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Original Article

# Post-harvest bacterial contamination of fish, their assessment and control strategies

## Contaminação bacteriana pós-captura de peixes, análise e estratégias de controle

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**Abstract**

Healthy fish populations lead to healthy aquatic ecosystems and it is our responsibility to be a part of the solution. Fish is one of the most favored foods and is suitable for people of all ages. Fish is an essential source of protein, vitamins, and minerals and a source of income for millions of people. Human population growth and climate change are putting a strain on our food system, demanding the development of sustainable services to enhance global food production and its security. Food safety is an intricate problem in both developed and developing countries. Fresh fish is a highly perishable food with a limited life span; as a result, it must be delivered and kept carefully to minimize deterioration and assure safety. Fish spoilage is linked to biochemical changes that occur post-harvest, such as storage and transportation. These modifications can account for fish spoilage by altering the taste, texture, and appearance. Fish harvesting, distribution, and post-harvest handling are all unhygienic, resulting in poor and unpredictable fish quality in the market. Many innovative and effective control measurements of various bacteria in fish have been proposed and evaluated. This review is a systematic approach to investigating post-harvest fish spoilage, its assessment, and control strategies.

**Keywords:** fish spoilage, contamination, foodborne pathogens, bacteria, microbial assessment.

**Resumo**

O peixe é um alimento popular e adequado para pessoas de todas as idades. É uma fonte essencial de proteínas, vitaminas e minerais, assim como uma fonte de renda para milhões de pessoas. O crescimento da população humana e as alterações climáticas tensionam nosso sistema alimentar, exigindo o desenvolvimento de serviços sustentáveis para melhorar a produção alimentar global e a sua segurança. A segurança alimentar é um problema complexo tanto para países desenvolvidos quanto para países em desenvolvimento. O peixe fresco é um alimento altamente perecível e com vida útil limitada, consequentemente, deve ser transportado e armazenado com cuidado para minimizar a deterioração, garantindo a segurança de seu consumo para a saúde. A deterioração do peixe está ligada a alterações bioquímicas que ocorrem após a captura, tais como armazenamento e transporte. Essas modificações podem ser responsáveis pela deterioração do peixe, alterando o sabor, a textura e a aparência. A despesca, distribuição e manejo pós-captura do peixe tendem a ser pouco higiênicos, resultando em uma baixa e imprevisível qualidade do peixe no mercado. Diversas medidas de controle inovadoras e eficazes em relação a diferentes bactérias encontradas em peixes foram propostas e avaliadas na literatura especializada. A presente revisão é uma abordagem sistemática que visa investigar a deterioração pós-captura do peixe, sua análise e estratégias de controle.

**Palavras-chave:** deterioração de peixes, contaminação, patógenos de origem alimentar, bactérias, avaliação microbiana.

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## 1. Introduction

Fish contains nutritional and digestive proteins, essential amino acids, minerals, and highly unsaturated fatty acids which are one of the major sources of high-quality protein (Tavares et al., 2021) in global markets for human consumption are used to develop nations economy (Emikpe et al., 2011; Hassan et al., 2022). The fishing sector is a significant source of current economic growth (Jianadasa et al., 2014; Hassan et al., 2022). Fish are widely considered high-risk and hazardous products in terms of pathogenic content, the availability of natural toxins, and other potential pollutants (Yousuf et al., 2008; Bilal et al., 2022; Bilal et al., 2023). Compared to other fresh resources, fish are perishable, and their hygienic quality declines rapidly. The consistency of the fish deteriorates due to the complicated process that involves physical, chemical and microbiological forms of degradation (Yagoub, 2009).

Fish are collected from their aquatic ecosystem, resulting in their death. Several changes occur in the body after death. These modifications are referred to as postmortem modifications. These alterations occur in the postmortem stage of fish due to spoilage. As a result, fish are regarded as highly perishable foods that deteriorate quicker than other foods, which is a significant barrier to fishing and impacts the whole national economy (Abd El-Hay, 2022). After a fish is captured, spoiling begins quickly, and rigor mortis is to account for the alterations in the fish. The changes in fragrance, aroma, and texture throughout the spoiling progression are triggered by the degradation of several mechanisms and the synthesis of new substances. Degradation happens quickly due to multiple mechanisms driven by microbial metabolic activity and lipid degradation (Tavares et al., 2021).

Fresh fish contains much water and comprises free amino acids that help bacterial growth (Sheng and Wang, 2021), and may pose a contamination hazard to customers due to microbial cross-contamination from different sources (Khalid et al., 2021). Bacteria, biotoxins, and others may be responsible for the possible biological contamination in aquaculture (Hassan et al., 2021). These may occur either in native aquatic ecosystems or due to ecosystem contamination. Fish-related zoonotic infections may be topically acquired infections resulting from contact with aquatic animals or infections caused by ingesting undercooked aquatic products such as fish (Sorsa et al., 2019). The number of bacteria associated with fish varies depending on the ecological area, weather, and harvesting methods. The microbiota of typical fish tends to be representative of microorganisms found in nearby water (Rhea, 2009). Fish's defense system prevents bacteria from reaching the skin while they are alive. As they respond to a complicated mixture of natural chemicals upon death, the bacteria can penetrate or spread into the flesh, resulting in clearly defined variances in fish meat quality (Karthiga Rani et al., 2016). Providing safe and healthy fish and their ingredients in the course of toxicity is critical (Jianadasa et al., 2014). The problem of food hazards posed by microorganisms, together with the extreme susceptibility of aquaculture to pollutants from domestic, industrial, and agricultural discharges (Muhammad et al., 2020). Farm workers are less concerned about protection because there is little contact with experts, and training is difficult due to the large number of farmers in Asia (Corsin et al., 2007). In small quantities, many of the chemical elements found in seafood are essential for human life but can be highly harmful (Abdel-Latif and Sedeek, 2017; Bilal et al., 2022; Bilal et al., 2024).

There are numerous conventional ways for determining the freshness of fish, including sensory estimation such as quality index systems (Grigorakis et al., 2004), chemical recognition practices depend on influential extents such as high-performance liquid chromatography (Itoh et al., 2013), mass spectrometry (MS) and gas chromatography (GC) (Aro et al., 2003) and microbial methods based on total viable counts (TVC) or special spoilage organisms (SSOs) (Gram and Dalgaard, 2002). Several ways have been examined to enhance the shelf-life of fish while minimizing the impression on an eminence, notably texture, and to prolong storage relative to chilling to prevent cold preservation (Tsironi et al., 2020). Food safety and quality control are almost ignored in the fish market. Although many papers have been published on bacterial contamination, few review papers specifically focus on post-harvest fish spoilage, safety, and control strategies. Experiments indicate that fish are very vulnerable to bacterial contamination. The primary objective of this review is to give updated information on bacterial contamination and its control in the fish market.

## 2. Spoilage of Fish

Spoilage refers to a fish's quality deterioration, which affects its appearance, aroma, taste, and meat texture. The increase in pH and nitrogen compounds promotes the growth of bacteria, affecting the color of the eyeballs, body surface, abdomen, and muscular tone after a brief initial spoiling stage (Alasalvar et al., 2011). Several variables are assessed microbiological quality of frozen fish fillets (Abd-El-Hady et al., 2017). Bacterial growth is the process that deteriorates fish, and spoiling has the most impact on the quality of fresh fish. Microorganism spoilage produces volatile amines, biogenic amines, and ketones, all of which have nasty and objectionable off-flavors. The existence of bacteria in fish suggests that bacterial proliferation allows some pathogenic and toxigenic microorganisms to multiply, posing a hazard to public health. Cross-contamination of fish may occur in the processing environment or during fish preparation before consumption (Ghanem et al., 2019).

