

Review

Processing, Quality and Elemental Safety of Fish

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Abstract: Fish is a food that is widely produced, marketed, and consumed around the world. It is a basic component of human nutrition due to its chemical and nutritional composition, but at the same time is highly perishable and susceptible to contamination throughout the food chain, compromising its quality and safety. Fishing and aquaculture products, being perishable, require adequate processing and preservation to maintain their quality and safety as much as possible until their acquisition and final consumption. Different preservation methods have been developed and used to extend the shelf life of fish products with minimal impact on their nutritional and organoleptic properties. Therefore, the objective of this document is to provide, through the search, analysis, and selection of information from various databases such as Scopus, Scielo, Web of Science, and Google Scholar, among others, a general and basic informative description of fish, aimed at academics, producers, industrialists, and the general public that allows them to identify the basic points in the processing and preservation of the quality and safety of fish. Aspects related to production; the nutritional qualities of fish; the various physical, chemical, and biological contaminating hazards of fish; the control and prevention of contaminants and diseases for consumers; and food legislation for products are included, as well as the main traditional and modern methods applied in the preservation of fishery and aquaculture products to maintain their nutritional value, quality, and safety that allow for the availability of food and the protection of public health.

Keywords: foodborne diseases; spoilage; saprophytes; biological hazards; contamination; food pathogens



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1. Introduction

Fish is any animal intended for human consumption extracted from aquatic environments and is used as a generic term that can cover different organisms such as fish, crustaceans, and mollusks, among others [1]. Fish is a basic component of the human diet, considered to have high nutritional value due to its proportion of proteins with biological value and digestibility, vitamins, minerals, and lipids, the latter helping to prevent diseases and contribute to the good functioning of the cardiovascular and nervous systems. Likewise, its consumption has been associated with fewer cases of diabetes [1–3].

Foods, including fish, are subjected to different processing and preservation conditions for marketing and consumption, which are focused on promoting their availability and

improving their sensory, nutritional, and safety properties. Aquatic foods are one of the most commercialized food products worldwide, representing a source of food, economic income, and employment. In their live, fresh, or refrigerated states, and excluding algae, they are the forms with the highest proportion intended for direct human consumption, followed by their frozen, prepared, preserved, and cured states [4].

Food safety is the guarantee that food products will not cause harm to the consumer when they are prepared and/or consumed according to their intended use [5], and is considered an essential part, along with the nutritional characteristics, sensory and commercial aspects, within the total quality of food [6].

The nutritional properties of food allow us to provide health and well-being to humans, but these are a function of the hygiene conditions to which food is subjected throughout the separate phases of the production chain (from the field to the consumer's table) [6,7]. Food can as a result be contaminated by physical, chemical, radiological, and biological agents in the absence of necessary hygienic conditions, as well as during processing and preparation processes, becoming a source of diseases which are a major health problem in the world, most frequently in developing countries [6,7]. Therefore, the objective of this document is to provide, through the search, analysis, and selection of information in various databases such as Scopus, Scielo, Web of Science, and Google Scholar, among others, a general and basic informative description of fish, aimed at academics, producers, industrialists and the general public that allows them to identify the basic points in the processing and preservation of the quality and safety of fish. Aspects related to production; the nutritional qualities of fish; the various physical, chemical, and biological contaminating hazards of fish; the control and prevention of contaminants and diseases for consumers; and food legislation for products are included, as well as the main traditional and modern methods applied in the preservation of fishery and aquaculture products to maintain their nutritional value, quality and safety that allow for the availability of food and the protection of public health.

2. The Fish Generalities

Fish are aquatic vertebrates capable of using the oxygen present in water for respiration through their gills. They have fins and a bone structure made up of a vertebral column from the head to the caudal fin constituted by vertebrae that extend to the sides, forming the ribs or spines [8,9].

The chemical composition and nutritional value of the muscle (edible part) of fish is a function of various factors such as species, age, sex, season, migratory behavior, sexual maturation, feeding, sexual changes related to spawning, region of capture, culture, and capture method, among others [10,11]. The main components of fish muscle are water and proteins (high biological value and digestibility), which constitute the main component of the muscular and edible part of the fish and are divided into structural proteins (actin, myosin, tropomyosin, and actomyosin), which constitute 70–80% of the total protein content, sarcoplasmic proteins with 25–30% (myoalbumin, globulin, and enzymes), and connective tissue proteins (collagen) with 3 to 5% [8,11,12]. Lipids (polyunsaturated ω -3 and ω -6) impact the nutritional value; bioactive, functional, and sensory properties; and stability during the preservation of these products [2,8,11,13]. On the other hand, among the minority constituents are carbohydrates (glycogen); vitamins of the B complex and in the case of fatty species, vitamins A and D; as well as various minerals such as sodium, calcium, phosphorus, iron, copper, and iodine (Table 1) [8,11]. It should be noted that a minor constituent group in fish are non-protein nitrogenous compounds such as ammonia, trimethylamine oxide, methylamine, dimethylamine, creatine, amino acids, nucleotides, purine bases, and urea, which significantly influence the quality and spoilage of fish [11].

Table 1. Chemical composition of fish [8,11].

