish pastes (Giri et al., 2010)

3) Fish sauce (Figure 1)

Fermentation is likely to occur in salt-only fish. The amount of salt used, the quantity of fish, the cleaning of the fish (such as the removal of all or part of the viscera), the nature of any additives added, and the temperature at which the salted fish is stored will all influence the size of the fermentation. One of the most critical production parameters during fermentation is temperature. This is evidenced by observations in which this process has been used correctly, but products with completely different specifications have been obtained by storing at different temperatures. (Santos et al., 2019; Zang et al., 2020).

In a variety of countries, fish products that have been fermented have been a cornerstone of diet. However, the organoleptic properties of fermented fish prepared in various

Received 05 June, 2021
Accepted 23 Nov., 2021
[1] Landmark University, Omu-Aran, Nigeria
[2] College of Science, Al-Nahrain University, Baghdad, Iraq
[3] Agriculture College, Basrah University, Basrah, Iraq
[4] Food Science Department, Agriculture College, Basrah University, Basrah, Iraq
[5] Department of Health and Rehabilitation Sciences, College of Applied Medical Sciences, Prince Sattam bin Abdulaziz University, Al Kharj, Saudi Arabia
[6] Department of Physical Therapy, Kasr Al-Aini Hospital, Cairo University, Giza, Egypt"
[7] Institute of Pharmacy, Sechenov First Moscow State Medical University, Moscow, Russian Federation
[8] Laboratory of Food Chemistry, Federal Research Center of Nutrition, Biotechnology and Food Safety, Moscow, Russian Federation
[9] Department of Pharmacology, Saveetha Dental College and Hospital, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai, India
**Corresponding author: LawalAdedoyinIsola@yahoo.com*

Figure 1. Homemade anchovy fish sauce.

countries vary due to differences in dietary preferences, and the availability of fish sources (Lee et al., 2017). Fermented fish products are intimately connected with many Southeast Asian countries' cultures, particularly the ones that are used by many different ethnic groups (Majumdar et al., 2016; Ruddle & Ishige, 2010; Tamang et al., 2020). Many of these fermented fish items were traditionally processed based on empirical expertise until the emergence of modern microbiology, with little knowledge of the method's microbiota. In modern language, fermented fish is fresh fish that has experienced a number of beneficial biochemical modifications as a result of the activity of microorganisms or enzymes (Xu et al., 2021). In addition, there is an increasing interest in designing strategies to study microbial succession during fermentation.

2 Geographical distribution of fermented products

Freshwater and marine finfish, shellfish, and crustaceans that have been treated with salt to promote fermentation and therefore avoid putrefaction are referred to as fermented fish products (Wolfe & Dutton, 2015). Because East Asia produces such a diverse range of cuisines, a rigorous classification by product type must be confined to certain nations or language groupings. As a result, we adopt a basic generic classification based on the end product's nature as well as the manner of preparation (Table 1 and Figure 2) (Sarangam & Priya, 2019). The heavily salted fish known as shiokara in Japan is most likely the prototype product. Shiokara is the result of mixing fish with salt that keeps the form of the original raw fish material (Kitamura et al., 2016). This may be ground into shiokara paste, which tastes like a condiment. The salt fish combination produces fish sauce, a liquid used as a pure condiment, if no vegetable components are added. It becomes narezushi when cooked vegetable components are added to the fish and salt combination.

3 Processing conditions with focus on thermal processing

Fermented fish items are generally made based on family custom as well as regional tastes, and production processes vary greatly. The majority of traditional fermented goods are salted, dried, and occasionally smoked, as well as marinated (Essuman, 1992). Fermentation efficiency is influenced by a number of parameters, including salt concentrations, humidity, duration, fermentation temperature, raw materials, and other variables. For reducing biogenic amine (BA) synthesis and affecting microbial growth, the most simple and successful technique has been discovered to be controlling fermentation temperature. Heat not only helps food to be more easily digested, but it also extends its shelf life by slowing or stopping chemical, enzymatic, and bacterial activity (Bhat et al., 2021; Duarte et al., 2009; Lavilla et al., 2007; Hanjabam et al., 2020). The greater the possibility of destroying microorganisms and inactivating enzymes, the higher the temperature and the longer the thermal process time; however, there are usually limitations due to possible and detrimental product quality changes. While serving the above purpose, the use of high temperature and short time (HTST) or low temperature and long-time low (LTLT) can prevent qualitative changes and nutritional value (Seyfzadeh et al., 2008; Singh & Anderson, 2004). Fish and other seafood are heated first to improve the food's quality before being cooled to stop the microbial and chemical activity. The way these products are heated or cooked, as well as the nature of their ingredients and it creates new products with a chemical composition that differs from that of the fresh product, for example, the thermal process in fish softens tissues, changes the nature of proteins, reduces moisture, and many other changes, but it improves the organoleptic properties and durability (Basu et al., 2002; Todgham et al., 2007). Hot water, steam, hot oil (frying), and dry heat can all be used in the heat process. Time and temperature for each of the above methods are dependent on market interest and the initial nature of the fish, and the characteristics of the product. Fish canning also entails preparing products that can be stored for an extended period of time and ensuring that the product is safe to eat at the end of that time (Cristóvao et al., 2015; Horner, 1997). Unlike other preservation methods, fish canning does not attempt to preserve the fish in its natural state. As a result, canned fish is a product with unique quality characteristics that have increased its preservation capacity. Storage of seafood by cooling, freezing, and canning is a common method used in almost every part of the world. Still, other techniques are used to preserve these products that have been used since time immemorial in addition to the above methods. Salting, drying, smoking, and fermentation were common before the use of freezing and heating, and they are still different in some countries (Allagbé et al., 2020; Doe & Olley, 2020; Michael et al., 2019).

There are two major sources of corruption. Bacterial and autolytic enzyme activity can be found in seafood (Duarte et al., 2020; Mei et al., 2019). Each method of maintenance is based on altering the environment and preventing the activity of bacteria and enzymes. Water is almost the most important component of all foods (Zhan et al., 2018). Although the amount varies depending on the food, a portion of it is available to microorganisms in the form of available water, which serves as the basis for spoilage. As a result, foods with a lot of water (milk, meat, fish) spoil faster, while foods with a little water (flour and honey) comparatively last longer. Measuring the water activity (a_w) in food determines the amount of water available (free water). The amount of water available to microorganisms to perform metabolic reactions

Table 1. Fermented fish foods in east asia: types and nomenclature.

Country	Fermented Food Product Category					*Narezushi*
	Shiokara	Shrimp Paste	Fish Paste	Fish Sauce	Shrimp Sauce	
Bangladesh		*nappi*				
Cambodia	*prahok*	*kapi*	*Padek*	*tuk trey*	*nam tom*	*Phaak*
China	*yujiang*	*shajiang*				
Indonesia	*bakasam*	*terasi udang*	*terasi ikan*	*kecap ikan*		*wadi bakasem ikan masim*
Japan	*shiokara*			*shiotsuru ishiri ikanago-shoyu*		*Narezushi*
Korea	*jeot*	*saewoo-jeot*		*myeol-chi-jeotguk*		*Shikhe*
Laos	*pa daek*		*pa daek*	*nam paa*		*som paa*
Malaysia		*belacan*		*budu*		*pekasam cincalok ikan masim*
Myanmar	*ngapigaung*	*ngapi seinsa*	*ngapitaungtha*	*ngagampyaye*	*pazunggampyaye*	*nga(+)ngapi*
Philippines	*bagoong*	*bagoong alamang dinailan guinamos oyap*		*patis*	*alamang patis*	*burong isda*
Thailand	*pla ra*	*kapi*		*nam pla budu thai pla*	*nam kapi*	*pla ra pla som*
Vietnam	*ca mam*	*mam ruoc mam tom*	*mam mem*	*nuoc mam*	*nam tom*	*mam chau*

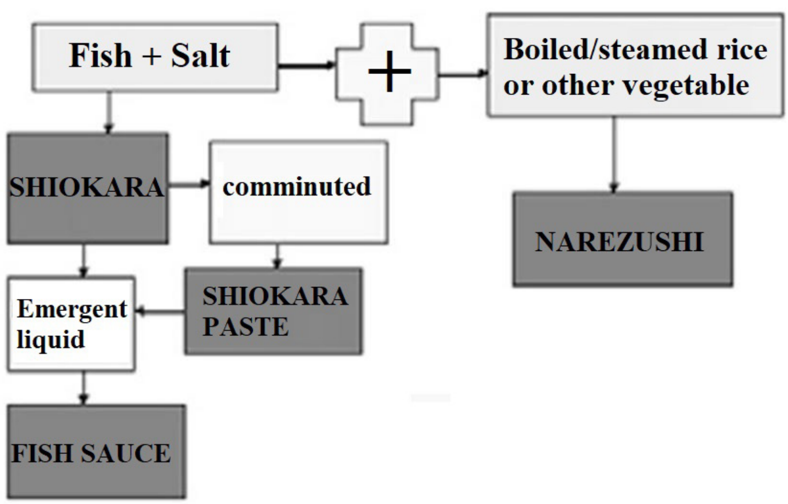

Figure 2. In Asia, there is a general categorization for fermented fish items.

and transfer metabolites is measured by water activity in food. Because $a_w = 1$ in pure water, the closer the amount of a_w in a food is to one, the more microbial activity and chemical interactions it has (Feng et al., 2021). Water activity in fish is close to 1, but after salting and drying, the amount of water activity in it drops to around 0.7-0.8, which is not conducive to bacterial growth. Salting, drying, and smoking processes are combined, and the final product is primarily marketed as smoked fish and is offered to the consumer with acceptable durability (Bomfeh, 2020; Tahir et al., 2020).