There are several specific spoilage microorganisms (e.g., *Pseudomonas* spp., *Enterobacteriaceae* spp., *Shewanella* spp.) and pathogens (e.g., *Escherichia coli, Vibrio* spp., and *Listeria monocytogenes*) in fresh fish and seafood, but bacterial metabolites (e.g., histamine) can also pose risks to human health (Andoni et al., 2021). The spoilage bacteria (Specific Spoilage Organisms—SSOs) of fresh fish are commonly found on the surface, gills, and intestines of different fish, with predominantly fermentative occurrences (i.e., *Vibrionaceae*) in refrigerated fish and psychro-tolerant (i.e., *Shewanella spp.*) in chilled fish (Boziaris and Parlapani, 2017). Significant levels of ammonia, creatine, free amino acids, uric acid, and histamine promote the formation of postmortem bacteria, resulting in fresh fish perishability. Furthermore, due to their poikilothermic nature (with a variable body temperature that tends to fluctuate with and is similar to or slightly higher than the temperature of its environment), fish have a neutral to slightly acidic pH and a high water content, which promotes the growth of a diverse range of bacteria. Bacterial contamination has been recognized as the leading cause of fish deterioration (Ghaly et al., 2010). Fish infestation is a new problem for the general population, and even today, with contemporary processing and freezing processes, it is difficult to continuously produce fresh and high-quality fish (Figure 1).

It is reported that 10 to 50% of all food grown globally is rejected due to spoilage after harvest. Bacterial activity is thought to be responsible for up to 25% of all fresh food poisoning. (Adelaja et al., 2018). It has been discovered that only a small number of bacteria can attack the internal tissues. As a result, spoilage is predicted to occur primarily due to bacterial enzymes penetrating soft tissue and distributing resources across the fish body (Ababouch et al., 2005). The factors that influence the spread of bacteria in fish can be categorized into two sorts: inborn (fish characteristics) and extrinsic (factors outside of the fish) (qualities of the fish environment) (Charm et al., 1972; Bernard and Scott, 2007).

## 3. Assessment of Quality and Freshness of Fish

The growing food industry and the petition for ongoing food storage and preservation have led to the expansion of systems for easily tracking and retaining food quality and safety throughout the shelf life of products. Monitoring systems and indicators, which can be attached to boxes, are examples of next-generation technology that aid product evaluation. These can be configured to perceive freshness indicators, provide a real-time quality index, and alert the user to potentially hazardous components. Additional features can be incorporated to deliver defensive mechanisms, such as packing with an oxygen barrier covering that avoids spoiling (Neethirajan and Jayas, 2011). As a result of metabolic processes or the growth of microorganisms, packaged food can undergo various changes over time. Modifications in gas progression can be used to assess the freshness or deterioration of food (Smolander, 2008).

A computer vision-based technique is created to forecast the freshness quality of fish from its image. The zone of interest is the fish eyes because there is a strong association between the eye's color and the storage day's period. It is segregated from an image of a fish sample, and then the selective features are extracted using a strategic framework. These extracted features exhibit a degradation pattern, which is an informative measure for determining the amount of freshness of the fish sample. These factors decide the freshness of a post-harvested fish (Banwari et al., 2022). Generally, *Enterobacteriaceae* and *Escherichia coli* are commonly used as standards for determining the quality of foods. A total bacterial count is used to govern the overall bacterial quality of fish and can be a valuable way to measure the shelf life of raw fish (Eizenberga et al., 2015). Sensors that can detect such deviations may be able to provide a general assessment of food quality. Food decays due to pH changes induced by volatile amines generated during fish spoiling (Kuswandi et al., 2012).

Various spoilage signs can be observed when fish degrade, suggesting protein degradation and adenosine triphosphate (ATP) decay. The product type, feeding patterns, storage temperature, and harvesting methods determine the rate at which a product degrades. Conventional methods for determining freshness rely on human perception; though necessary, they do not provide quantitative data on ruined food. Approaches that can quantitatively evaluate degradation markers through chemical or biological interactions can help analyze the state and quality of fish more precisely. Hypoxanthine, formed by the metabolic decomposition of ATP, is one of the most crucial freshness markers in fish products (Mustafa and Andreescu, 2018). Electrochemical recognition has been established to quantify the level of hypoxanthine (Lawal and Adeloju, 2012). A copper nanocluster with peroxidase-like activity created a colorimetric sensor for xanthine analysis. In the presence of H2O2 generated by xanthine oxidation, copper nanoclusters were discovered

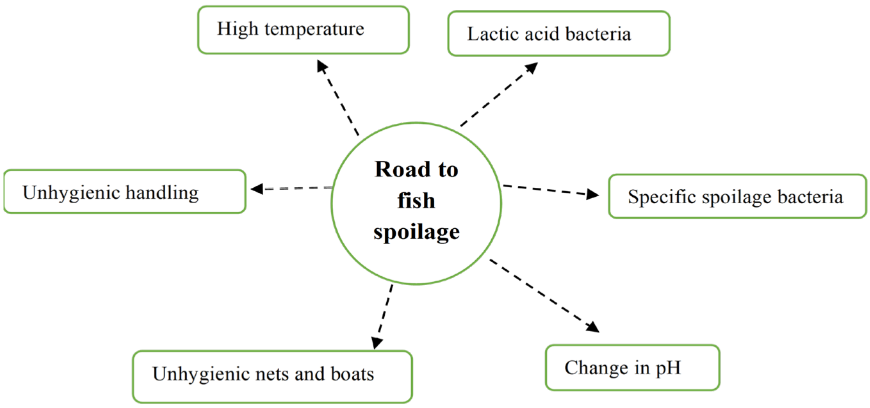


**Figure 1.** Causes of fish spoilage from catch to consumer.

to enhance the oxidation of tetramethylbenzidine dye (TMB) (Yan et al., 2017).

*3.1. Sensory method*

Sensory properties, which are attributed to fish texture, meat elasticity or texture, and taste, are the primary parameters of fish quality. Sensory attributes such as appearance brightness, meat color, gill color, meat elasticity, and smell could be used to interpret freshness based on parameter changes (Parlapani et al., 2014). The quality index method (QIM) is the most commonly used sensory evaluation technique. It is based on the analysis of sensory quality parameters pertaining primarily to the skin, eyes, gills, and abdomen of raw fishes (Hyldig and Green-Petersen, 2005). These methods can replace expensive food product monitoring procedures and boost sample throughput. We explain the current state of biological and chemical sensors that monitor fish quality and safety, which can be utilized to extend the shelf life of fish and increase their measurement capacities. Sensors are often made up of biological and chemical sensors that are mainly intended to identify a target analyte and a physical converter that turns the recognition process into a measured signal, resulting in a quantitative or qualitative output (Kerry et al., 2006). Biological sensors, known as biosensors, rely on biomolecules like enzymes, aptamers, and antibodies to recognize them (Mostafa, 2020).

*3.2. Electronic nose and electronic tongue*

With the increasing demand for food and the need for quick quality assessments. Under this presumption, methods capable of simulating human sensorial perception, such as e-nose and e-tongue, colorimetric sensor array, and e-eye, have received increased attention in research papers and industrial uses (Hassoun and Karoui, 2017). The electronic nose is an approach aimed at replicating the dimensions of the human nose, not through receptor-based transduction concepts but through the use of arrays of biochemical transducers obtained from data processing. In the range of e-noses invented and built over the past two decades, we may see frameworks based on electrochemical gas, metal oxide, and conducting polymer sensors matched with numerous feature matching and data processing techniques (Franceschelli et al., 2021). It's a solid-state-based gas-sensor array framework that's been fixed up to observe the industrial smoked salmon process, with measures like TVC and lactic acid bacteria being monitored (LAB) (Hassoun and Karoui, 2017).

The term 'electronic tongue' refers to a sensor-based device that, through the transmission of a sensor or a pattern of signals, allows for the recognition of tastes in (soluble) food and the rapid evaluation of complicated liquids, whereas the e-nose explained above works with gaseous systems. Different electrochemical sensors utilized in constructing these devices can be found in the literature. Amperometry, potentiometric, and voltametric sensor arrays are the most prevalent (Hassoun and Karoui, 2017). E-tongues have been widely used in assessing fish freshness, with various applications and outcomes based on sensor characteristics (Gil et al., 2008).