Compound	Fillet Fish		
	Minimum %	Normal %	Maximum %
Proteins	6	16–21	28
Lipids	0.1	0.2–25	67
Carbohydrates		<0.5	
Ashes	0.4	1.2–1.5	1.5
Water	28	66–81	96

3. Fish Production

Through fishing and aquaculture activities humans have access to aquatic foods, so their contribution to global food security and nutrition is vital and continues to grow. The Food and Agriculture Organization (FAO)'s estimates indicate that during 2020, capture fishing and aquaculture recorded a worldwide production of 177.8 million tons, of which 157.4 million tons were destined for human consumption, with an apparent per capita consumption of 20.2 kg, and where the main producing countries were from Asia and America, among which China, India, Indonesia, Vietnam, and Peru stand out, contributing to 58% of the world's fishing and aquaculture production of aquatic animals [4]. From this estimate, the live, fresh, or refrigerated modality represents the highest proportion of fishery and aquaculture production and is regularly the preferred and highest cost form for direct human consumption; after that are products subjected to different processing and preservation conditions such as products that are frozen, prepared, canned, and cured; later come indirect uses in the forms of fishmeal and oils for the formulation of animal feed mainly [4,14]. The consumption of aquatic foods has been increasing in recent years and it is estimated that this trend will continue. It is expected that increasing incomes, urbanization, improvements in post-harvest practices, and changes in food trends will generate greater consumption of products to supply an average of 21.4 kg per capita by 2030 [4].

4. Food and Fish Safety

Food safety is defined as the guarantee that food will not cause harm to the consumer when prepared and/or consumed [5,15]. The safety of food can be compromised at any stage of the food chain due to contamination by biological, chemical, and/or physical agents, generating a risk of illness for the consumer [15].

Foodborne diseases are considered an important public health problem due to their impact on millions of people around the world [1,5,16], their negative socioeconomic impact due to the decrease in productivity, their impact on trade in food products, and their imposition of a substantial burden on health systems due to expenses for hospitalizations and medications [5,16].

More than 250 diseases are transmitted through food and their incidence has increased considerably in recent decades due to factors such as the globalization of the food market, changes in eating habits, as well as the emergence of new forms of transmission in vulnerable population groups, and the increase in antimicrobial resistance due to causal agents [5].

Fish and fish products are foods that are very susceptible to spoilage and contamination by various physical, biological, and chemical hazards at any point in the food chain (Table 2) [1,4,17,18], so the application of appropriate handling, hygiene, and preservation practices and conditions from capture or harvest to the consumer's table becomes essential [1,4,7,17]. Otherwise, these may become products that are not suitable for consumption and may pose a health risk as their safety is compromised due to contamination, growth of microorganisms, chemical and/or autolytic changes [4].

Table 2. The main contaminant hazards present in fish and fish products considered to be a risk to the health of consumers [19–28].

Hazard	Agent(s)	Examples	References
Biological	Virus	Norovirus, astrovirus, hepatitis A, hepatitis E, adenovirus, rotavirus, and enterovirus.	[21,24,26]
	Bacteria	<i>E. coli</i> , <i>Shewanella</i> spp., <i>Bacillus cereus</i> , <i>Campylobacter jejuni</i> , <i>Aeromonas</i> spp., <i>Citrobacter</i> spp., <i>Legionella pneumophila</i> , <i>Mycobacterium</i> spp., <i>Streptococcus</i> spp., <i>Vibrio</i> sp., <i>Salmonella</i> spp., <i>Shigella</i> spp., <i>Plesiomonas shigelloides</i> , <i>Yersinia enterocolitica</i> , <i>Edwardsiella tarda</i> , <i>Listeria monocytogenes</i> , <i>Erysipelothrix rhusiopathiae</i> , <i>Leptospira</i> spp., <i>Nocardia</i> spp., <i>Staphylococcus aureus</i> , <i>Klebsiella pneumoniae</i> , and <i>Clostridium</i> spp.	[19–21,24–27]
	Parasites	<i>Capillaria philippinensis</i> , <i>Gnathostoma</i> spp., <i>Pseudoterranova</i> spp., <i>Phagicola</i> spp., <i>Clonorchis</i> spp., <i>Opisthorchis</i> spp., <i>Paragonimus</i> spp., <i>Anisakis</i> spp., <i>Phocanema</i> spp., <i>Angiostrongylus</i> spp., <i>Contracaecum</i> spp., <i>Diphylobothrium</i> spp., <i>Heterophyes</i> spp., <i>Cryptosporidium</i> spp., <i>Giardia lamblia</i> , and <i>Eustrongylides</i> spp.	[21–23,25,26]
Chemical	Heavy metals	Nickel, cadmium, lead, arsenic, copper, and mercury.	[26]
	Biotoxins	Gempilotoxin, tetrodotoxin, ciguatoxin, mycotoxins, maitotoxin, palytoxin, and okadaic acid.	[26]
	Biogenic amines	Cadaverine, espermidine, spermine, histamine, and putrescine.	[21,26,28]
	Organic compounds	Polybrominated diphenyl ethers, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, dioxins, pesticides, antibiotics, hormones, and microplastics.	[21,26]

Fish and products have been associated with outbreaks of diseases due to consumption, where frequently the causal agents are of biological origin (bacteria, viruses, and parasites) and chemical origin (biotoxins and biogenic amines) [18,29–32].

It has been pointed out that the risk of illness from consuming fish is high when it is ingested in a fresh and raw state, either in gastronomic preparations such as ceviche, sushi, and sashimi, among others, or when it has been previously subjected to inadequate hygienic processes and conditions during handling and cooking [17,22,23]. Finally, the consumption of dry, dry-salted, dry-smoked, fresh, and frozen products consumed after being subjected to an adequate cooking process is of low risk to health [17].

Currently, in regions of the world such as the European Union and the European Economic Area, it has been reported that the presence and persistence of various microbiological hazards are of interest for public health. In environments of production and processing of foods of aquatic origin, some of these hazards are bacteria such as *C. botulinum*, *C. perfringens*, *B. cereus*, pathogenic *E. coli*, *Campylobacter* spp., *L. monocytogenes*, *Vibrio parahaemolyticus* and *S. enterica*, emphasizing that the latter three are associated with a great number of hospitalizations and deaths from foodborne disease outbreaks [33].