Low temperatures, or ambient temperature, have been claimed to be the optimal temperature for natural fermentation. Furthermore, the temperature is often adjusted to match the optimum growing temperature of the starter cultures (Thapa, 2016). For instance, Lactobacillus helveticus CCRC 14092, Lactococcus lactis subsp. lactis CCRC 12315, Lactobacillus plantarum CCRC 10069, and lactic acid bacteria (LAB), have been employed to make fermented mackerel mince at 37 °C (Choorit & Prasertsan, 1992; Saithong et al., 2010). Consumer acceptability was highest for Pediococcus pentosaceus fermented silver carp sausages at 23–30 °C. Furthermore, most fermentations using mixed starting cultures have been carried out at a temperature of 25 °C (Xu et al., 2010a, b). Due to the fact that various microorganisms have varied optimal growth and metabolite synthesis temperatures, to increase the quality and safety of fermented fish, a two-stage temperature control system was used (Xu et al., 2019). In different forms of fermented fish, the salt content can range from 0 to 30% (w/w). Depending on the salt content and fermentation temperature, fermentation period might range from a few weeks to many months (El Sheikha et al., 2014; Sampels, 2015). Furthermore, it's best to keep fermented fish's moisture level between 50 and 70%, since this will extend the shelf life. Furthermore, adding glucose to the fermentation system can give an additional energy source, allowing microorganisms to proliferate faster (Fatimah et al., 2017).

When it comes to improving the thermal processing of fish to optimize efficiency, the main problems are loss of water and structure shifts. As heated, the translucent, gooey cellular mass becomes opaque, friable, mildly rigid, and soft. When a muscle is heated, it shrinks, and liquid is released. The proteins in this liquid could coagulate and form a curd on the surface of the firm fish (Studer et al., 2004). Cooked fish quickly falls apart and becomes palatable after moderate heating since the connective tissue that holds the cells together is easily destroyed. Mechanically immobilized water, also known as free water, makes up about 95% of the water in tissue (Ramírez et al., 2013). When evaluating Water Holding Capacity (WHC) in muscle, this water is free to flow across the muscle tissue and is of concern. Cod muscle has a fat content of around 0.3 percent. Non-fatty fish types have an estimated gross liquid loss of 18.6%. As a result, the liquid loss must be mostly composed of water and dissolved proteins (Beddows, 1998; Koo et al., 2016). For non-fatty fish species, the distinction between water and liquid retaining ability is less important, and water holding capacity is used to refer to all liquid emitted from the fish, even though it includes dissolved proteins and minor quantities of fat. Figure 3 shows the results of WHC screening of farmed cod using isothermal heating ranging from 20 to 95°C, averaged overheating periods of 1–60 minutes (Skipnes, 2014).

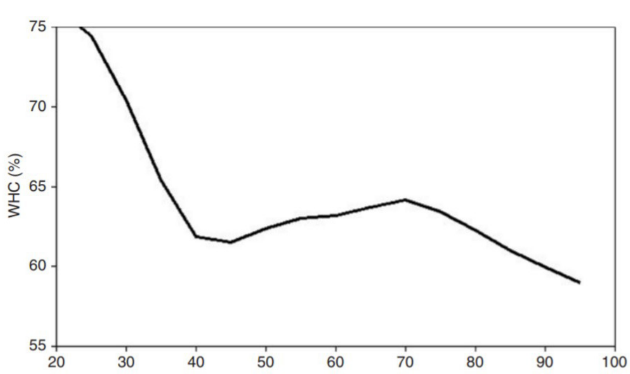

Figure 3. WHC at heat treatment temperatures.

WHC is lost as the heat and processing time are increased, as predicted. WHC dropped dramatically from 20 to 45 °C. The WHC rose in the range 45–70 °C within a small range of processing time and temperatures (Tsuda et al., 2012). Excessive loss of water holding capacity due to time and temperature combinations may be linked to high drip loss and juiciness loss during delivery and storage. WHC was in the range of 66–70% in mixtures with a medium thermal load, such as 30 minutes at 60 °C. WHC and cook loss are caused by a variety of physical factors (such as concentration and temperature gradients) as well as protein denaturation (Riebroy et al., 2005). The internal composition of the fish muscle and its capillaries varies as a result of protein denaturation. Another result of protein denaturation is juice shrinkage and mechanical expulsion. The opaque cod muscle becomes white when heated. This occurs as the temperature is raised to 30 to 40 °C. There was no discernible colour difference at temperatures ranging from 70 to 90 °C (Ghaly et al., 2010). Whiteness scores were higher in cod samples at temperatures higher than 60 °C than samples treated at colder conditions. The colour shifts in salmon and trout from red to pink and then to light pink as the heat load increases are more noticeable than the minor colour changes observed in whitefish. Processors are also grappling with the release of water-soluble proteins that later form a yellow to grey curd on the fish product's surface. A brine containing a small percentage of salt and small quantities of citric acid is well known for reducing this problem (Pérez Palacios et al., 2017; Skipnes et al., 2011).

4 Common procedures and processing conditions across the world

Fermented fish items are already very common in Northern Europe, Africa, and Asia, in which several countries have their own distinct fermented fish items (Table 2) (Zang et al., 2020). Each region's unique blend of raw resources, atmospheric conditions, microbes, and dietary customs contributes to its distinctiveness.

In many European nations, fermented fish is a traditional staple dish. Only a few traditional fermented fish items, however, are still made. Garum, for example, is a well-known Greek and Roman fermented fish sauce. The greatest components for making garum are mackerel and herring. The fermentation took at least nine months to complete. Many small Italian and Spanish businesses continue to make garum-style fish sauces (Skåra et al., 2015). Hakarl is a fermented shark flesh that can be kept for a long time (up to several years) and is a popular Icelandic delicacy (Osimani et al., 2019). Fermentation and drying are the only ways to get it. Shark fermentation can take 3–6 weeks, while drying can take anything from a few weeks to months, depending on the climate and fishing season. During fermentation, bacterial ureases transformed urea in the hakarl to ammonia, and the bacteria also degraded trimethylamine (TMA) N-oxide into TMA. During the drying process, however, the ammonia and TMA levels decreased somewhat (Zhang et al., 2020). Furthermore, fresh shark meat, which is considered deadly, may be turned into a healthy food product. In former times, Icelanders relied heavily on fermented Hakarl for energy and nourishment, and it remains popular among the elderly today (Rajauria et al., 2016). Surstromming, a fermented

Table 2. Various types of fermented fish items from across the world.