*3.3. Quality index method*

Fish endure a complex process of microbial and enzymatic activity after harvesting, resulting in protein denaturation and lipid oxidation. This operation causes changes in sensory and nutritional properties and consumer refusal, rendering the fish unfit for commercial viability and usage. QIM is regarded as a practical and quick method of determining the freshness and quality of fish. QIM highlights credit points (0 to 3) adjusted for the species under consideration. Scores reasonably close to 0 reveal freshness, while scores closer to 3 imply a critical stage of decay, indicating the appearance of predefined fish variables linked to the sale of food. The scores assigned by QIM are unbiased and fair. However, as a sensory method, it depends on a small number of highly trained assessors. Qualitative approaches, such as QIM, are affected by sampling size, storage conditions, and species specificity, resulting in protocol gaps. Furthermore, the bacteriological validation yielded contentious results (Bernardo et al., 2020).

*3.4. Optical methods*

The term 'optical' refers to a group of methods that use electromagnetic waves in the ultraviolet (UV), visible (VIS), and infrared (IR) ranges to gather data about the freshness and quality of fish. Because of the reduction in instrument costs, the advancement of appliances, and the amalgamation of chemometric tools, it has become a fascinating and appealing research area. The major applications for fish freshness are tracking microbial growth and spoilage, forecasting physicochemical and texture features, and detecting issues caused by different species and manufacturing processes. Fluorescence, infrared, hyperspectral imaging, spectroscopy, and Raman spectroscopy are the primary techniques considered (Hassoun and Karoui, 2017).

*3.5. Hyperspectral and vibrational spectroscopy techniques*

Many hyperspectral and vibrational spectroscopy technologies have been implemented in past years to assess chemical properties and microbial spoilage in fish. When coupled with partial least squares regression (PLS-R) analysis, Fourier transform infrared (FTIR) spectroscopy has been indicated as an encouraging analytical tool for determining and quantifying spoilage bacteria in meat and fish. Multispectral imaging (MSI), a viable, non-invasive, and rapid technology, acquires spatial and spectral criteria to assess food spoilage and quality attributes, including fish (Govari et al., 2021).

*3.6. Histamine level for fish quality assessment*

Histamine builds up due to the growth of histidine decarboxylase-positive bacteria. The presence of a high histamine level in fish muscles indicates spoilage. Histidine is an amino acid found in various foods, including fish. Histidine is transformed into the biogenic amine histamine at temperatures above 16 °C/ 60 °F by the enzyme histidine decarboxylase. Fresh fish do not contain free histamine, but they do contain the amino acid L-histidine. Histamine is made in fish by certain microorganisms capable of producing histidine decarboxylase enzyme, which can convert the free histidine, naturally present within the muscle of some fish, to histamine (Hassan and Hussam, 2020).

### *3.7. Total volatile basic nitrogen*

Total volatile basic nitrogen is an important parameter for the quality determination of seafood products, and it is the most prevalent chemical indicator for fish spoilage. Also, it has a close relationship with bacterial counts and sensory scores. Total volatile basic nitrogen consists of volatile amines such as dimethylamine, trimethylamine, and ammonia produced by spoilage bacteria. Moreover, the total volatile basic nitrogen is produced by autolytic enzymes during frozen fish storage. So, it indicates bacterial spoilage, increasing the permissible limit and making the fish unsafe for human consumption. Trimethylamine oxide is one of the components of non-protein nitrogen (NPN) used to assess fish shelf life and freshness. Due to the unpleasant odors that are combined with the products' degradation, volatile amines accumulate faster and play a greater role in the quality loss of fish products degradation. An increase in the TMA content leads to an increase in the TVB-N content during spoilage. Lipid oxidation is a major cause of many problems that decrease the shelf-life of fish products. It led to texture, color changes, rancid odors, and off-flavor (Mostafa, 2020).

## 4. Bacteria Causing Spoilage of Fish

***Pseudomonas spp.*** *Pseudomonas* is a group of rod-shaped, gram-negative, and aerobic bacteria. *Pseudomonas* are saprophytes that live in various niches and are frequently found in the indigenous microbiota of foods. Because of their psychotropic, lipolytic, and proteolytic properties, as well as their use of a diverse variety of nutrients for growth, including refrigerated proteinaceous foods, these bacteria are problematic spoilers. *Pseudomonas* spp. is a distinctive spoiler of freshwater fish maintained under aerobic chilled temperatures, and *Pseudomonas fragi* and *Pseudomonas psychrophila* are also important spoilers of fish meat. Because it adheres to surfaces and biofilm mode of life under challenging conditions, *Pseudomonas sp.* is a severe issue in the fish-processing sector. Pathogenic bacteria can also be observed on fish meat and in fish processing plants, where they can attach to surfaces and create biofilms. As a result, spoilage and pathogenic bacteria can form complex multispecies biofilms in this environment, where they can cross-contaminate other foods, reducing shelf life and encouraging pathogen dissemination through food (Sterniša et al., 2019). *Pseudomonas* spp. are widespread, highly adaptable bacteria, which in many cases are characterized as species-specific and used as bacterial indicators of fish spoilage, being part of the natural gut microbiota and isolated from scales, gills, and skin (Seker and Ocak, 2016).

During the storage of fish *Pseudomonas* spp. produces spoilage compounds like ketones, esters, aldehydes, methyl mercaptan dimethyl sulfide, hypoxanthine, and ammonia (Tavares et al., 2021). The capacity of *Pseudomonas* spp. to grow at chilled temperatures enables them to become the dominant microflora during refrigerated storage. *Pseudomonas* spp. produces lipolytic and proteolytic enzymes that alter fish sensory traits during storage and decrease their shelf life (Franzetti and Scarpellini, 2007). They exist during the winter months (Pridgeon and Klesius, 2012). *Pseudomonas aeruginosa* is oxidase positive, catalase positive, fructose negative, sucrose negative bacteria (Emmanuel et al., 2020). *Pseudomonas* spp. from fish is extremely important because this bacterium plays a significant role as a possible human pathogenic bacterium and as a food quality marker as a spoilage organism. Due to the unhygienic nature of fish handlers, *Pseudomonas* spp. is a major public health threat that leads frozen fish to contamination by pathogenic microorganisms.

In order to reduce the incidence of pathogens, this calls for public health issues, and improvements in handling and processing are essential (Adebayo-Tayo et al., 2012). Research conducted in Peshawar, Pakistan, investigating *Pseudomonas* spp. from the epidermis of various carp fish species has been isolated and reported as a possible causes of fish spoilage (Jan et al., 2014). Research undertaken in the retail market of Nigeria isolated *Pseudomonas aeruginosa* to analyze the microbiological and organoleptic assessment of smoked *Sarotherodon melanotheron*. The sensory assessment of smoked *S. melanotheron* showed a reduced quality as the day progressed in both the exposed and cellophane-sealed samples. Compared to the exposed smoked fish samples, the cellophane-wrapped smoked fish were contaminated with more microorganisms (Emmanuel et al., 2020). Another study in Zimbabwe revealed the antimicrobial profile of Pseudomonas species recovered from fish sold at an informal market in Mufakose. *Pseudomonas* showed antibiotic resistance to lincomycin, ampicillin, penicillin tetracycline, and sulphathiazole. The isolated multidrug-resistant bacteria are hazardous to human, animal, and environmental health (Gufe et al., 2019). In addition, Pseudomonas *psychrophile* and *Pseudomonas fragi* have been recognized in Slovenia. Temperature influences *Pseudomonas fragi* and *Pseudomonas psychrophila* adhesion and biofilm formation, which can occur during the preparation and storage of fish flesh (Sterniša et al., 2019). *Pseudomonas* spp. were isolated from Grass carp (*Ctenopharyngodon idellus*) fillets (Dabadé et al., 2015), European sea bass (*Dichentrarchus labrax*) (Wang et al., 2017), Sea bream (*Sparus aurata*) (Parlapani et al., 2015) and Common carp (*Cyprinus carpio*) (Zhang et al., 2015).

***Enterobacteriaceae.*** Microorganisms of *Enterobacteriaceae* family are positives for catalase, gram-negatives, non-glucose fermenters, and facultative aerobics. Enterobacteriaceae are usually water-borne bacteria extensively disseminated in nature and feces and may occur in fish tissues. These bacteria survive and multiply in the gut, mucus, and fish (Onyango et al., 2009). They are also considered to spoil fish, as they can diminish trimethylamine oxide (TMAO) to trimethylamine (TMA) and produce biogenic amines or volatile amines responsible for off-odors and flavors (Tsogas et al., 2019). The involvement of *Enterobacteriaceae* in fish farming results in a significant public health risk. In most cases, however, these microorganisms are part of the usual fish microbiota (Yagoub, 2009).