Microbiology and Safety of Fish

Aquatic organisms have microbiota dependent on environmental conditions and those existing in the waters where they live [34]. Fish have microorganisms in their digestive tract, gills, and skin; their proportions vary between 10^3 – 10^9 CFU/g and 10^2 – 10^7 CFU/cm², respectively [8]. During the animal's lifetime, the muscle package is sterile and microorganisms do not invade it due to protection from natural defenses, but when the fish dies after capture, they can penetrate the muscle, contaminating it [8,34]. Likewise, contaminating microorganisms can come from the production environment such as facilities, environmen-

tal conditions, and processing operations (handling and cutting), causing the penetration mainly of bacteria, favoring spoilage and risk to the health of consumers [8,9,34].

The bacteria present in fish of interest that contribute to the safety and spoilage of these foods are classified as follows: (1) autochthonous such as *C. botulinum*, *Clostridium perfringens*, *Vibrio* spp., *Aeromonas* spp., *Listeria monocytogenes*, *Bacillus* spp., and *Plesiomonas* spp., which are common and widely distributed in aquatic environments around the world, where water temperature and salinity have a selective effect [35]. In temperate or warm waters, the fish microbiota are generally formed by Gram-negative mesophilic and psychrophilic microorganisms of the genera *Pseudomonas* spp., *Moraxella* spp., *Acinetobacter* spp., *Shewanella* spp., *Flavobacterium* spp., *Vibrio* spp., *Aeromonas* spp.; and Gram-positives such as *Clostridium* spp., *Lactobacillus* spp., *Coryneformes* spp., *Bacillus* spp., and *Micrococcus* spp. [8,36]. Meanwhile, in cold water fish, the microbiota are composed of Gram-negatives, mainly *Pseudomonas* spp., *Alteromonas* spp., *Photobacterium* spp., *Shewanella* spp.; Gram-positives such as *Clostridium* spp. from intestinal contents; and (2) non-indigenous bacteria, including *Enterobacteriaceae* such as *Campylobacter* sp., *Citrobacter* spp., *P. morgani*, *Yersinia* spp., *Klebsiella* spp., *Serratia* spp., *Salmonella* spp., *E. coli*, *Shigella* spp.; and Gram-positive bacteria such as *S. agalactiae* and *S. aureus*, among others, that are related to contaminated water or the presence of fecal contamination as well as a consequence of inadequate hygiene practices by handlers in the capture, transportation, processing, and preservation of products [34–36].

It must be considered that enteric microorganisms live in the digestive tract of fish, so it is necessary to avoid the rupture of viscera during processing and preservation activities, whose contents can contaminate the muscles [9]. During fish processing, the most common contamination can come from direct handling and the transfer of intestinal bacteria, gills, or skin to the fillet or muscle surfaces, as well as from microorganisms present in the environment such as contaminated surfaces, knives, machines, etc. [37]. Within the muscle, microorganisms multiply mainly on the surface of the meat, the diffusion of microbial enzymes heads towards the interior, and exit of nutrients produces exudation of liquids, loss of juiciness and firm texture, discoloration, and the formation of unpleasant flavors and odors due to the production of volatile compounds such as trimethylamine, contributing to spoilage and compromising product safety [9,36,37].

5. Control and Prevention of Diseases Transmitted by Fish Consumption

The quality of fishing and aquaculture products is largely determined by their degree of freshness, where intrinsic characteristics, such as high water content, proteins, low proportion of connective tissue, and the qualitative and quantitative profile of microorganisms present, will determine the occurrence of the set of changes that contribute to its devaluation, rejection, and health risk [1].

Around the world, numerous outbreaks of diseases due to the consumption of contaminated foods have been reported, pointing them out as a serious public health problem due to their negative economic and social repercussions [29,30,38]. Fish is a food that is frequently implicated as a cause of disease and among its contributing factors in different phases in the food chain are absent or inadequate hygiene conditions and practices in handling and processing; the use of contaminated raw materials; inadequate quality controls (time/temperature) in transformation processes, production, warehouse and dispensing services; absence or failures in standardized cleaning and disinfection programs; good practices in primary production and manufacturing; poor equipment design; high humidity conditions; inadequate or absent zoning and hygienic barriers (these allow the spread of contamination from contaminated to clean areas); and poor ventilation design in processing areas [5,29,30,33,39,40].

Therefore, food safety management activities have been generated at various levels of the food chain that include a sampling program and environmental tests to identify possible sources of contamination and detect dangers; training in hygiene conditions and practices in the production of food to handlers; the development and implementation of

hygiene requirements in infrastructure and design (building, equipment); cleaning and disinfection procedures; technical maintenance and calibration of equipment; water and air control; the hygiene and health status of personnel; and the methodology of work and the culture of food safety with consequent development and implementation of the Hazard Analysis and Critical Control Points (HACCP) system which is considered a basic tool in the production and marketing of fish and fish products [5,29,33,40–42].

Regulations regarding food safety and sovereignty become relevant with the development of the processed food industry due to the continuous liberalization of markets and a reduction in tariff barriers, particularly in the fishing and aquaculture industry. The expansion and demand of global supermarket and retail chains have influenced the development, implementation, and compliance of legislation on aspects of the quality and safety of products for market access [4].

To guarantee the protection of consumer health at an international level, laws, certifications, and standards have been established with actions that guarantee product quality throughout the entire supply chain [1,4]. Within the international legislation to achieve food safety are the general principles of food hygiene (CXC 1-1969) [43], the code of practice for fish and fishery products (CXC 52-2003) [44], and the application of good hygiene practices and food safety management based on Hazard Analysis and Critical Control Points (HACCP) throughout the food chain [4].