Country	Microbe	Fermentation time	Salt to Fish ratio	Raw Material	Type	Name
Thailand	Homofermentative tetradforming lactic acid bacteria	5–12 months	>20%	Stolephorus spp. Ristrelliger spp. Cirrhinus spp., salt	Sauce	Nam-pla
Thailand	Pediococcus pentosaceus, Lactobacillus alimentarius, Weissella, L. planetarium, Lactococcus garvieae, Zygosaccharomyces rouxii	8–12 days	6–11%	Puntius sophore, salt, palm sirup, roasted rice	Whole (slices)	Plaa-som
Sweden	Halanaerobium	3–4 weeks	17%	Baltic herring, salt	Whole (slices)	Surströmming
Roman	None reported	9 months	25%	Tunnus thynnus, Scomber scombrus	Sauce	Garum
Philippine	None reported	3–12 months	22–26%	Clupea spp. Decapterus spp. Leionathus spp., salt	Sauce	Patis
Norway	Lactobacilli	9–10 weeks	>5%	Salmonid freshwater fish, salt	Whole (slices)	Rakfisk
Malaysia	Micrococcus luteus, Staphylococcus arlettae	3–12 months	20–30%	Raw anchovies (Stolephorus spp.) and salt	Sauce	Budu
Malaysia	None reported	2–3 weeks or 12 months	>10%	lampam java (Pontius gonionotus), black tilapia (Oreochromis mossambicus), uncooked rice, salt	Whole	Pekasam
Korean	Achromobacter, Bacillus, Brevibacterium, Flavobacterium, Halobacterium, Leuconostoc, Micrococcus, Pseudomonas, Staphylococcus, Sarcina, Saccharomyces, Torulopsis	2 months or a few years	5–30%	Shrimp, shellfish, fish, salt	Whole (slices)	Jeotgal
Japan	Aspergillus, Eurotium	3–4 months	10–15%	Skipjack (Euthynnus pelamis or Katsuwonus pelamis), eastern little tuna (E. affinis), frigate mackerel (Auxis rochei), frigate tuna (A. thazard), oriental bonito (Sarda orientalis)	Whole (slices)	Katsuobushi
Japan	Lactobacillus acidipiscis, Lactobacillus versmoldensis	2–3 months	20–30%	Crucian carp, horse mackerel, chub mackerel, salt, cooked rice	Whole (slices)	Narezushi
Japan	Tetragenococcus muriaticus, Tetragenococcus halophilus	12 months	10–15%	Mackerel, sardine, salt, cooked rice	Whole (slices)	Fish-nukazuke
Indonesia	Micrococcus, Streptococcus, Pediococcus sp.	40 days	10–20%	Sardines (Engraulis japonicus), salt, glucose	Sauce	Bakasang
India	Staphylococcus; Micrococcus, Bacillus	3–5 months	0	Punti fish (Puntius sophore), phasa fish (Setipinna phasa)	Whole	Shidal
India	Lactococcus lactis ssp. lactis	12 months	None reported	Puthy maas (Ticto barb), roasted green chilies, tomatoes, ginger, rice, salt	Whole (slices)	Hukuti maas
India	Lactococcus lactis subsp. cremoris, L. plantarum, Bacillus subtilis, Candida, Saccharomycopsis.	4–6 months	0	Puntius sophore	Whole (slices)	Ngari
Iceland	Moraxella, Acinetobacter, Lactobacillus sp.	3–6 weeks	0	Greenland Shark (Somniosus microcephalus), salt	Whole (slices)	Hakarl
Ghana	Micrococcus, Staphylococcus aureus, Staphylococcus sp., Bacillus sp., Lactobacillus sp., Pseudomonas, Pediococcus, Klebsiella, Debaryomyces, Hansenula, Aspergillus.	2–3 days	15–40%	Snakehead fish, salt, palm sirup, roasted rice	Whole (slices)	Momoni
Egypt	None reported	60 days	20–30%	Alestes baremose, Hydrocynus sp., salt	Whole (slices)	Feseekh
China	Halotolerant, LAB and Yeast	6 months	33%	Anchovies (Engraulis japonicus), snakehead fish (Channa asiatica)	Sauce	Yu-lu
China	L. plantarum, Pediococcus pentosaceus, Leuconostoc, Paralimentarius, Saccharomyces cerevisiae, Hansenula anomala	30–60 days	3%	Fresh-water fish (Cyprinus carpio L.), roasted rice, salt and sugar	Whole (slices)	Suan yu
Benin, Togo, Ghana	Bacillus, Staphylococcus, Corynebacterium, Pseudomonas, Micrococcus, Streptococcus, Achromobacter, Alcaligenes	3–8 days	15–35%	Cassava fish (Pseudotolithus sp.), Spanish mackerel (Scomberomorus tritor), salt	Whole (slices)	Lanhouin

fish product created from herring, is well-known in Sweden's northern regions for its distinct aroma (Kobayashi et al., 2000). The herring is pre-salted in a saturated salt solution before being fermented in barrels at 15–18 °C for 3–4 weeks, with the head and intestines removed. The fermented product, together with the brine, is then put to cans. Fermentation lasts for around six months in the can (Belleggia et al., 2020). Haloanaerobium, an anaerobic halophile bacterium, is responsible for the Surstromming features throughout the fermentation process. Surstromming It has a pH of 7.1–7.4 and includes 11.8 percent protein, 8.8 percent salt, and 3.8 percent fat (El Sheikha, 2018). In Europe, fish fermentations take anywhere from a few days to a year, and sugars and spices are sometimes added to the brine as additions. In Europe, fermented fish is commonly offered as whole fish or as a fish sauce. Salting and drying, drying without salting, or salting without drying are all common steps in the fermentation process. All northern European fermented fish items are salted, with the exception of Hakarl.

5 Thermal processing methods to optimize the production and enhance products characteristics

Because of the benefits of a high degree of safety, comfort, and healthier food, heat preservation is the most common strategy for extending packaged seafood's shelf life. Heat preservation is used after the packaging has been hermetically sealed to protect microorganisms from contaminating fresh food. Thermally cured in-pack fish products have been manufactured for almost two decades. Thermal processing can be classified into multiple categories depending on temperature regime, thermal processing procedure or equipment, fish species, packaging method, or the process's microbial goal (Niu et al., 2017; Pan et al., 2018). The traditional approach is canning. The goal of thermal processing during the production of canned fisheries products is to destroy bacteria using moist heat. Both pathogenic bacteria and their spores are inactivated during the manufacturing process. During manufacturing, the temperature will range from 110 to 135 °C. The mechanism is designed to inactivate *Clostridium botulinum* type A spores in low acid foods (pH > 4.5) (Maier et al., 2018; Pernu et al., 2020). Some non-pathogenic spore-forming strains can tolerate this thermal load., which is referred to as commercial sterility. Other sterilization subgroups exist, but they are not discussed here. Pasteurization is used to eradicate vegetative cells, but not all pathogenic bacteria's spores (Ghanem et al., 2019).

Fish has long been regarded as a source of essential nutrients, and marine omega fatty acids are also found to reduce the risk of cardiovascular disease and depression. In most developing countries, changing lifestyles have had a major effect on food eating patterns (Stormo et al., 2017). Heat treatment is one of the most popular approaches for manufacturing nutritious packaged foods with a long shelf life (Rosnes et al., 2011).

Microwave heating still has difficulties with irregular heating and a shallow penetration depth (a few millimetres). Figure 4 shows a fish pudding shaped like a sausage fried in a microwave at 2,450 Megahertz and immediately cut a string after heat treatment. After that, a thermal imaging camera records thermal photographs of the cross-sections. Steam is created within the package during microwave heating, which increases the risk of the package exploding. As a consequence, counterpressure or venting can be needed to prevent the package from bursting due to excessive pressure. There are a variety of valves that release steam and air during heat treatment; as a result, when the vapor condenses during chilling, a "vacuum" is created in the processed box, as in "steamplicity" (Edwards & Hartwell, 2006).

The fish's quality suffers considerably if the heat treatment is designed for a shelf life lasting longer than twenty-one days under cold conditions. The amount of heat used to inactivate enzymes and microorganisms creates adverse effects such as a drying texture and flaking, rendering it impossible to design a heating system for this sort of product (Darvishi et al., 2013; Duan et al., 2011; Jiao et al., 2019). Reduced processing duration at a cooler temperature enhances seafood sensory quality, but it decreases the shelf life. New methods focusing on accelerated or limited heating of fish products while ensuring a high degree of safety are therefore critical for new technologies. Quantifying product quality and safety for processed foods is an important yet nuanced issue due to high biological variability and degrees

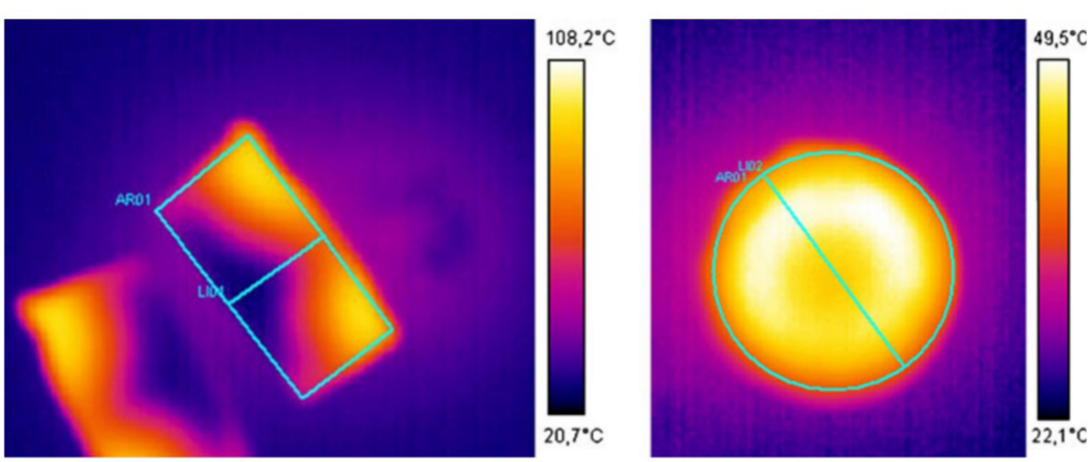

Figure 4. Temperature distribution in a microwave-heated fish pudding.

of uncertainty in terms of specifically increasing variables impact product quality and reliability (Chen et al., 2012; Peck, 2006; Sivertsvik et al., 2002). Some certain bacteria can become less prone to more threats as a result of sub-lethal pressures, which must be taken into account when developing food safety or shelf life in processed foods. There are questions about the safety of seafood products, especially when a higher temperature is possible. In the current paper, we've described processed seafood products as a group of products that have been thermally processed for Ten to Thirty minutes at a temperature varying from 60 °C to 95 °C, with a water activity > 0.85 and pH > 4.6.