*Enterobacteriaceae* are the predominant family*; Raoultella planticola, Enterobacter cloacae, Citrobacter freundii, and Enterobacter* aerogenesis are the most common organisms (Sabry et al., 2019). *Escherichia coli* belongs to the Enterobacteriaceae family, a facultative anaerobic, non-spore-forming bacteria (Tilahun and Engdawork, 2020). *E. coli* is an indole-positive, citrate-negative, and oxidase-negative motile bacteria (Karthiga Rani et al., 2016). Because of its entirely fecal origin, the *Escherichia coli* bacterium is commonly used to indicate the bacteriological state of food and environment (Rocha et al., 2014). This bacterium has been observed in fisheries and other seafood at rates of severity that differ greatly from country to country. *E. coli* is usually linked with tropic seafood contamination (Thampuran et al., 2005; Van et al., 2008). *Enterobacteriaceae* was a leading cause of microbial contamination isolated from raw fish traded at fish markets in Khartoum state (Yagoub, 2009). In India and Vietnam, *E. coli* susceptibility and isolation rates have been reported to be higher, possibly due to inadequate food hygiene (Molinari et al., 2003). Since *E. coli* is found in the tilapia's intestine, its existence in the muscle indicates poor handling. In Saudi Arabia, a study was designed to examine the bacterial assessment of contamination caused by *E. Coli* and the incidence of foodborne pathogens in imported frozen fish (Table 1) (Elhadi et al., 2016).

Research performed in Nigeria isolated human pathogenic bacteria *Escherichia coli* prevalent in the gills, gut, and skin of apparently healthy Catfish (*Clarias lazera*) and Tilapia (*Oreochromis niloticus*) (Table 1) (Muhammad et al., 2020). A large population of *Escherichia* indicates high levels of fecal contamination from the environment. Another study performed in Lagos state identified the *Escherichia coli in Pseudotolithus senegalensis* and *Micromesistus poutasou* sold in some markets of Victoria Island (Table 1) (Oluwagunke et al., 2019). These organisms indicate that the samples were contaminated and may pose serious public health threats.

*Salmonella* is a gram-negative bacillus that belongs to the Enterobacteriaceae family and is not sporulated (Fernandes et al., 2018). *Salmonella* is not a biological contaminant first found in fish and was spread by contaminated water or improper handling . The ability of this bacterium to live for long periods on food contact surfaces is the most significant factor in Salmonella cross-contamination (Carrasco et al., 2012). Salmonella

**Table 1.** Bacterial species causing contamination at fish markets in different countries.

| Fish species | Source | Bacterial spp. | References |
|---|---|---|---|
| Catfish *(Clarias lazera)* | Sudan | *E. colli* | (Elhadi et al., 2016) |
| Nile Tilapia (*Oreochromis niloticus*) | Brazil | *Salmonella spp.* | (Esposto et al., 2007) |
| Silver Carp *(Hypophthalmichthys molitrix),* Rohu *(Labeo rohita),* Grass Carp *(Ctenopharyngodon idella),* Mahseer *(Tor putitora),* Common Carp *(Cyprinus carpio)* | Pakistan | *Pseudomonas spp., Staphylococcus aureus, Escherichia coli, Klebsiella spp.,* | (Jan et al., 2014) |
| King Mackerel *(Scomberomorus guttatus)* | India | *Escherichia coli, Klebsiella pneumonia, Proteus vulgaris, Staphylococcus aureus, Pseudomonas aeruginosa* | (Karthiga Rani et al., 2016) |
| Boston mackerel *(Scomber scombrus)* | Nigeria | *Staphylococcus aureus, Lactobacillus plantarum* | (Eze et al., 2011) |
| Rohu *(Labeo rohita),* Grass Carp *(Ctenopharyngodon idella),* Silver Carp *(Hypophthalmichthys molitrix)* | Pakistan | Escherichia coli | (Chatta et al., 2018) |
| Nile Tilapia *(Oreochromis niloticus*) | Sudan | Enterobacteriaceae | (Yagoub, 2009) |
| Nile Tilapia *(Oreochromis niloticus),* Catfish *(Cliaris lazera)* | Nigeria | *Escherichia coli* | (Muhammad et al., 2020) |
| Croaker *(Pseudotolithus senegalensis),* Blue Whiting *(Micromesistus poutasou)* | Lagos State | *Escherichia coli* | (Oluwagunke et al., 2019) |
| Tilapia *(Sarotherodon melanotheron)* | Nigeria | *Staphylococcus saprophticus* | (Emmanuel et al., 2020) |
| Milkfish (*Chanos chanos)* | Indonesia | *Salmonella spp.* | (Yanestria et al., 2019) |
| African Catfish (*Clarias gariepinus*) | Nigeria | *Vibrio spp.* | (Afolayan et al., 2020) |
| | | *Lactobacillus spp.* | (Oluwagunke et al., 2019) |
| Asian seabass (*Lates calcarifer*) | Thailand | *Vibrio parahaemolyticus* | (Islam et al., 2024) |
| Salmon (*Salmo salar*) | Turkey | *L. monocytogenes* | (Yang et al., 2017) |
| | Norway | *L. monocytogenes* | (Tosun et al., 2018) |
| Yellowfin tuna (*Tunnus albacares*) | France | *Brochothrix thermosphacta* | (Heir et al., 2019) |

in freshwater fish is generally associated with fecal contamination of the water from which fish are harvested (Mhango et al., 2010). Salmonella contamination of fish may have been caused by excessive poultry and livestock dung used as manure in fish farms. As a result, in the rainy season, the upper part of the earth's surface is drained into the fish ponds, resulting in water contamination. This has greatly paid to the growing population of fish bacteria. Harmful sewage disposal paired with a high-water table allows raw wastewater to infiltrate via runoff into fish farms. Other considerations include processing fish in contaminated containers, fishing vessels, open market show practices, and transport. Washing fish with lake water may also intensify the risk of pollution (Raufu et al., 2014).

*Salmonella spp.* is responsible for a significant percentage of all hospitalizations and was implicated in the largest fish-related outbreak of foodborne illness in 2012, which resulted in 425 illnesses and 55 hospitalizations across 28 states as a result of eating infected raw tuna items (Barrett et al., 2017). The occurrence of *salmonella* spp. causing contamination in the fish market was reported in Brazil (Table 1) (Esposto et al., 2007). Another study led in Indonesia confirmed the prevalence of *Salmonella in* milkfish *at* wet fish markets (Table 1) (Yanestria et al., 2019), *Salmonella* infection in milkfish, indicating probable sources and routes of *Salmonella* dissemination in the fisheries. The isolation of *Salmonella* bearing the invasion gene (InvA gene) in this study could indicate poor sanitation of the setting in which milkfish are sold at the Sidoarjo wet fish market in East Java Province, Indonesia. Countries such as India, Hong Kong, Mexico, Thailand, Spain, and Turkey have documented salmonella contamination in fish (Bibi et al., 2015). Research undertaken in Lagos state isolated presented bacterial pathogens *salmonella* spp. Isolated from *Micromesistus poutasou* and *Pseudotolithus senegalensis* retailed in some markets in Victoria Island (Oluwagunke et al., 2019). *Salmonella* spp. were isolated from the fish patty of common carp (*Cyprinus carpio*) in Turkey (Ilhak and Guran, 2014). Fillets of common carp in Greece (Tassou et al., 2004). A study conducted in the USA also identified *Salmonella* from fillets of Catfish fillets *(Ictalurus punctatus*) (Liu et al., 2016). *Salmonella enterica Typhi* and *Salmonella enterica* weltevreden were isolated from Mackerel fish in India (Kumar et al., 2015).