Food legislation in highly importing and producing countries such as the United States of America aims to guarantee the consumer that food is prepared under hygienic conditions and with the necessary care to avoid harm to the health of consumers. The Food and Drugs Administration (FDA), through title 21 of the Code of Federal Regulations (21 CFR) chapter I, subchapter B of sections 100 to 199, establishes the provisions to ensure that the supply of food for human consumption is safe. Part 117 (21 CFR 117) includes good manufacturing practices, hazard analysis, and risk-based preventive controls for food [45]. Meanwhile, particularly in fish and shellfish, the regulation (21 CFR) in section 123 (21 CFR 123) indicates good manufacturing practices and adherence to the Hazard Analysis and Critical Control Point (HACCP) system [46].

In the European community, through different regulations, hygiene issues are addressed in the production and marketing of food, guaranteeing the safety of products available for human consumption. Some of these are Regulation 178/2002 [47], which establishes the principles, creates the European Food Safety Authority and the general requirements of food law, and sets procedures relating to food safety; Regulation 852/2004 [48], regarding food hygiene with the application of the principles of Hazard Analysis and Critical Control Points, from the European Commission No 2016/C 278/01 [49], which indicates the application of food safety management systems that contemplate Prerequisite Programs and procedures based on the principles of HACCP; Regulation 853/2004 [50], where specific hygiene standards for foods of animal origin, including fish, are established; Regulation 854/2004 [51], which establishes specific rules for the organization of official controls for products of animal origin intended for human consumption; Regulation 2073/2005 [52], related to microbiological criteria applicable to foodstuffs; and Regulation 2017/625 [53], which involves controls and other official activities carried out to ensure the application of food and feed legislation. Likewise, at an international level, various management systems for the safety and marketing of fishing and aquaculture products have been developed and implemented for different phases of the food chain. Some of these internationally recognized management systems that promote commercial openness for producers are ISO 22000, FSSC 22000, Safe Quality Food (SQF), Global GAP, Marine Aquarium Council (MAC), and the British Retail Consortium (BRC), among others [54].

In countries such as Mexico, with significant fishing and aquaculture production, the food legislation associated with the safety of products intended for human consumption is constituted by the standard NOM-242-SSA1-2009 [55], referring to fresh, refrigerated, frozen, and processed fishery products. NOM-251-SSA1-2009 [56] refers to hygiene practices for the processing of food, beverages or food supplements; NOM-128-SSA1-1994 [57]

establishes the mandatory nature of the Risk Analysis and Critical Point Control System in the process and/or marketing of fishing products; NMX-F-605-NORMEX-2018 [58] sets the provisions of good hygiene and health practices which food and beverage service providers must comply with to obtain the “H” Distinction; and NOM-051-SCFI/SSA1-2010 [59] is related to general labeling specifications for food, commercial, and health information.

6. Post-Mortem in Fish

Once the fish is captured, death occurs and it undergoes a series of changes that lead to spoilage, discarding, and loss of safety. These changes are as follows: (a) sensory, (b) autolytic, (c) microbiological, and (d) oxidation and hydrolysis of lipids [8,10,60].

Sensory change refers to changes perceived through the senses (smell, color, flavor, and texture), the most drastic being rigor mortis [8]. After death, the muscle of the fish is completely relaxed and the texture is flexible and elastic, persisting for a while and later contracting, thus the animal becomes hard, rigid, and inflexible, showing rigor mortis. This condition is maintained, and its disappearance occurs when the muscle relaxes and regains flexibility, but not elasticity [8]. Fresh fish is fish that is in the pre-rigor phase (soft and flexible tissue) or rigor mortis (hard and rigid muscle tissue) since there is no enzymatic and microbiological alteration. The duration of these phases will depend on the species, physiological condition of the animal, capture effort, temperature, fishing gear used, chemical composition, and post-capture manipulation [10,61]. Autolytic changes are the first to occur after the death of the animal; these are caused by endogenous autolytic enzymes present in the fish muscle that produce the degradation of glycogen, proteins, lipids, and compounds related to adenosine triphosphate and make metabolites available for the muscle's consequent microbiological degradation. Enzymatic activity is responsible for initial sensory changes in fish such as loss of flavor and alterations in color and texture. Some related enzymes are calpains, cathepsins, collagenases, and glycolytic enzymes, among others [8,9,62].

Microbiological changes are one of the main causes of spoilage derived from intrinsic properties of fish such as high water activity, a pH close to neutrality, low oxidation reduction potential, and the presence of various low molecular weight compounds such as trimethylamine oxide that metabolize contaminating microorganisms, generating compounds of unpleasant and unacceptable odors and flavors in the quality of the fish [8,62].

As fish contains a high proportion of polyunsaturated lipids, it is very susceptible to muscle degradation due to lipid oxidation from being in contact with atmospheric oxygen and lipid hydrolysis due to the activity of endogenous or microbial enzymes, causing the loss of nutritional properties and the developing odors and unpleasant flavors (rancid) as well as the color and texture of a deteriorating product [8].

After the capture or harvest of fish, it has been reported that factors such as the type of fish, capture conditions, handling and temperature affect the speed of appearance and degree of changes associated with spoilage and loss of product quality [60]. Therefore, after fishing, it is recommended to reduce the temperature of the animal as soon as possible for its immediate preservation or processing. In aquaculture products, this condition preferably involves keeping the fish alive prior to being subjected to rapid processing and low temperatures to present a quality and fresh product for direct sale, or alternatively applying some preservation method [9].