Fish pathogens are generally divided into four groups: viral agents, microbial agents, fungal and algal agents, and parasitic agents. Each group of pathogens presents specific symptoms in fish. In other words, pathogens, as they progress, cause changes in the behaviour of fish that are often accompanied by certain physical symptoms. Specific changes in diseased fish include loss of appetite, abnormal scattering in the pool, such as swimming on the water's surface, gathering by the pool, or gathering at the inlet and outlet of the pool water, spinning. And the loss of balance, loss of balance, and loss of ability to withstand normal stress. Physical symptoms that may appear in a sick fish's body include discoloration of certain parts of the body, swelling of the body, protrusion of the eyes, scratches or sores on the head, body, and fins discoloration of tissues such as decolouration of the liver. In lightly preserved fish items, high incidences have been discovered.

This research will focus on recent research on fermented fish from all over the globe, via a particular emphasis on the impact of pathogens on the fermented fish's nature. Future prospects and developments will also be discussed. This research looks at the technologies and machinery that can be used for processes like mild heat treatment and high-pressure manufacturing (HPP).

Continuous processing is more suited to rapid heating processes. Uneven ventilation and a shallow penetration depth (a few millimetres) are two issues of microwave heating. Emerging thermal and non-thermal developments have obvious environmental advantages, such as increasing total process energy efficiency or reducing the usage of non-renewable resources. However, a fair analysis of the procedures is difficult due to the possibility that the end result will vary or that comparative details will be missing, as shown by the references mentioned below. As compared to conventional thermal pasteurization, cold pasteurization using high-pressure processing (HPP) will save up to 20% on energy (Erkan et al., 2014; Mújica-Paz et al., 2011). Modelling has been commonly applied in thermal processing, such as for effective energy management, but volumetric heat treatment and HPP are yet to be studied or configured for water and energy savings. Vitamins that are fat-soluble are more heat resistant than vitamins that are water-soluble. Thus, fatty acids are well contained in heat-preserved fish since it is usually air sealed. Preventing oxidation is also vital for the survival of the numerous minerals that fish provides. Finally, preservatives are unnecessary in thermally treated seafood. Even if there are other problems that affect the nutritional result, such as heat denaturation of proteins increasing the digestibility, balancing the heat load between the optimal sensorial content and microbial restrictions to achieve the necessary safety and shelf life is more difficult. Proteins are the most abundant nutrient in fish tissue. Thermal processing below 100 °C has little effect on amino acid composition, but it can affect their functional properties and improve digestibility (Chalamaiah et al., 2012; Sathe et al., 2005). The thermal load, which's determined by inactivation conditions for microorganisms, has a big effect on the quality of heat-treated products. Legislation requiring the inactivation of infectious agents often provides a safety margin that may also lead to overprocessing in certain items. In certain laws for tightly sealed wrapped, temperature-preserved foods, the following subjects, in addition to more relevant topics like hygiene, are of specific interest:

- Determining a safe heating technique, such as sterilization or pasteurization criteria.
- How to determine a scheduled heating process and achieve the necessary sterilization, for example, thermal absorption analysis and other assessment methods.
- Method and instrument evaluation, as well as maintaining records.
- Regulation over the final product.
- Packaging integrity

The microbial load on the fish's surface is thought to be far higher than in the flesh, which may pose problems when coupled with high-temperature resistance (Dimitroglou et al., 2011; Ripolles-Avila et al., 2019). When using traditional heating systems, though, the product's surface's heat load is much higher than on the core. This isn't necessarily the case for accelerated heating systems. We can only optimize heat treatment for efficiency and safety by quantifying the kinetics of inactivation of microorganisms and quantifying quality preservation. While many pathogen microorganisms' thermal inactivation kinetics are well understood, knowledge on quality improvements during heat treatment is often lacking. Basic chemical processes may be thoroughly described, but correlations in the food matrix and biochemical variability in humans make matters more complicated (Alba et al., 2019; Serment-Moreno et al., 2017).

The effect of rapid heating can, however, have some limitations. Protein denaturation is usually a low z-value operation, meaning that a slight shift in temperature causes a significant change in the time it takes to denaturate proteins. As a result, process temperature will significantly impact improvements in the water holding capacity (WHC) and cook loss, while process time will become less critical. Thermal denaturation of muscle proteins is the main cause of cook loss. Heating fish muscle allows myosin to denature and myosin to shrink, allowing water to escape (Aman, 1983; Olsson et al., 2003; Sánchez-Valencia et al., 2014; Skipnes et al., 2007; Wada & Ogawa, 1996). However, when the specimens were warmed to extreme temperatures than that of the proteins required to denaturalize, and the liquid in the specimen might be expected to be accessible for removal through a weak force applied, the loss of cookery appeared to increase. Since the majority of the target microorganisms have a higher z-value, a low temperature and a reasonably long process period would be beneficial. Rapid heating adds zero value to a method in which this is the case.

6 Overview of health benefits and potential risks

Fish products are high in polyunsaturated fatty acids and basic minerals, and they supply almost 20 percent of the animal protein consumption of approximately three billion people (Pal et al., 2018). Several studies have discovered a positive connection between fish-eating and health. For instance, metabolic syndrome reduction and cardiovascular disease prevention. Furthermore, recent surveys have consistently shown that Japan has a longer life expectancy and a lower obesity rate than the United States, which is due to the higher per capita fish consumption (Bao et al., 2019; Fuentes-Gandara et al., 2018; Kundam et al., 2018). According to research, consumption of fish and fish-related goods has also been linked to a lower risk of dementia and a strong inverse relationship with the annual incidence of major depression (Ngabirano et al., 2019; Tsurumaki et al., 2019). In addition to health advantages, fermented fish has certain detrimental consequences for humans. High levels of salt added to fermented fish, for example, might be an issue, and biogenic amines could be produced throughout the fermentation process in some cases (Sivamaruthi et al., 2021). If the quantities of biogenic amines in foods surpass the prescribed limits, it is recognized that the presence of BA can cause harm to people. Furthermore, they might be carcinogenic nitrosamine precursors. High sodium chloride consumption is linked to hypertension, which raises the risk of heart disease. Some fish fermentation research is focusing on how to lower the amount of BA and salts (Singh et al., 2018; Ricci et al., 2018). The biogenic amines breakdown mechanism which might be a viable solution to the problem has to be explained further, and whether it applies to specific fermentation products is yet unknown (Bavisetty et al., 2021). In addition to reducing salt intake, there are a variety of alternative options for addressing this issue. One option is to employ potassium chloride (KCl) in conjunction with masking agents and taste enhancers to partially replace salt, or to desalt fermented fish products using electrodialysis or other methods such as soaking prior to ingestion (Mohammadzadeh, 2020; Photi et al., 2020). Fermentations employing starter cultures applied directly to the raw materials provide for more precise control of the fermentation process, allowing for the standardization of quality features (Blana et al., 2014; Hugas & Monfort, 1997). Even so, meticulous attention to detail is still required throughout production. When utilizing this procedure, choosing the right starter cultures is critical. Only non-pathogenic bacteria, ideally probiotics that may create bacteriocins or other antimicrobials against undesired species, should be chosen (Raghuwanshi et al., 2018).