Salmonella *enteritidis* was reported from sea bream (*Sparus auratus*) in Spain (Provincial et al., 2013). Research undertaken in Latvia showed the count of Enterobacteriaceae to assess the microbial quality (Eizenberga et al., 2015). TBC and Enterobacteriaceae are found in significant concentrations in raw fish sold in Latvian retail markets. E. coli was discovered in all gobby samples. *Klebsiella* spp. are citrate-positive, Indole-negative, oxidase-negative, and non-motile bacteria. *Klebsiella* Coliforms naturally exist in the gastrointestinal tract of animals (Tosun et al., 2016). The study was undertaken in India to assess the hygienic consistency and freshness of *Scomberomorus guttatusus* fish Indo-pacific king mackerel to isolate *Klebsiella* from marine market fish (Table 1) (Karthiga Rani et al., 2016). Raw fish sold in the Madurai fish market are being contaminated due to temperature and improper hygiene.

Proteus species have high proteolytic activity and can quickly spoil seafood stored above cooling temperatures (Tosun et al., 2016). In Sudan, studies have been carried out to determine the hygienic consistency and freshness of fresh fish (*Tilapia nilotica Linn*) and to examine the incidence of *Protius volgerus* as an indicator of the quality of fish (Table 1) (Yagoub, 2009). Antimicrobial Profiling of *Proteus* species isolated from fish sold at an informal market was the focus of the study in Mufakose in Zimbabwe (Gufe et al., 2019). Human pathogenic bacteria can be found in fish taken from contaminated water bodies for human consumption. The contaminated water might also cause disease in the fish. The isolated multidrug-resistant bacteria are hazardous to human, animal, and environmental safety. *Proteus mirabilis* was also isolated from marine edible species *Sardinella longiceps* and *Loligo duvauceli* from Tuticorin, southeast coast of India (Darsana et al., 2021), workers who manage the species and containers, nets used in the captative procedure, and the quality and quantity of ice used for preservation can all cause spoiling. According to the findings of this study, spoiling happens as a result of the length of time it takes to reach the landing market from the moment of capture, which can take more than two days. In Nigeria the *Microccoccus* spp. *Proteus* spp. and *Bacillus* spp. were identified from African catfish *(Clarias gariepinus)* (Uedeme-Naa and John-Amadi, 2022). Fish rearing in fish tanks has been found to have a massive population of bacteria, some of which are opportunistic diseases to both fish and humans. The bacterial load in fish organs varied by season and was higher in the gills than in the other organs studied. *Bacillus spp.* was the most antibiotic-resistant bacterium, whereas erythromycin was the antibiotic-resistant antibiotic. A study by Ikpesu and Ariyo (2021) identified various spp. of *Enterobacteriaceae,* namely *Klebsiella species, Bacillus species, Shigella species,* from Fish from Yenagoa Metropolis, Nigeria. Strains of *Enterobacteriaceae (Citrobacter freundii, E. coli, Citrobacter youngae, Klebsiella planticola, Klebsiella ornithinolytica* and *Klebsiella pneumonia)* were identified from Fish sold in the fish markets of Allahabad India .

***Staphylococcus* spp.** *Staphylococcus* is a gram-positive pathogen in freshwater and marine cultured fish (Kümmerer, 2009). Staphylococcus is cocci, oxidase-positive, catalase positive, indole negative, and citrates positive (Muhammad et al., 2020). Microbes thrive in their environment and can be collected in various ways, including animals and humans. *S. aureus* can cause severe food poisoning (Wu et al., 2021). In water, mud, and wetlands, and even the equipment used in normal operations, these bacteria can live for long periods, but often the occurrence and prevalence are linked to high temperatures (>27°C) (Mian et al., 2009). The processing of fish products during the process entails a chance of infection by pathogenic bacteria such as *S. aureus*, which causes human foodborne poisoning. This bacterium is salt-tolerant and can thus irradiate all preserved fish products. It was also reported that *S. aureus* can live at -50 to -100 ºC in fish. Different authors stated that invasive *S. aureus* was present in fish and fish products, with an incidence rate of 6.50% in Egypt (Sorsa et al., 2019).

The existence of *Staphylococcus aureus*, a pathogenic bacterium of public health problem, is important because it is likely to contaminate frozen seafood products from the source as a result of inappropriate processing of frozen food items (Okonko et al., 2008). Research reported by (Eze et al., 2011) in Nigeria shows the presence of *S. aurius* causing contamination of the frozen mackerel fish (*Scomber scombrus*) in a humid tropical environment . The study performed at the retail market in Nigeria showed the isolation of *Staphylococcus saprophyticus* to assess the microbiological analysis and organoleptic assessment of smoked *Sarotherodon melanotheron* (Emmanuel et al., 2020).

***Lactobacillus plantarum.*** *Lactobacillus plantarum* is indole negative, catalase negative, lactase positive and non-motile positive bacilli (Eze et al., 2011). *L. plantarum* is a lactic acid bacterium that is widely spread and versatile. It is part of many foods and feeds that are microbiota, including dairy, poultry, and fish (Sabo et al., 2014). *Lactobacillus plantarum* isolated from frozen mackerel fish in Nigeria was the main cause of contamination (Eze et al., 2011). Lactobacillus plantarum was isolated from smoked mackerel *scomber scombrus*, from main fish markets in Ibom state, Nigeria (Effiong and Christopher, 2020). Another study determined the isolation of *Lactobacillus* spp. from frozen shellfish retailed within the Lagos metropolis, Nigeria (Afolayan et al., 2020). The study found that almost all frozen shellfish are kept in an unsanitary environment, and harmful metals in the samples argue for ongoing monitoring. *Lactobacillus* spp. were also reported from raw salmon (*Salmo salar*) (Macé et al., 2012), steaks gutted European sea bass (*Dichentrarchus labrax*) (Parlapani et al., 2015). A species of *Lactobacillus* was isolated from *Clarias gariepinus* (African Catfish) in Nigeria . The study identified a high microbial load in the internal organs of fish, and many of the bacteria are resistant to several of the antibiotics examined.

***Brochothrix* spp.** *Brochothrix thermosphacta* is a well-known but little-studied meat spoilage organism. *Brochothrix* is a close relative of the foodborne pathogen *Listeria monocytogenes,* and is the second genus in the *Listeriaceae* family (Stanborough et al., 2017). It has been described as being generally dispersed throughout the food chain and in the food processing environment (Illikoud et al., 2019). *Brochothrix* spp. was reported by (Macé et al., 2012) from raw salmon (*Salmo salar*), *Pangasius hypophthalmus* (Olofsson et al., 2007) and gutted European sea bass (Parlapani et al., 2015). *Brochothrix thermosphacta* causing spoilage of yellowfin tuna (*Tunnus albacares*) was isolated in France (Silbande et al., 2018), and the bacterial species had a diverse impression on the sensory quality of the fish. The bacterial interactions lead to an improvement or an inhibition of the spoilage potential and bacterial growth. *Brochothrix thermosphacta* was isolated as a spoilage indicator of farmed salmon (*Salmo salar*) (Fogarty et al., 2019), *Brochothrix thermosphacta* led to the spoiling of salmon stored aerobically at 2 °C, suggesting that the development of these organisms, rather than TVC growth, may be a better diagnostic of fish spoilage.

***Listeria monocytogenes.*** The genus Listeria is broadly spread as gram-positive and anaerobic bacteria in the natural environment. *Listeria spp.* has the potential to boost over a wide temperature range (0-45 °C) and increased stress, such as intense pH (4.4-4.9), with moisture above 0.92, total acidity up to 14% tolerance to osmotic stress, and perseverance under mild preservation control has been demonstrated (Hamidiyan et al., 2018). Geographic areas, product forms, fish species, sampling pieces, sampling stages, and sample origins all affect the prevalence of *L. monocytogenes* in fish (Sheng and Wang, 2021). In Latvia, *Listeria monocytogenes* was found in 26% of retail freshwater and wild-caught freshwater fish (Terentjeva et al., 2015). *Listeria monocytogenes* have been observed to induce foodborne infection in humans by consuming contaminated raw or improperly treated fish (Eizenberga et al., 2015). The general commonness of *L. monocytogenes* in freshwater fish in China was 2.6%, according to the survey (Li et al., 2019).