7. Fish Processing and Preservation

Food products are generally divided into fresh and processed products, where fresh products are those that are characterized as having a minimum or no level of processing, and processed products are those subjected to a physical or chemical transformation process, contributing to their safety, reducing food waste, improving and preserving nutritional quality, allowing the diversity of foods available and for a longer time, helping their culinary preparation, turning them into products attractive to the palate, and making them easy to consume and digest [9,63–66]. Currently, the consumer trend is to value the freshness

and safety of the product, bringing these demands to producers in order to select more appropriate procedures to achieve these characteristics in the foods offered [63].

Food processing involves any method that preserves fresh or raw foods and transforms them into food products for consumption, involving various actions considered as minimal processes such as washing, peeling, cutting, grinding, pasteurization, cooking, sterilization, refrigeration, freezing, drying, fermentation, and packaging, among many others. Thus, a food product can be processed in different ways, either at home or at the industrial level [64,66,67].

In fish derived for its nutrient content, high water activity and a pH close to neutral make it a highly perishable food, so it becomes necessary to implement some immediate processing and preservation action that stops or reduces the activity of enzymes, microorganisms, and oxygen which are mainly responsible for its spoilage [36,68]. When choosing a food processing and preservation method, a factor to consider is its characteristics and composition, from its capture or harvest until a final product is delivered to the consumer. Along with this, it is important to know the type of fish (fat composition), size, and degree of freshness, as a good product cannot be obtained with low-quality raw materials [9,11,69,70].

The methods focused on evaluating the quality of fresh fish are commonly divided into the following: sensory (analyze and interpret characteristics of food through the senses of sight, smell, taste, and touch), physical (electrical properties, pH, Eh, and texture), chemical (analysis of total volatile bases, ammonia, trimethylamine, dimethylamine, biogenic amines, nucleotide catabolites, ethanol, and peroxides), and microbiological (total aerobic count and detection of pathogens as *Salmonella* spp., *E. coli*, *S. aureus*, *Vibrio* spp., *Listeria* sp., *Aeromonas* sp., and *Plesiomonas* sp. among others), either by traditional or molecular methods [8,35]. It should be noted that the consumer is the final judge of quality, so the sensory evaluation may be related to other evaluation methods for use in the laboratory [8].

The analysis of the freshness degree or fish spoilage in products for direct consumption or raw material for processing and preservation is carried out quickly and commonly through sensory evaluation of different organs such as skin, eyes, gills, muscle, and internal organs [17,60,71]. Table 3 shows the evaluation characteristics of the state of freshness and fish spoilage in different components.

Table 3. Characteristics of fresh or spoiled fish intended for human consumption.

Fish Compound	Fresh Status	Spoilage Status	References
Skin	Brilliant coloration Transparent mucus Non-viscous	Discoloration Opaque mucus Viscous	[9,17,60,71]
Eyes	Convex Transparent Brilliant	Concave Milky Opaque	[9,17,60,71]
Gills	Red-colored Brilliant	Yellowish Brownish Colorless Viscose	[9,17,60,71]
Muscle appearance	Firm Elastic Uniform colored	Soft Stained	[9,17,60]
Odor	Fresh, ocean-like	Rotten/rancid Sulfides, amines, and ammonia	[9,17,60,71]
Internal organs	Brilliant Defined	Autolysate Acid odor	[9,17]
Scales	Firm, bright, and detachment resistant	Easy detachment and low firmness	[60]

In general, the term quality refers to the appearance, freshness, or degree of spoilage of the fish. However, it also involves safety by considering the absence of pathogenic microorganisms or chemical substances. It should be noted that the term quality can be different for each individual and is a characteristic term associated with a particular product. It is usually considered that the highest quality is found in fish that is consumed in the immediate post-mortem period. However, fish in rigor mortis makes the filleting and skinning process difficult and inappropriate for smoking. Therefore, for processors, fish that has passed rigor mortis is recommended [8].

Food processing and preservation technologies address the continuous challenge of generating more durable products by minimizing the nutritional and sensory characteristics of the fresh product, contributing to its microbiological stability and extending shelf life [72].

In the processing of fishing and aquaculture products, the edible portion (fillet) is commonly separated to favor its shelf life [9,61], also generating by-products that are discarded or used for processing, obtaining different value-added products intended for human or animal use such as fishmeal, oils, and hydrolysates, among others [72,73]. The stages for the generic and basic processing of fish constitute sensory evaluation and selection (species and size), washing (causing reduction in microbial load), scaling, gutting, heading, and cutting according to the species, size, shape, preservation process, and consumer needs (Figure 1).