7 Conclusion

Food is processed in greater quantities today than in the past. Food technology is expanding the food market and transforming perishable and delicate goods into more durable goods. As a result, food is available for longer periods of time while maintaining its nutritional value and quality. As a result, many countries have adopted the use of fish and other aquatic products for food production. Thermal processing is among the most common methods for producing healthy convenience fish with a long shelf life. Some people are concerned about such fish's health, especially given the possibility of exploitation due to storage temperature. As a result, new methods relying on limited or rapid heating of fish products are critical. Modern developments' main goal is to reduce total heat flux by lowering temperature gradients in products or concentrating on polluted areas. Minimal processing frequently relies on the use of several sub-lethal stresses or processes to achieve a comparable degree of microbial regulation as that previously achieved through utilizing single lethal stress. Most minimally processed foods require refrigerated storage and delivery to ensure food safety.

The association between flavour production control and microbial metabolites is still unknown. Furthermore, despite the fact that traditional fermented fish foods do have long history around the globe, just some few processing methods have been heavily marketed. The comprehensive processes of microbial impact on fermented fish production are expected to be investigated in future research. The nutritional benefit and sustainability of fermented fish products are two other research areas that need to be discussed. Because of the growing need for fermentation goods on both domestic and foreign markets, it should be best known.

According to this study, fermented fish processes are becoming more and more common as research topics. Fermented fish is made in a variety of forms all around the world. A vast variety of biological processes and chemicals have been discovered to be useful. Fermented seafood and fish products have a lot of promise for creating new food products with health benefits, nutritional value and better sensory qualities.

References

Alba, M., Pérez-Andrés, J. M., Harrison, S. M., Brunton, N. P., Burgess, C. M., & Tiwari, B. K. (2019). High pressure processing on microbial inactivation, quality parameters and nutritional quality indices of mackerel fillets. *Innovative Food Science & Emerging Technologies*, 55, 80-87. http://dx.doi.org/10.1016/j.ifset.2019.05.010.

Allagbé, A. C., Degnon, R. G., Konfo, C. T. R., Kpatinvoh, B., & Farid, B. (2020). Improvement of smoked and fermented dried fish processing and application of essential oils as their natural preservatives. *World Journal of Advanced Research and Reviews*, 6(2), 129-138. http://dx.doi.org/10.30574/wjarr.2020.6.2.0147.

Aman, M. B. (1983). Effect of cooking and preservation methods on the Water Holding Capacity (WHC) of mullet fish in relation with changes occurred in muscle proteins. *Zeitschrift fur Lebensmittel-Untersuchung und -Forschung*, 177(5), 345-347. http://dx.doi.org/10.1007/BF01042194.

Bao, M., Pierce, G. J., Strachan, N. J., Pascual, S., González-Muñoz, M., & Levsen, A. (2019). Human health, legislative and socioeconomic issues caused by the fish-borne zoonotic parasite Anisakis: Challenges in risk assessment. *Trends in Food Science & Technology*, 86, 298-310. http://dx.doi.org/10.1016/j.tifs.2019.02.013.

Basu, N., Todgham, A. E., Ackerman, P. A., Bibeau, M. R., Nakano, K., Schulte, P. M., & Iwama, G. K. (2002). Heat shock protein genes and their functional significance in fish. *Gene*, 295(2), 173-183. http://dx.doi.org/10.1016/S0378-1119(02)00687-X. PMid:12354651.

Bavisetty, S. C. B., Benjakul, S., Olatunde, O. O., & Ali, A. M. M. (2021). Bioactive compounds in fermented fish and meat products: health aspects. In A. K. Rai & A. A. KA (Eds.), *Bioactive compounds in fermented foods: health aspects*. Milton: Taylor & Francis Group.

Beddows, C. G. (1998). Fermented fish and fish products. In B. J. B. Wood (Ed.), *Microbiology of fermented foods* (pp. 416–440). London: Springer. http://dx.doi.org/10.1007/978-1-4613-0309-1_13.

Belleggia, L., Aquilanti, L., Ferrocino, I., Milanović, V., Garofalo, C., Clementi, F., Cocolin, L., Mozzon, M., Foligni, R., Haouet, M. N., Scuota, S., Framboas, M., & Osimani, A. (2020). Discovering microbiota and volatile compounds of surströmming, the traditional Swedish sour herring. *Food Microbiology*, 91, 103503. http://dx.doi.org/10.1016/j.fm.2020.103503. PMid:32539969.

Bhat, Z. F., Morton, J. D., Bekhit, A. E.-D. A., Kumar, S., & Bhat, H. F. (2021). Thermal processing implications on the digestibility of meat, fish and seafood proteins. *Comprehensive Reviews in Food Science and Food Safety*, 20(5), 4511-4548. http://dx.doi.org/10.1111/1541-4337.12802. PMid:34350699.

Blana, V. A., Grounta, A., Tassou, C. C., Nychas, G.-J. E., & Panagou, E. Z. (2014). Inoculated fermentation of green olives with potential probiotic Lactobacillus pentosus and Lactobacillus plantarum starter cultures isolated from industrially fermented olives. *Food Microbiology*, 38, 208-218. http://dx.doi.org/10.1016/j.fm.2013.09.007. PMid:24290645.

Bomfeh, K. (2020). *The shift from traditional to an improved fish smoking oven in Ghana: implications for food safety and public health* (PhD Thesis). Ghent University, Gent.

Chalamaiah, M., Dinesh kumar, B., Hemalatha, R., & Jyothirmayi, T. (2012). Fish protein hydrolysates: proximate composition, amino acid composition, antioxidant activities and applications: a review. *Food Chemistry*, 135(4), 3020-3038. http://dx.doi.org/10.1016/j.foodchem.2012.06.100. PMid:22980905.

Chen, J. H., Ren, Y., Seow, J., Liu, T., Bang, W. S., & Yuk, H. G. (2012). Intervention technologies for ensuring microbiological safety of meat: current and future trends. *Comprehensive Reviews in Food Science and Food Safety*, 11(2), 119-132. http://dx.doi.org/10.1111/j.1541-4337.2011.00177.x.

Choi, H. (2021). Influence of acidogenic fermented fish by-products with rice bran for sludge reduction and biogas recovery in anaerobic co-digestion. *Environmental Engineering Research*, 26(1), 182-192. http://dx.doi.org/10.4491/eer.2019.409.

Choorit, W., & Prasertsan, P. (1992). Characterization of proteases produced by newly isolated and identified proteolytic microorganisms from fermented fish (Budu). *World Journal of Microbiology & Biotechnology*, 8(3), 284-286. http://dx.doi.org/10.1007/BF01201880. PMid:24425479.

Cristóvao, R. O., Botelho, C. M., Martins, R. J., Loureiro, J. M., & Boaventura, R. A. (2015). Fish canning industry wastewater treatment for water reuse–a case study. *Journal of Cleaner Production*, 87, 603-612. http://dx.doi.org/10.1016/j.jclepro.2014.10.076.

Darvishi, H., Azadbakht, M., Rezaeiasl, A., & Farhang, A. (2013). Drying characteristics of sardine fish dried with microwave heating. *Journal of the Saudi Society of Agricultural Sciences*, 12(2), 121-127. http://dx.doi.org/10.1016/j.jssas.2012.09.002.

Dimitroglou, A., Merrifield, D. L., Carnevali, O., Picchietti, S., Avella, M., Daniels, C., Güroy, D., & Davies, S. J. (2011). Microbial manipulations to improve fish health and production: a Mediterranean perspective. *Fish & Shellfish Immunology*, 30(1), 1-16. http://dx.doi.org/10.1016/j.fsi.2010.08.009. PMid:20801223.

Doe, P., & Olley, J. (2020). Drying and dried fish products. In P. Doe & J. Olley (Eds.), *Seafood: resources, nutritional composition, and preservation* (pp. 125–145). Boca Raton: CRC Press. http://dx.doi.org/10.1201/9781003068419-10.

Duan, Z., Jiang, L., Wang, J., Yu, X., & Wang, T. (2011). Drying and quality characteristics of tilapia fish fillets dried with hot air-microwave heating. *Food and Bioproducts Processing*, 89(4), 472-476. http://dx.doi.org/10.1016/j.fbp.2010.11.005.

Duarte, A. M., Silva, F., Pinto, F. R., Barroso, S., & Gil, M. M. (2020). Quality assessment of chilled and frozen fish: mini review. *Foods*, 9(12), 1739. http://dx.doi.org/10.3390/foods9121739. PMid:33255842.

Duarte, F. A., Pereira, J. S. F., Barin, J. S., Mesko, M. F., Dressler, V. L., Flores, E. M. M., & Knapp, G. (2009). Seafood digestion by microwave-induced combustion for total arsenic determination by atomic spectrometry techniques with hydride generation. *Journal of Analytical Atomic Spectrometry*, 24(2), 224-227. http://dx.doi.org/10.1039/B810952D.