*In a study in the United States, L. monocytogenes was present on 65.2% of skin samples from raw frozen salmon* but not on flesh samples from under the skin (Eklund et al., 1995). This study also indicated that Listeria contamination is limited to the fish's surface areas and that the meat is not affected during the thawing of frozen fish or the harvest and processing of live fish. The study conducted in Iran showed that 14.16% of retail rainbow trout tested positive for *L. monocytogenes*, compared to 4.16% of fish samples obtained from fish farms (Rezai et al., 2018). Studies in Iran also evaluated the pervasiveness of *Listeria* spp. contamination in fresh and frozen fish (Rahimi et al., 2012), and intake of these raw or undercooked sea items may lead to foodborne disease in Iran. Furthermore, *L. monocytotenes* in raw seafood may constitute a health danger in kitchens if they contaminate ready-to-eat food. Another study reported the existence of *Listeria monocytogenes* to assess the microbiological quality of raw fish from the retail market in Riga, Latvia (Eizenberga et al., 2015). A research commenced in Turkey isolated facultative anaerobe *Listeria monocytogenes to* evaluate the seafood safety health hazards for traditional fish products (Köse, 2010). *In Serbia, L. monocytogenes was also reported* from vacuum-packaged *Oncorhynchus mykiss* (Dimitrijević et al., 2019). The study performed by (Tosun et al., 2018) reported *L. monocytogenes* from *Salmo salar* in Turkey. *Listeria monocytogenes* were also reported from Norway's cold-smoked salmon (Heir et al., 2019).

***Vibrio* spp.** Vibrio species have been considered both spoiling bacteria and foodborne pathogens since the 1970s. Some Vibrio species have been mostly allied with disease due to seafood ingestion (DePaola et al., 2010). A report in Iran isolated *V. vulnificus V. parahaemolyticus* from fish (Raissy et al., 2015). *A V. parahaemolyticus* was also isolated from flesh, gills, and tract of freshwater fish *Pangasius hypophthalmus* (catfish) and *Oreochromis* spp. (red tilapia) sold at hypermarkets (Noorlis et al., 2011), *Vibrio spp.* and *V. parahaemolyticus* in freshwater fish suggest another potential source of food safety concerns for consumers. Another study isolated *V. mimicus* from fish sold at a market in Kerala, India (Nilavan et al., 2021). *Vibrio parahaemolyticus* was isolated from freshwater fish in China (Chen et al., 2021). According to the findings, the *V. parahaemolyticus* population in freshwater fish is genetically heterogeneous. The *V. parahaemolyticus* contamination could have arisen from fishing farms and cross-contamination from seafood. Freshwater fish may serve as a reservoir for pathogenic and pandemic *V. parahaemolyticus* isolates, implying that freshwater fish intake may pose public health and food safety risks. Another report in China also determines the prevalence of *Vibrio parahaemolyticus* from market fish (Xie et al., 2015), China (Yang et al., 2017). *In Turkey, Vibrio vulnificus was isolated from spoiled fish species* (Özogul et al., 2021). *Vibrio* spp. were also isolated from *Clarias gariepinus* (African Catfish) from various fish farms in Nigeria .

## 5. Prevention and Control Strategies

*5.1. Use of antibiotics, vaccines, and probiotics*

Usually, the fishing industry handles diseases with medical approaches such as inhibitors and therapeutic drugs. Biologically safe vaccines, or biotin (live bacteria that offer health assistance to the server when supplied in large numbers). Experts suggest that fish farming uses farming methods to test pesticides and medicines so that they have safe dose and departure periods. Aquaculture has also started to use probiotics to substitute pathogenic bacteria with valuable bacteria within the body. Scientists are also creating chemotherapeutics and antibiotics that kill specific bacteria. Antibiotics and chemotherapy have been used in aquaculture for a long time to limit pathogen multiplication, resulting in the spread of antibiotic-resistant microorganisms (Taoka et al., 2006). Antibiotic use for a prolonged period may promote the establishment of antibiotic-resistant strains, lowering therapeutic efficacy. Natural compounds to manage diseases of aquatic animals are required to establish antibiotic-free and chemical-free aquaculture. Natural products have recently gained popularity as substitutes for antibiotics in treating bacterial infections in aquaculture (Rattanachaikunsopon and Phumkhachorn, 2010).

The use of probiotics (used in feed to have a helpful result on the host) in the aquaculture sector has been credited with efficient disease control and increased production (Hassan et al., 2024). A probiotic live microorganism is usually used to improve food digestibility, immune response, and stress tolerance (Kuebutornye et al., 2020). Many of these approaches are new; further work is required to evaluate their effects on foodstuffs and the environment (Galaviz-Silva et al., 2009). Bacteria identification in food is the key to control contamination (Elhadi et al., 2016).

*5.2. Non-thermal technologies*

Fish contamination may originate in three ways: from natural water microorganisms, present in nature, spread by environmental pollution, improper food handling, and post-process introduction (Branciari et al., 2020; Ghafar et al., 2024). It is, therefore, complicated to prevent the presence of these bacteria in fish; thus, the food industry is looking at techniques, other than heat processing, capable of reducing and minimizing the growth of pathogenic and spoilage pathogens without changing the attributes of the fresh fish and perhaps combined with cold temperature storage and packaging. Interest has been shown in novel fish decontamination methods that inhibit undesirable microorganisms and extend shelf life without affecting quality traits such as color, taste, and nutritional value (Zhang et al., 2019).

The main non-thermal inactivation techniques studied in fisheries are high hydrostatic pressure processing (HPP), irradiation, ultraviolet (UV), cold plasma (CP), pulsed-light technology (PLT), and ozone treatments. Nonetheless, other methods, such as pulsed electric fields and ultrasound, are reported in food but less developed in the fish industry (Gómez et al., 2019). Most are still in their early stages of development. Nevertheless, when the industry decides what type of non-thermal processing method could be implemented, strict scientific parameters must be considered, such as the type and level of pathogens and the type of fish. Reviews were recently published on the different aspects of non-thermal technologies, describing the procedures, the mechanisms, the potential application, the efficacy in terms of food decontamination and preservation, and the effects on the physicochemical, rheological, and sensory properties of food (Gómez et al., 2019; López et al., 2019; Mahendran et al., 2019; Morales-de la Peña et al., 2019; Perinban et al., 2019; Rowan, 2019). Using non-thermal technologies represents a possible alternative or complementary strategy to the traditional processes. The main goals of non-thermal methods are the direct inactivation of microorganisms and the preservation of nutritional quality without causing enzymatic alteration or oxidation. Different modes of action against microorganisms are proposed for the different selected technologies (Zhang et al., 2018).

*5.2.1. Irradiation*

It is the most widely studied decontamination method in fish species and is utilized in fresh, frozen, canned, dried, and cured fish and ready-to-eat fish (Arvanitoyannis et al., 2008). This method helps preserve fish in three ways: reduction in pathogen load, extension of shelf life, and inactivation of parasites. Bacteria seem more sensitive than viruses but less than parasites to ionizing radiation . Inactivation of microorganisms may be induced by direct or indirect damage. Disruption to cell structures could occur as a result of this contact, with the fragmentation of one or both DNA strands, which isn't always repaired by the cell (Andoni et al., 2021), and indirectly by the formation of reactive molecules (i.e., hydroxyl radicals) from the water found inside foods and bacteria. These chemicals can react with surrounding substances, amplifying the fatal impact on cells (Ravindran and Jaiswal, 2019).

*5.2.2. High-pressure processing*

In the fish industry, HPP is designed for microbial load reduction and shelf life extension in different fish and seafood, both fresh and processed (Humaid et al., 2020). The inactivation of microorganisms by HPP is affected by the microorganism species and physiological status, the parameters adopted during treatment (i.e., pressure and time), and environmental conditions, such as food composition and chemical-physical traits (i.e., pH and temperature) (Huang et al., 2014). The mechanisms of bacterial inactivation are a combination of factors, such as damage to cell membrane structure and modification of cellular functions linked with protein or enzyme activities (Campus et al., 2010).