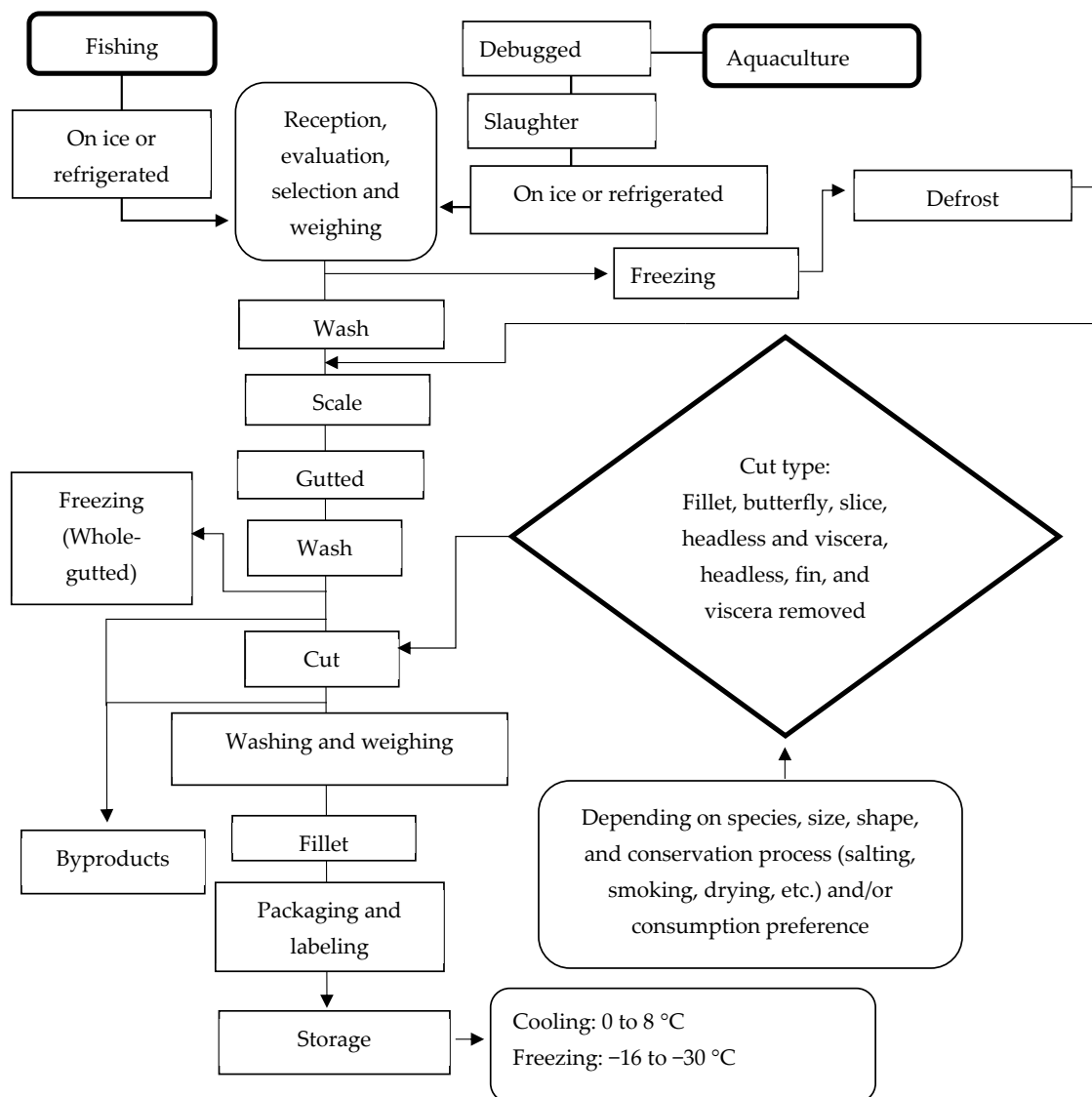


Figure 1. Elemental processing diagram of fresh fish to obtain various products [9,61,74,75].

In foods of aquatic origin, there are a variety of processing and preservation technologies that contribute to extending their shelf life and guaranteeing their safety so that they can be distributed and marketed in areas far from where they are produced. Food preservation methods are classified as modern (refrigeration, freezing, canning, vacuum packaging, and modified atmospheres) and traditional (salting, smoking, cooking, drying, and pickling), the latter being of basic and common use in fish, and which can be applied individually or jointly [76].

Preservation methods are generally based on the modification of biological activity's optimal conditions (enzymes and microorganisms) such as lowering the temperature (refrigeration, chilling, or icing and freezing), heat application (canning, cooking, and smoking), reduction in available water (drying, salting, and smoking), pH modification (pickling), change in storage conditions, and absence or presence of oxygen or other gases (vacuum packaging or modified atmosphere) [4,9,60,65,70].

On the other hand, it should be noted that different processing and preservation technologies that are focused on mainly reducing or preventing microbial activity, chemical or enzymatic reactions that give rise to spoilage, can often also have different influences and effects on chemical, nutritional, and sensory properties of the product, mainly being the loss of vitamins, the degradation of amino acids and proteins, lipid oxidation, and the formation of compounds derived from the interaction between oxidized lipids and proteins that generally produce changes in color, aroma, flavor, and texture [36,68,77].

The different preservation technologies commonly and basically applied to fish are described below.

Chilled

This method is used to preserve fresh fish once caught, which are conditioned in boxes and/or cold chambers with ground or flaked ice, distributing the ice below and above [11,60,78]. It is advisable to use ice in a 1:1 proportion with fish, and it must be replaced as it melts. Ice can be used directly or mixed with water so that there is ample contact between the fish and chilled water [78]. The ice storage temperature ranges between 0 °C and −7 °C, and heat transfer occurs by direct contact of the fish with the ice (conduction) [11,60]. Reducing the ice's temperature reduces the growth of pathogenic microorganisms and spoilage, as well as the speed of enzymatic reactions, specifically those associated with the first post-mortem changes and extending the rigor mortis period [8]. Ice can be made with seawater or fresh water and among its main advantages are that it has a large cooling capacity, it is harmless, it is portable and relatively cheap, it causes cooling but not freezing, it prevents dehydration of the fish, and it favors constant washing when removing dirt and mucus due to melted ice; however, the preservation time is limited [9,11,60,79].

Refrigeration

This method is based on reducing and maintaining the temperature of food above its freezing point, usually between −1 °C and 8 °C. The effect of the cold slows down microbiological activity and chemical and enzymatic reactions related to the degradation of fish, extending its useful life, with a minimal consequence on its nutritional and sensory characteristics, of approximately 1 to 2 days [9,11]. Direct cooling by this means is slow, however, so it is advisable to quickly pre-cool the fish in ice with water until it reaches a temperature close to 0 °C and then subject it to refrigeration [9]. The drawbacks of this technology are the superficial drying of areas of the food and loss of aroma and nutritional properties, as well as this method not preventing lipid oxidation and browning [80].