Edwards, J. S. A., & Hartwell, H. J. (2006). Hospital food service: a comparative analysis of systems and introducing the 'Steamplicity'concept. *Journal of Human Nutrition and Dietetics*, 19(6), 421-430. http://dx.doi.org/10.1111/j.1365-277X.2006.00730.x. PMid:17105539.

El Sheikha, A. F. (2018). Revolution in fermented foods: from artisan household technology to the era of biotechnology. In A. F. El Sheikha, R. E. Levin & J. Xu (Eds.), *Molecular techniques in food biology: safety, biotechnology, authenticity & traceability* (pp. 241–260). Hoboken: Wiley. http://dx.doi.org/10.1002/9781119374633.ch10.

El Sheikha, A. F., Ray, R., Montet, D., Panda, S., & Worawattanamateekul, W. (2014). African fermented fish products in scope of risks. *International Food Research Journal*, 21(2), 425-432.

Erkan, N., Gunlü, A., & Genç, İ. Y. (2014). Alternative seafood preservation technologies: Ionizing radiation and high pressure processing. *Journal of FisheriesSciences.Com*, 8(3), 238. http://dx.doi.org/10.3153/jfscom.201430.

Essuman, K. M. (1992). *Fermented fish in Africa: a study on processing, marketing, and consumption*. Rome: FAO.

Fatimah, F., Pelealu, J. J., Gugule, S., Yempormase, H. V., & Tallei, T. E. (2017). Quality evaluation of bakasang processed with variation of salt concentration, temperature and fermentation time. *Pakistan Journal of Biological Sciences: PJBS*, 20(11), 543-551. http://dx.doi.org/10.3923/pjbs.2017.543.551. PMid:30187737.

Feng, L., Tang, N., Liu, R., Gong, M., Wang, Z., Guo, Y., Wang, Y., Zhang, Y., & Chang, M. (2021). The relationship between flavor formation, lipids metabolisms, and microorganisms in fermented fish products. *Food & Function*, 12(13), 5685-5702. http://dx.doi.org/10.1039/D1FO00692D.

Fuentes-Gandara, F., Herrera-Herrera, C., Pinedo-Hernández, J., Marrugo-Negrete, J., & Díez, S. (2018). Assessment of human health risk associated with methylmercury in the imported fish marketed in the Caribbean. *Environmental Research*, 165, 324-329. http://dx.doi.org/10.1016/j.envres.2018.05.001. PMid:29778966.

Gassem, M. A. (2019). Microbiological and chemical quality of a traditional salted-fermented fish (Hout-Kasef) product of Jazan Region, Saudi Arabia. *Saudi Journal of Biological Sciences*, 26(1), 137-140. http://dx.doi.org/10.1016/j.sjbs.2017.04.003. PMid:30622417.

Ghaly, A. E., Dave, D., Budge, S., & Brooks, M. S. (2010). Fish spoilage mechanisms and preservation techniques. *American Journal of Applied Sciences*, 7(7), 859-877. http://dx.doi.org/10.3844/ajassp.2010.859.877.

Ghanem, N. A., Samaha, I. A., & Nossair, M. A. (2019). Incidence of some pathogenic bacteria in smoked and salted fish products. *Alexandria Journal of Veterinary Sciences*, 60(2), 104-109.

Giri, A., Osako, K., Okamoto, A., & Ohshima, T. (2010). Olfactometric characterization of aroma active compounds in fermented fish paste in comparison with fish sauce, fermented soy paste and sauce products. *Food Research International*, 43(4), 1027-1040. http://dx.doi.org/10.1016/j.foodres.2010.01.012.

Giyatmi & Irianto, H. E. (2017). Enzymes in fermented fish. *Advances in Food and Nutrition Research*, 80, 199-216. http://dx.doi.org/10.1016/bs.afnr.2016.10.004. PMid:28215327.

Hanjabam, M. D., Elavarasan, K., Kumar, A., Uchoi, D., Tejpal, C. S., & Ninan, G. (2020). Effects of cooking methods and in-vitro digestion on the digestibility and antioxidant properties of ngari (a fermented fish product of India). *Indian Journal of Traditional Knowledge*, 19(4), 879-888.

Horner, W. F. A. (1997). Canning fish and fish products. In G. M. Hall (Ed.), *Fish processing technology* (pp. 119–159). Boston: Springer. http://dx.doi.org/10.1007/978-1-4613-1113-3_5.

Hugas, M., & Monfort, J. M. (1997). Bacterial starter cultures for meat fermentation. *Food Chemistry*, 59(4), 547-554. http://dx.doi.org/10.1016/S0308-8146(97)00005-8.

Jiao, X., Cao, H., Fan, D., Huang, J., Zhao, J., Yan, B., Zhou, W., Zhang, W., Ye, W., & Zhang, H. (2019). Effects of fish oil incorporation on the gelling properties of silver carp surimi gel subjected to microwave heating combined with conduction heating treatment. *Food Hydrocolloids*, 94, 164-173. http://dx.doi.org/10.1016/j.foodhyd.2019.03.017.

Kitamura, Y., Kusumoto, K.-I., Oguma, T., Nagai, T., Furukawa, S., Suzuki, C., Satomi, M., Magariyama, Y., Takamine, K., & Tamaki, H. (2016). Ethnic fermented foods and alcoholic beverages of Japan. In J. P. Tamang (Ed.), *Ethnic fermented foods and alcoholic beverages of Asia* (pp. 193–236). New Delhi: Springer. http://dx.doi.org/10.1007/978-81-322-2800-4_9.

Kobayashi, T., Kimura, B., & Fujii, T. (2000). Strictly anaerobic halophiles isolated from canned Swedish fermented herrings (Surströmming). *International Journal of Food Microbiology*, 54(1-2), 81-89. http://dx.doi.org/10.1016/S0168-1605(99)00172-5. PMid:10746577.

Koo, O. K., Lee, S. J., Chung, K. R., Jang, D. J., Yang, H. J., & Kwon, D. Y. (2016). Korean traditional fermented fish products: Jeotgal. *Journal of Ethnic Foods*, 3(2), 107-116. http://dx.doi.org/10.1016/j.jef.2016.06.004.

Kundam, D. N., Acham, I. O., & Girgih, A. T. (2018). Bioactive compounds in fish and their health benefits. *Asian Food Science Journal*, 4(4), 1-14. http://dx.doi.org/10.9734/AFSJ/2018/41803.

Lavilla, I., González-Costas, J. M., & Bendicho, C. (2007). Improved microwave-assisted wet digestion procedures for accurate Se determination in fish and shellfish by flow injection-hydride generation-atomic absorption spectrometry. *Analytica Chimica Acta*, 591(2), 225-230. http://dx.doi.org/10.1016/j.aca.2007.03.075. PMid:17481413.

Lee, H. J., Choi, I. H., Kim, D. H., Joo, Y. H., & Kim, S. C. (2017). Influence of fermented fish meal supplementation on growth performance, blood metabolites, and fecal microflora of weaning pigs. *Revista Brasileira de Zootecnia*, 46(5), 433-437. http://dx.doi.org/10.1590/s1806-92902017000500010.

Maier, M. B., Schweiger, T., Lenz, C. A., & Vogel, R. F. (2018). Inactivation of non-proteolytic Clostridium botulinum type E in low-acid foods and phosphate buffer by heat and pressure. *PLoS One*, 13(7), e0200102. http://dx.doi.org/10.1371/journal.pone.0200102. PMid:29969482.

Majumdar, R. K., Roy, D., Bejjanki, S., & Bhaskar, N. (2016). An overview of some ethnic fermented fish products of the Eastern Himalayan region of India. *Journal of Ethnic Foods*, 3(4), 276-283. http://dx.doi.org/10.1016/j.jef.2016.12.003.

Mei, J., Ma, X., & Xie, J. (2019). Review on natural preservatives for extending fish shelf life. *Foods*, 8(10), 490. http://dx.doi.org/10.3390/foods8100490. PMid:31614926.

Michael, S., Cai, J., Akwasi, A., & Adele, A. (2019). Fish smoking in ghana: a review. *Journal of FisheriesSciences.Com*, 13(3), 13-24.

Mohammadzadeh, B. (2020). Effect of sodium chloride replacement with potassium chloride on some quality indices of fish sauce from Caspian Sea sprat (Clupeonella cultriventris. *Utilization and Cultivation of Aquatics*, 9(2), 81-93.