*5.2.3. Ultra violet light*

UV light is used in the fish industry to diminish the microbial load and increase the shelf life of fish, reduce the microbiological load in fish meal, disinfect working surfaces, and sterilize the water in aquaculture and wastewater facilities (Skowron et al., 2018). The main mechanism of action is direct bacterial DNA injuries or water radiolysis with free radical production (Byelashov and Sofos, 2009). DNA and RNA denaturation are due to the direct absorption of UV, resulting in the formation of a pyrimidine dimer that can inactivate the bacteria by blocking DNA replication (Liltved et al., 2006). Cold plasma can be used in the fish business to cleanse pathogens, improve shelf life, create plasma active water (PAW, which has an antibacterial impact), and treat effluent (Thirumdas et al., 2018). Reactive oxygen species (ROS) usually attack bacterial cell lipid membranes, making them prone to strong oxidizing agents. The ROS from CP could damage cell membranes and interact with DNA, enzymes, and proteins (Critzer et al., 2007).

*5.2.4. Ozone*

The application of ozone in the fish industry includes antimicrobial intervention, an extension of shelf life, improvement of sensory qualities, improvement of water quality, refrigeration systems, production of ozonized ice, surface and equipment sanitation, detoxification of harmful marine algae, reducing foam and slime in the fish tanks, and control of odor in offal rooms. The advantages of applying ozone as a decontaminant are based on its rapid decomposition of the treated foods into oxygen, leaving no residues (Gonçalves, 2009). Smoking of fish products has been noted to be widely practiced, and a satisfactory approach to preservation where advanced equipment for improved techniques is insufficient. Fish smoking is the process of reducing the activity of the water through the use of low heat. The floor of the fish skin, which is susceptible to microorganism growth, is dried, while the heat and chemicals in the smoke prevent microorganism growth (Oluwagunke et al., 2019).

*5.2.5. Essential oils*

(EO) are aromatic liquid extracts collected from whole or particular parts of plants (seeds, flowers, branches, barks, leaves, fruits, and roots) that are used to enhance the shelf life and enhance the protection of meat and fish. EO comprises various active substances with various biological roles, including antibacterial activity (Kaale et al., 2011).

*5.3. Preservation strategies*

Food preservation without preservatives has become popular among customers, bringing new issues, particularly perishable goods such as meat or fish. Fish quality retention is a complicated process. Various cooling methods and materials are employed during their storage and transit. These characteristics determine the freshness of a post-harvest fish (Banwari et al., 2022). Freezing temperatures are crucial during fish harvest, storage, and transportation worldwide. Chilling, super chilling, and freezing techniques (Figure 2) allow fish to be preserved for extended periods without deterioration in quality, ensuring economic benefits for fish industries (Kaale et al., 2011; Hussain et al., 2021). As a result, chilling, along with freezing and, more recently, super chilling, is one of the most commonly applied procedures for fish preservation. Chilling is the process of lowering the temperature of fish to that of melting ice by using, for example, ice. Chilling increases shelf life by decreasing physical and chemical reactions as well as the activity of degrading microbes and enzymes. Cooling down (frozen storage) can keep fish safe for longer than any other low-temperature preservation method, but some quality attributes may be impacted (Kaale et al., 2011).

Traditional packaging methods have been utilized to preserve nutrient value, increase shelf life, decrease spoilage, and facilitate product handling. In addition to food preservation, new efforts have been made to establish clever

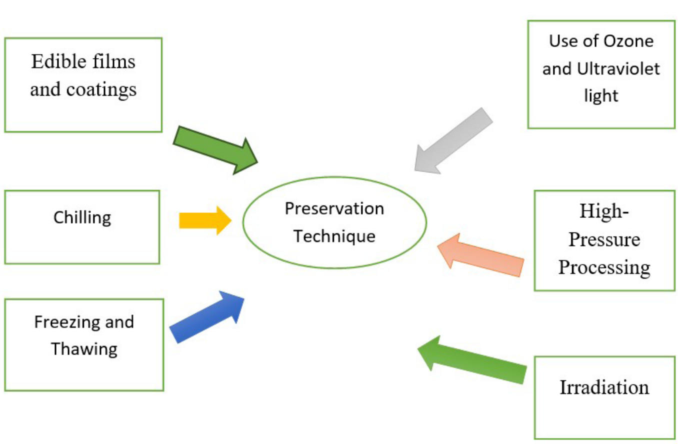


**Figure 2.** Recently used techniques of preservation.

and active packaging solutions that can deliver additional services such as monitoring and interaction to notify consumers when deterioration starts. Sensing systems can be integrated into smart packaging to offer data on food quality along the food chain, such as contents, processing methods, and growth of bacteria (Mustafa and Andreescu, 2018).

Other innovative food preservation techniques include edible films and coatings, which are revealed to help keep the sensory attributes and nutritional properties of food while enhancing its stability and extending shelf-life by decreasing bacterial activity during the production process (Kaale et al., 2011; Valdés et al., 2017). Edible films are described as a light coating of edible material generated distinctly and spread on the top of the food in the first phase (as wraps or separation layers, respectively). These films and sealants are bio-based ingredients, and they are referred to as bioplastics because of their eco-friendly sources, such as food industry residues and devalued materials of proteins (such as corn zein, gelatine, and casein) (Tavares et al., 2021). High-pressure handling is an encouraging "non-thermal" food preservation method that effectively inhibits the vegetative bacteria most frequently associated with foodborne diseases. Elevated processing uses excessive strain to preserve food with limited impact on taste and nutritional characteristics (Yordanov and Angelova, 2010). Due to its emphasis on energy conservation and shelf-life extension, a unique preservation approach developed on mediated compression storage has recently piqued the curiosity of researchers (Nakazawa and Okazaki, 2020).

## 6. Conclusion and Recommendations

The post-harvest spoilage of fish, as well as advanced technologies for determining fish freshness and control, were addressed in this review. The findings obtained from this study pertain to our knowledge of the spoilage-causing bacteria that may pose threats to fish. This review provides critical data for assessing and managing the risk associated with the presence of spoilage-causing bacteria in fish. Fish and their retail products should be processed and displayed to customers to minimize possible risks and deficiencies in food safety while preserving critical quality. Advanced physical non-thermal methods and natural preservatives (e.g., plant extracts and essential oils) during post-harvest treatment are gaining interest in reducing pathogenic and spoilage bacteria in fish. Implementing effective cold chains, as well as safe fish handling by customers, can help to ensure the safety of fish throughout the supply chain.

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## References

ABABOUCH, L., GANDINI, G. and RYDER, J., 2005. *Causes of detentions and rejections in international fish trade*. Rome: Food and Agriculture Organization of the United Nations, vol. 473.

ABD EL-HAY, M.M., 2022. Processing and preparation of fish. In: S.M. JAFARI, ed. *Post-harvest and postmortem processing of raw food materials: unit operations and processing equipment in the food industry*. Duxford: Woodhead Publishing, pp. 315-342. http://doi.org/10.1016/B978-0-12-818572-8.00008-5.

ABD-EL-HADY, H.A., ALI, G.I. and YASSIN, S.A., 2017. Assessment of the bacterial quality and toxic heavy metal residues of frozen fish fillet in Kaferelsheikh markets. *Alexandria Journal of Veterinary Sciences*, vol. 54, no. 1, pp. 108-116.

ABDEL-LATIF, H.M. and SEDEEK, E.K., 2017. Diversity of Enterobacteriaceae retrieved from diseased cultured *Oreochromis niloticus*. *International Journal of Fisheries and Aquatic Studies*, vol. 5, no. 1, pp. 29-34.

ADEBAYO-TAYO, B.C., ODU, N.N., IGIWILOH, N.J.P.N. and OKONKO, I.O., 2012. Microbiological and physicochemical level of fresh catfish (*Arius hendelotic*) from different markets in Akwa Ibom State, Nigeria. *New York Science Journal*, vol. 5, no. 4, pp. 46-52.

ADELAJA, O.A., KAMARUDDIN, R.B. and CHIAT, L.W., 2018. Assessment of post-harvest fish losses croaker *Pseudotolithus elongatus*, (Bowdich, 1825), catfish *Arius heudeloti*, (Valenciennes, 1840) and shrimp *Nematopalaemon hastatus* (Aurivillius, 1898) in Ondo State, Nigeria. *Aquaculture and Fisheries*, vol. 3, no. 5, pp. 209-216. http://doi.org/10.1016/j.aaf.2018.05.002.