Freezing

This method consists of converting water into ice, which produces a dehydration effect on the food, inhibiting enzymatic activity and microbial activity. It allows storage for months, where the loss of vitamins and minerals is minimal, but the texture, stability, and water retention capacity of proteins can be affected [11,60,77]. It has been pointed out that in freezing, oxidation and lipid hydrolysis especially generate the degradation of

products in storage, mainly affecting fatty species of fish [77]. Freezing systems for fish can include freezing in (a) brine, consisting of immersing the fish in a NaCl freezing solution at a temperature of $-21\text{ }^{\circ}\text{C}$; (b) forced air, which is based on subjecting the fish or fish products to a strong air current, at temperatures of $-40\text{ }^{\circ}\text{C}$ and an air speed of 4 m/s for 4 h; (c) contact, which consists of freezing the fish through contact with a metal surface that is at $-40\text{ }^{\circ}\text{C}$, being frequently used for fillets or pulps; and (d) ultra-freezing, which is used to quickly freeze the food by spraying it with liquid nitrogen at $-192\text{ }^{\circ}\text{C}$; however, this is an expensive method and is used for small parts mainly [78].

The recommended freezing temperature is -18 to $-30\text{ }^{\circ}\text{C}$. After freezing, it is necessary to glaze the product by immersing the fish for 45 s in drinking water, or a mixture of 0.2% sugar, 0.5% salt, and 0.3% polyphosphates, to avoid cold damage such as dehydration and oxidation of fats in storage [42,61,69]. The quality of frozen fish depends on the quality of the raw material prior to freezing and the design of the freezing process (type, time, and temperature). Therefore, in slow freezing, reaching the desired temperature in the product takes from 3 to 72 h, during which large ice crystals are produced, favoring the oxidation of lipids and cell rupture, and causing loss of fluid from the cytoplasm after thawing. Additionally, during the denaturation of proteins, there may be a loss in water retention capacity, changes in texture, and a greater speed of spoilage upon thawing [9,11,68,74]. Another method can be rapid freezing, reaching the desired product temperature within 3 h, producing small ice crystals that cause less damage to the cell walls when frozen, and during pre- and post-freezing handling and storage [9,11,74]. The duration of the product stored under adequate conditions can be estimated at 6 to 8 months. It should be noted that to maintain the quality and duration of the frozen product, there should be no variations in temperature during storage. Finally, if there are thaws, do not freeze again [78].

Cooking

This method involves applying a heat treatment through boiling, baking, roasting, frying, or grilling. The application of heat inactivates pathogenic microorganisms and microorganisms and enzymes responsible for spoilage, improving the flavor, shelf life, and safety of the fish. Heat treatment is a function of time and temperature, since the higher values the greater the impact on protein quality (denaturation), texture, color, and loss of vitamins and minerals [68]. The choice of the way to cook the fish is mainly a function of the type of fish, where for lean fish, moist cooking is recommended and where steam is a thermal regulator that helps preserve the meat by avoiding dryness. Meanwhile, for fatty fish, dry cooking is suggested, since the fat content allows its qualities to be preserved [12].

Canned

This method consists of canning or packaging products in hermetically closed containers. These products are subjected to high heat treatment (cooking and sterilization) for their preservation and safety during prolonged storage at room temperature, reducing excess humidity and inactivating endogenous enzymes and microorganisms, but generating effects on the nutritional food composition [10,60,77]. On the other hand, it has been reported that during the cooking process, the leaching of soluble vitamins and proteins in cooking liquors is the main source of nutrient loss [68]. This method is generally applied to fatty fish (sardines and tuna) and shellfish (mussels, cockles, razor clams, and cephalopods) [10,60]. This preservation method is not suggested for lean fish since the meat is considerably affected by high temperatures in its integrity, flavor, and texture [68].

Drying

This method consists of the loss of water that reduces the water activity necessary for microbial growth and enzymatic activity through elimination by evaporation of water from the surface of the fish muscle, either by exposure to the sun and wind or using various equipment [9,81–83]. It is not recommended for fatty species due to the tendency towards lipid rancidity, which is the most important route of alteration. Prolonged exposure to the sun causes lipid oxidation, reducing its nutritional quality [68]. This method can be combined with salting, reaching a final product humidity of 15 to 20%. An ideal drying

temperature of between 35 °C and 40 °C has been estimated, in addition to the fact that the process is influenced by factors such as temperature, humidity, air flow speed, and the size and thickness of the fillet [83].

Salting

The application of salt to fish can be performed by itself or along with drying, smoke or vinegar to improve preservation and achieve sensory characteristics [60]. This method generates dehydration of the food and reduces water activity, inhibiting microbial growth due to a cellular osmotic imbalance [83,84]. Concentrations of 6% inhibit microbial growth, and autolysis above 9% generates denaturation in muscle proteins [82,83]. A high concentration of salt in muscle favors the loss of soluble proteins and a reduction in water retention capacity [68]. Factors such as the fish or fillet thickness, degree of freshness, fat content, salt purity, salt particle size, temperature, and hygiene during handling influence the salting process and speed of salt absorption [69,82,83,85]. Salt can be generally used through a dry means for lean species in a proportion of 8 to 30% according to the region, climate, and final product characteristic, and through a wet means for fatty species [61,69,74,82,84].