Mújica-Paz, H., Valdez-Fragoso, A., Samson, C. T., Welti-Chanes, J., & Torres, J. A. (2011). High-pressure processing technologies for the pasteurization and sterilization of foods. *Food and Bioprocess Technology*, 4(6), 969-985. http://dx.doi.org/10.1007/s11947-011-0543-5.

Ngabirano, L., Samieri, C., Feart, C., Gabelle, A., Artero, S., Duflos, C., Berr, C., & Mura, T. (2019). Intake of meat, fish, fruits, and vegetables and long-term risk of dementia and Alzheimer's disease. *Journal of Alzheimer's Disease*, 68(2), 711-722. http://dx.doi.org/10.3233/JAD-180919. PMid:30883348.

Niu, L., Sun, X., Tang, J., Wang, J., Rasco, B. A., Lai, K., & Huang, Y. (2017). Free and protein-bound Nε-carboxymethyllysine and Nε-carboxyethyllysine in fish muscle: biological variation and effects of heat treatment. *Journal of Food Composition and Analysis*, 57, 56-63. http://dx.doi.org/10.1016/j.jfca.2016.12.017.

Olsson, G. B., Olsen, R. L., & Ofstad, R. (2003). Post-mortem structural characteristics and water-holding capacity in Atlantic halibut muscle. *Lebensmittel-Wissenschaft + Technologie*, 36(1), 125-133. http://dx.doi.org/10.1016/S0023-6438(02)00205-0.

Osimani, A., Ferrocino, I., Agnolucci, M., Cocolin, L., Giovannetti, M., Cristani, C., Palla, M., Milanović, V., Roncolini, A., Sabbatini, R., Garofalo, C., Clementi, F., Cardinali, F., Petruzzelli, A., Gabucci, C., Tonucci, F., & Aquilanti, L. (2019). Unveiling hákarl: a study of the microbiota of the traditional Icelandic fermented fish. *Food Microbiology*, 82, 560-572. http://dx.doi.org/10.1016/j.fm.2019.03.027. PMid:31027819.

Pal, J., Shukla, B. N., Maurya, A. K., Verma, H. O., Pandey, G., & Amitha, A. (2018). A review on role of fish in human nutrition with special emphasis to essential fatty acid. *International Journal of Fisheries and Aquatic Studies*, 6(2), 427-430.

Pan, L., Li, P., Tao, Y., & Guo, H. (2018). Antimicrobial agent effectiveness in fish glue prepared by heat treatment and enzymatic hydrolysis of swim bladders. *BioResources*, 13(2), 3275-3283. http://dx.doi.org/10.15376/biores.13.2.3275-3283.

Peck, M. W. (2006). Clostridium botulinum and the safety of minimally heated, chilled foods: an emerging issue? *Journal of Applied Microbiology*, 101(3), 556-570. http://dx.doi.org/10.1111/j.1365-2672.2006.02987.x. PMid:16907806.

Pérez Palacios, T., Caballero, D., Bravo, S., Mir Bel, J., & Antequera, T. (2017). Effect of cooking conditions on quality characteristics of confit cod: prediction by MRI. *International Journal of Food Engineering*, 13(8), 20160311. http://dx.doi.org/10.1515/ijfe-2016-0311.

Pernu, N., Keto-Timonen, R., Lindström, M., & Korkeala, H. (2020). High prevalence of Clostridium botulinum in vegetarian sausages. *Food Microbiology*, 91, 103512. http://dx.doi.org/10.1016/j.fm.2020.103512. PMid:32539985.

Photi, J., Chavasit, V., Chitchang, U., Egkantrong, P., Chinchanupap, K., & Boonpraderm, A. (2020). Reduction of sodium intake from papaya salad with the use of sodium-reduced fermented fish in producing traditional seasoning sauce. *Journal of Nutritional Science and Vitaminology*, 66(Suppl.), S173-S178. http://dx.doi.org/10.3177/jnsv.66.S173. PMid:33612589.

Raghuwanshi, S., Misra, S., Sharma, R., & PS, B. (2018). Probiotics: nutritional therapeutic tool. *Journal of Probiotics Health*, 6(01), 194. http://dx.doi.org/10.4172/2329-8901.1000194.

Rajauria, G., Sharma, S., Emerald, M., & Jaiswal, A. K. (2016). Novel fermented marine-based products. In K. S. Ojha & B. K. Tiwari (Eds.), *Novel food fermentation technologies* (pp. 235–262). Cham: Springer. http://dx.doi.org/10.1007/978-3-319-42457-6_11.

Ramírez, J. C. R., Ibarra, J. I., Romero, F. A., Ulloa, P. R., Ulloa, J. A., Matsumoto, K. S., Cordoba, B. V., & Manzano, M. Á. M. (2013). Preparation of biological fish silage and its effect on the performance and meat quality characteristics of quails (Coturnix coturnix japonica). *Brazilian Archives of Biology and Technology*, 56(6), 1002-1010. http://dx.doi.org/10.1590/S1516-89132013000600016.

Ricci, A., Allende, A., Bolton, D., Chemaly, M., Davies, R., Fernández Escámez, P. S., Girones, R., Herman, L., Koutsoumanis, K., Nørrung, B., Robertson, L., Ru, G., Sanaa, M., Simmons, M., Skandamis, P., Snary, E., Speybroeck, N., Ter Kuile, B., Threlfall, J., Wahlström, H., Takkinen, J., Wagner, M., Arcella, D., Felicio, M. T. S., Georgiadis, M., Messens, W., & Lindqvist, R. (2018). Listeria monocytogenes contamination of ready-to-eat foods and the risk for human health in the EU. *EFSA Journal*, 16(1), e05134. PMid:32760461.

Riebroy, S., Benjakul, S., Visessanguan, W., & Tanaka, M. (2005). Physical properties and microstructure of commercial Som-fug, a fermented fish sausage. *European Food Research and Technology*, 220(5), 520-525. http://dx.doi.org/10.1007/s00217-004-1094-z.

Ripolles-Avila, C., Hascoët, A. S., Ríos-Castillo, A. G., & Rodríguez-Jerez, J. J. (2019). Hygienic properties exhibited by single-use wood and plastic packaging on the microbial stability for fish. *LWT*, 113, 108309. http://dx.doi.org/10.1016/j.lwt.2019.108309.

Rosnes, J. T., Skåra, T., & Skipnes, D. (2011). Recent advances in minimal heat processing of fish: effects on microbiological activity and safety. *Food and Bioprocess Technology*, 4(6), 833-848. http://dx.doi.org/10.1007/s11947-011-0517-7.

Ruddle, K., & Ishige, N. (2010). On the origins, diffusion and cultural context of fermented fish products in Southeast Asia. In J. Farrer & J. Daigaku (Eds.), *Globalization, food and social identities in the Asia Pacific region* (pp. 1-17). Tokyo: Sophia University.

Saithong, P., Panthavee, W., Boonyaratanakornkit, M., & Sikkhamondhol, C. (2010). Use of a starter culture of lactic acid bacteria in plaa-som, a Thai fermented fish. *Journal of Bioscience and Bioengineering*, 110(5), 553-557. http://dx.doi.org/10.1016/j.jbiosc.2010.06.004. PMid:20609623.

Sampels, S. (2015). The effects of processing technologies and preparation on the final quality of fish products. *Trends in Food Science & Technology*, 44(2), 131-146. http://dx.doi.org/10.1016/j.tifs.2015.04.003.

Sánchez-Valencia, J., Sánchez-Alonso, I., Martinez, I., & Careche, M. (2014). Estimation of frozen storage time or temperature by kinetic modeling of the Kramer shear resistance and water holding capacity (WHC) of hake (Merluccius merluccius, L.) muscle. *Journal of Food Engineering*, 120, 37-43. http://dx.doi.org/10.1016/j.jfoodeng.2013.07.012.

Santos, H. M. C., Méndez, L., Secci, G., Parisi, G., Martelli, R., & Medina, I. (2019). Pathway-oriented action of dietary essential oils to prevent muscle protein oxidation and texture deterioration of farmed rainbow trout. *Animal*, 13(9), 2080-2091. http://dx.doi.org/10.1017/S1751731119000016. PMid:30774047.

Sarangam, S., & Priya, K. S. C. (2019). Range of fermented fish products across the globe: scope, uses, and methods of preparation. In M. R. Goyal, H. A. R. Suleria & S. Kirubanandan (Eds.), *Technological processes for marine foods, from water to fork: bioactive compounds, industrial applications, and genomics* (pp. 183–216). Burlington, Canada: Apple Academic Press.