Smoked

This method consists of the application of non-resinous wood smoke where the color, smell, and flavor of the fish are modified while partial dehydration of the fish tissues occurs and its texture is modified [60,74]. It can be used after salting and drying. The dehydration and reduction in water activity of the tissues and the presence in the smoke of compounds (phenols, organic acids, esters, and polycyclic aromatics) with antimicrobial and antioxidant activity determine the increase in the useful life of the fish, but are insufficient to allow its preservation at room temperature, so these products must be preserved through refrigeration [60,84]. Smoking can be hot when exposed to the action of smoke at temperatures between 60 and 120 °C or cold at temperatures below 60 °C [69,78]. Despite the benefits of smoking, it has been pointed out that lipid oxidation, protein denaturation and non-enzymatic browning reactions are the main factors responsible for these changes in the nutritional quality of these products [68,77], specifically in the availability of lysine where its loss is proportional to the temperature and duration of smoking [68]. Once smoking is completed, the product must be stored in refrigerated conditions with a shelf life of approximately 30 days [69].

Pickled

Pickling is performed through the combined action of salt and vinegar. The medium is acidified and the decrease in available water manages to increase the fish's useful life by slowing down microbial and enzymatic action [60,74]. The added salt contributes to the stability of the pickle and reduces the softening action of the acid. The product is characterized by its strong flavor and smell that can be accentuated by the addition of different spices, and refrigeration is also required to preserve these products [60,74].

Vacuum packaging and modified atmospheres

Vacuum packaging is performed by removing air from inside the food packaging to protect the food from environmental contaminants and extend its shelf life. It enables the stoppage of present aerobic microorganism activity, reducing the degree of oxidation, and is generally associated with the use of refrigeration [76,84]. The disadvantage of this technology combined with refrigeration is the dehydration of the product and loss of water due to evaporation [62]. On the other hand, in different foods, transpiration is necessary, so the use of modified atmospheres has become popular where, instead of vacuum, the method consists of changing the gaseous environment (pure gas or mixtures) of the product in the packaging, maintaining control of enzymatic reactions and microbial organisms associated with spoilage [76,84]. The frequently used gases are CO₂, N₂ and O₂ [76]. The presence of 10–20% of carbon dioxide (CO₂) in the atmosphere of the food suppresses the growth of *Pseudomonas* spp., the main microorganism responsible for spoilage, considering a storage temperature of 4 °C or less [80]. However, the drawbacks of this technology

are that it requires expensive equipment, and the gas mixture can alter the organoleptic properties of the food [76].

A mixture of gases is recommended to maintain the freshness and quality of the food, where the gas mixture to be used will depend on the type of fish and the storage temperature [84]. For fresh fish, the shelf life is 10 to 14 days at 4 °C and increases to 18–20 days at 2 °C [62] (Navarro, 2020). In fish fillets, it has been reported that mixtures of 0.4% CO + 30% CO₂ + 69.6%N₂ and 10%O₂ + 30% CO₂ + 60%N₂ achieve a shelf life of 20 to 21 days [84]. For non-fatty fish, the mixtures that have shown the greatest interest are 30% O₂ + 40% CO₂+40%N₂ and 0% O₂ + 40% CO₂ + 60% N₂ for smoked fatty fish [62].

Fermented

In fish, fermented products are categorized into three types: sauces, pastes, and salted fish. The basic principle of fermentation is the use of lactic acid bacteria, naturally or intentionally, allowing an anaerobic environment along with the production of metabolites (organic acids and bacteriocins) and a salt concentration, low pH, and water activity that controls the development of pathogens and those responsible for spoilage. The sensory properties of fermented products are typical and unique, being a function of the composition of the substrate, type of microorganism, and added additives [86].

Other alternative preservation methods

On the other hand, in addition to the aforementioned methods, in recent years, innovative or modern technologies of a non-thermal nature have been proposed, considering preservation alternatives focused on controlling microbial growth and reducing spoilage without further affecting nutritional and sensory properties. Among these technologies include the use of high hydrostatic pressure, pulsed electric fields, ultrasound, pulsed light, non-thermal atmospheric plasma, use of ozone (O₃), and electrolyzed water, as well as the use of natural preservatives (organic acids, essential oils and plant/algal extracts, bacteriocins, and chitosan); most of these technologies present different advantages such as having lower energy consumption and shorter production times, being active at low concentrations, being non-toxic, and promoting profitable use of these last three qualities in the case of natural preservatives. Among the disadvantages reported in the different technologies are the high cost of acquisition and operation, inactivation of microorganisms on the surface of solid foods due to their poor penetration capacity, the favoring of the oxidation of lipids, low activity against endogenous product enzymes, effectiveness depending on the composition of the food matrix, specific activity depending on the extraction solvent (in the case of essential oils), and the fact that they must be applied in conjunction with other preservation technologies for greater effectiveness [36,87,88].

8. Conclusions

Fish is a basic food in the human diet due to its high nutritional value, with its main contribution being proteins, lipids, vitamins, and minerals. Fish is among the most produced and commercialized foods around the world, in presentations ranging from a whole raw state to products derived from the application of various processing and preservation methods. In addition to being very nutritious, fish is also one of the foods with a high susceptibility to spoilage and contamination throughout the food chain due mainly to its intrinsic properties, conditions, and post-capture hygienic practices, generating a decrease in product availability and causing economic losses due to losses throughout the supply chain and the introduction of diseases to consumers.

The need to guarantee nutritional and sensory quality, safety, and extend the shelf life of food to promote food availability is increasingly demanding due to a constantly growing population. Given this, different actions focused on food regulation, processing and the preservation of fish have been developed to combat post-mortem changes associated with spoilage and contamination by various biological hazards to guarantee the safety and availability of fresh, safe, and nutritious foods.

Fish preservation technologies are varied, being used individually or together, and increase the shelf life and safety of products but affect nutritional, sensory, and freshness properties; however, more research remains to be conducted on the development and implementation of technologies that allow the freshness and nutritional qualities of the food to be respected, that avoid or reduce to a minimum or safe levels the different hazards and factors associated with spoilage and health risk alongside consequent economic accessibility, and promote a reduction in process time and energy consumption in their implementation.

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