Sathe, S. K., Teuber, S. S., & Roux, K. H. (2005). Effects of food processing on the stability of food allergens. *Biotechnology Advances*, 23(6), 423-429. http://dx.doi.org/10.1016/j.biotechadv.2005.05.008. PMid:15978770.

Serment-Moreno, V., Fuentes, C., Guerrero-Beltrán, J. Á., Torres, J. A., & Welti-Chanes, J. (2017). A Gompertz model approach to microbial inactivation kinetics by high-pressure processing incorporating the initial counts, microbial quantification limit, and come-up time effects. *Food and Bioprocess Technology*, 10(8), 1495-1508. http://dx.doi.org/10.1007/s11947-017-1916-1.

Seyfzadeh, M., Shojaei, A. A., & Amir, M. N. (2008). Comparison and monitoring of psychrophilic bacteria in fish fillet packaged by sous-vide method in refrigerator and freeze. *Journal of Marine Sciences and Technology*, 6(3-4), 39-50.

Singh, R. P., & Anderson, B. A. (2004). The major types of food spoilage: an overview. In R. Steele (Ed.), *Understanding and measuring the shelf-life of food* (pp. 3-23). Cambridge: Woodhead Publishing. http://dx.doi.org/10.1533/9781855739024.1.3.

Singh, S. S., De Mandal, S., Mathipi, V., Ghatak, S., & Kumar, N. S. (2018). Traditional fermented fish harbors bacteria with potent probiotic and anticancer properties. *Biocatalysis and Agricultural Biotechnology*, 15, 283-290. http://dx.doi.org/10.1016/j.bcab.2018.07.007.

Sivamaruthi, B. S., Kesika, P., & Chaiyasut, C. (2021). A narrative review on biogenic amines in fermented fish and meat products. *Journal of Food Science and Technology*, 58(5), 1623-1639. http://dx.doi.org/10.1007/s13197-020-04686-x. PMid:33897002.

Sivertsvik, M., Jeksrud, W. K., & Rosnes, J. T. (2002). A review of modified atmosphere packaging of fish and fishery products–significance of microbial growth, activities and safety. *International Journal of Food Science & Technology*, 37(2), 107-127. http://dx.doi.org/10.1046/j.1365-2621.2002.00548.x.

Skåra, T., Axelsson, L., Stefánsson, G., Ekstrand, B., & Hagen, H. (2015). Fermented and ripened fish products in the northern European countries. *Journal of Ethnic Foods*, 2(1), 18-24. http://dx.doi.org/10.1016/j.jef.2015.02.004.

Skipnes, D. (2014). *Heat processing of fish. Seafood processing: technology, quality and safety.* Hoboken: Wiley.

Skipnes, D., Johnsen, S. O., Skåra, T., Sivertsvik, M., & Lekang, O. (2011). Optimization of heat processing of farmed Atlantic cod (Gadus morhua) muscle with respect to cook loss, water holding capacity, color, and texture. *Journal of Aquatic Food Product Technology*, 20(3), 331-340. http://dx.doi.org/10.1080/10498850.2011.571808.

Skipnes, D., Østby, M. L., & Hendrickx, M. E. (2007). A method for characterising cook loss and water holding capacity in heat treated cod (Gadus morhua) muscle. *Journal of Food Engineering*, 80(4), 1078-1085. http://dx.doi.org/10.1016/j.jfoodeng.2006.08.015.

Stormo, S. K., Skipnes, D., Sone, I., Skuland, A., Heia, K., & Skåra, T. (2017). Modeling-assisted minimal heat processing of Atlantic cod (Gadus morhua). *Journal of Food Process Engineering*, 40(6), e12555. http://dx.doi.org/10.1111/jfpe.12555.

Studer, A., Blank, I., & Stadler, R. H. (2004). Thermal processing contaminants in foodstuffs and potential strategies of control. *Czech Journal of Food Sciences*, 22, S1-S10. http://dx.doi.org/10.17221/10600-CJFS.

Tahir, M., Salengke, S., Mursalim, Metusalach & Caesarendra, W. (2020). Performance of smokehouse designed for smoking fish with the indirect method. *Processes*, 8(2), 204. http://dx.doi.org/10.3390/pr8020204.

Tamang, J. P., Cotter, P. D., Endo, A., Han, N. S., Kort, R., Liu, S. Q., Mayo, B., Westerik, N., & Hutkins, R. (2020). Fermented foods in a global age: East meets West. *Comprehensive Reviews in Food Science* *and Food Safety*, 19(1), 184-217. http://dx.doi.org/10.1111/1541-4337.12520. PMid:33319517.

Thapa, N. (2016). Ethnic fermented and preserved fish products of India and Nepal. *Journal of Ethnic Foods*, 3(1), 69-77. http://dx.doi.org/10.1016/j.jef.2016.02.003.

Todgham, A. E., Hoaglund, E. A., & Hofmann, G. E. (2007). Is cold the new hot? Elevated ubiquitin-conjugated protein levels in tissues of Antarctic fish as evidence for cold-denaturation of proteins in vivo. *Journal of Comparative Physiology. B, Biochemical, Systemic, and Environmental Physiology*, 177(8), 857-866. http://dx.doi.org/10.1007/s00360-007-0183-2. PMid:17710411.

Tsuda, H., Matsumoto, T., & Ishimi, Y. (2012). Selection of lactic acid bacteria as starter cultures for fermented meat products. *Food Science and Technology Research*, 18(5), 713-721. http://dx.doi.org/10.3136/fstr.18.713.

Tsurumaki, N., Zhang, S., Tomata, Y., Abe, S., Sugawara, Y., Matsuyama, S., & Tsuji, I. (2019). Fish consumption and risk of incident dementia in elderly Japanese: The Ohsaki cohort 2006 study. *The British Journal of Nutrition*, 122(10), 1182-1191. http://dx.doi.org/10.1017/S0007114519002265. PMid:31477191.

Wada, S., & Ogawa, Y. (1996). High pressure effects on fish lipid degradation: myoglobin change and water holding capacity. *Progress in biotechnology*, 13, 351–356. http://dx.doi.org/10.1016/S0921-0423(06)80059-6.

Wolfe, B. E., & Dutton, R. J. (2015). Fermented foods as experimentally tractable microbial ecosystems. *Cell*, 161(1), 49-55. http://dx.doi.org/10.1016/j.cell.2015.02.034. PMid:25815984.

Xu, Y., He, L., Xia, W., Jiang, Q., Yang, F., Gao, P., & Wang, B. (2019). The impact of fermentation at elevated temperature on quality attributes and biogenic amines formation of low-salt fermented fish. *International Journal of Food Science & Technology*, 54(3), 723-733. http://dx.doi.org/10.1111/ijfs.13986.

Xu, Y., Xia, W., Yang, F., & Nie, X. (2010a). Physical and chemical changes of silver carp sausages during fermentation with Pediococcus pentosaceus. *Food Chemistry*, 122(3), 633-637. http://dx.doi.org/10.1016/j.foodchem.2010.03.023.

Xu, Y., Xia, W., Yang, F., Kim, J. M., & Nie, X. (2010b). Effect of fermentation temperature on the microbial and physicochemical properties of silver carp sausages inoculated with Pediococcus pentosaceus. *Food Chemistry*, 118(3), 512-518. http://dx.doi.org/10.1016/j.foodchem.2009.05.008.

Xu, Y., Zang, J., Regenstein, J. M., & Xia, W. (2021). Technological roles of microorganisms in fish fermentation: a review. *Critical Reviews in Food Science and Nutrition*, 61(6), 1000-1012. http://dx.doi.org/10.1080/10408398.2020.1750342. PMid:32292041.

Zang, J., Xu, Y., Xia, W., & Regenstein, J. M. (2020). Quality, functionality, and microbiology of fermented fish: a review. *Critical Reviews in Food Science and Nutrition*, 60(7), 1228-1242. http://dx.doi.org/10.1080/10408398.2019.1565491. PMid:30676059.

Zhan, X., Sun, D.-W., Zhu, Z., & Wang, Q.-J. (2018). Improving the quality and safety of frozen muscle foods by emerging freezing technologies: a review. *Critical Reviews in Food Science and Nutrition*, 58(17), 2925-2938. http://dx.doi.org/10.1080/10408398.2017.1345854. PMid:28723226.

Zhang, W., Wei, L., Xu, R., Lin, G., Xin, H., Lv, Z., Qian, H., & Shi, H. (2020). Evaluation of the antibacterial material production in the fermentation of bacillus amyloliquefaciens-9 from whitespotted bamboo shark (Chiloscyllium plagiosum). *Marine Drugs*, 18(2), 119. http://dx.doi.org/10.3390/md18020119. PMid:32085415.