AFOLAYAN, O.A., MORUF, R.O. and LAWAL-ARE, A.O., 2020. Bacterial contamination and heavy metal residues in frozen shellfish retailed within Lagos Metropolis, Nigeria. *Science World Journal*, vol. 15, no. 1, pp. 11-14.

ALASALVAR, C., MIYASHITA, K., SHAHIDI, F. and WANASUNDARA, U. 2011. *Handbook of seafood quality, safety and health applications*. Chichester: John Wiley & Sons.

ANDONI, E., OZUNI, E., BIJO, B., SHEHU, F., BRANCIARI, R., MIRAGLIA, D. and RANUCCI, D., 2021. Efficacy of non-thermal processing methods to prevent fish spoilage. *Journal of Aquatic Food Product Technology*, vol. 30, no. 2, pp. 228-245. http://doi.org/10.1080/10498850.2020.1866131.

ARO, T., TAHVONEN, R., KOSKINEN, L. and KALLIO, H., 2003. Volatile compounds of Baltic herring analysed by dynamic headspace sampling–gas chromatography–mass spectrometry. *European Food Research and Technology*, vol. 216, no. 6, pp. 483-488. http://doi.org/10.1007/s00217-003-0678-3.

ARVANITOYANNIS, I.S., STRATAKOS, A. and MENTE, E., 2008. Impact of irradiation on fish and seafood shelf life: a comprehensive review of applications and irradiation detection. *Critical Reviews in Food Science and Nutrition*, vol. 49, no. 1, pp. 68-112. http://doi.org/10.1080/10408390701764278. PMid:18949599.

BANWARI, A., JOSHI, R.C., SENGAR, N. and DUTTA, M.K., 2022. Computer vision technique for freshness estimation from segmented eye of fish image. *Ecological Informatics*, vol. 69, 101602. http://doi.org/10.1016/j.ecoinf.2022.101602.

BARRETT, K.A., NAKAO, J.H., TAYLOR, E.V., EGGERS, C. and GOULD, L.H., 2017. Fish-associated foodborne disease outbreaks: United States, 1998–2015. *Foodborne Pathogens and Disease*, vol. 14, no. 9, pp. 537-543. http://doi.org/10.1089/fpd.2017.2286. PMid:28682115.

BERNARD, D. and SCOTT, V.N. 2007. Hazard analysis and critical control point system: use in controlling microbiological hazards. In: M.P. DOYLE and L.R. BEUCHAT, eds. *Food microbiology: fundamentals and frontiers*. 3rd ed. Washington: ASM Press, pp. 971-985.

BERNARDO, Y.A., ROSARIO, D.K., DELGADO, I.F. and CONTE-JUNIOR, C.A., 2020. Fish Quality Index Method: principles, weaknesses, validation, and alternatives—a review. *Comprehensive Reviews in Food Science and Food Safety*, vol. 19, no. 5, pp. 2657-2676. http://doi.org/10.1111/1541-4337.12600. PMid:33336975.

BIBI, F., QAISRANI, S.N., AHMAD, A.N., AKHTAR, M., KHAN, B.N. and ALI, Z., 2015. Occurrence of Salmonella in freshwater fishes: a review. *Journal of Animal and Plant Sciences*, vol. 25, no. 3, pp. 303-310.

BILAL, M., ALI, H., HASSAN, H.U., KHAN, S.U., GHAFFAR, R., AKRAM, W., AHMAD, H., MUSHTAQ, S., JAFARI, H., YAQOOB, H., KHAN, M.M., ULLAH, R. and ARAI, T., 2024. Cadmium (Cd) influences calcium (Ca) levels in the skeleton of a freshwater fish *Channa gachua*. *Brazilian Journal of Biology = Revista Brasileira de Biologia*, vol. 84, e264336. http://doi.org/10.1590/1519-6984.264336. PMid:36169408.

BILAL, M., QADIR, A., YAQUB, A., HASSAN, H.U., IRFAN, M. and ASLAM, M., 2023. Microplastics in water, sediments, and fish at Alpine River, originating from the Hindu Kush Mountain, Pakistan: implications for conservation. *Environmental Science and Pollution Research International*, vol. 30, no. 1, pp. 727-738. http://doi.org/10.1007/s11356-022-22212-8. PMid:35906523.

BILAL, M., UL HASSAN, H., SIDDIQUE, M.A.M., KHAN, W., GABOL, K., ULLAH, I., SULTANA, S., ABDALI, U., MAHBOOB, S., KHAN, M.S., ATIQUE, U., KHUBAIB, M. and ARAI, T., 2022. Microplastics in the surface water and gastrointestinal tract of salmo trutta from the Mahodand Lake, Kalam Swat in Pakistan. *Toxics*, vol. 11, no. 1, 3. http://doi.org/10.3390/toxics11010003. PMid:36668729.

BOZIARIS, I.S. and PARLAPANI, F.F., 2017. Specific spoilage organisms (SSOs) in fish. In: A. BEVILACQUA, M.R. CORBO and M. SINIGAGLIA, eds. *The microbiological quality of food*. Duxford: Woodhead Publishing, pp. 61-98. http://doi.org/10.1016/B978-0-08-100502-6.00006-6.

BRANCIARI, R., FRANCESCHINI, R., ROILA, R., VALIANI, A., PECORELLI, I., PIERSANTI, A., HAOUET, N., FRAMBOAS, M. and RANUCCI, D., 2020. Nutritional value and contaminant risk assessment of some commercially important fishes and crawfish of Lake Trasimeno, Italy. *International Journal of Environmental Research and Public Health*, vol. 17, no. 7, 2545. http://doi.org/10.3390/ijerph17072545. PMid:32276363.

BYELASHOV, O.A. and SOFOS, J.N. 2009. Strategies for on-line decontamination of carcasses. In: F. TOLDRÁ, ed. *Safety of meat and processed meat*. New York: Springer, pp. 149-182. http://doi.org/10.1007/978-0-387-89026-5_6.

CAMPUS, M., ADDIS, M.F., CAPPUCCINELLI, R., PORCU, M.C., PRETTI, L., TEDDE, V., SECCHI, N., STARA, G. and ROGGIO, T., 2010. Stress relaxation behaviour and structural changes of muscle tissues from Gilthead Sea Bream (*Sparus aurata* L.) following high pressure treatment. *Journal of Food Engineering*, vol. 96, no. 2, pp. 192-198. http://doi.org/10.1016/j.jfoodeng.2009.07.013.

CARRASCO, E., MORALES-RUEDA, A. and GARCÍA-GIMENO, R.M., 2012. Cross-contamination and recontamination by Salmonella in foods: a review. *Food Research International*, vol. 45, no. 2, pp. 545-556. http://doi.org/10.1016/j.foodres.2011.11.004.

CHARM, S.E., LEARSON, R.J., RONSIVALLI, L.J. and SCHWARTZ, M., 1972. Organoleptic technique predicts refrigeration shelf life of fish. *Food Technology*, vol. 26, pp. 65-68.

CHATTA, A.M., KHAN, M.N., MIRZA, Z.S., ALI, A. and YAQUB, S.S., 2018. Microbial quality of farmed fish in markets of Lahore, Pakistan: a health concern. *Pakistan Journal of Agricultural Sciences*, vol. 55, no. 4, pp. 921-927.

CHEN, H., DONG, S., YAN, Y., ZHAN, L., ZHANG, J., CHEN, J., ZHANG, Z., ZHANG, Y. and MEI, L., 2021. Prevalence and population analysis of Vibrio parahaemolyticus isolated from freshwater fish in Zhejiang province, China. *Foodborne Pathogens and Disease*, vol. 18, no. 2, pp. 139-146. http://doi.org/10.1089/fpd.2020.2798. PMid:33493422.

CORSIN, F., GIORGETTI, G. and MOHAN, C.V., 2007. Contribution of science to farm-level aquatic animal health management. *Developments in Biologicals*, vol. 129, pp. 35-40. PMid:18306517.

CRITZER, F.J., KELLY-WINTENBERG, K., SOUTH, S.L. and GOLDEN, D.A., 2007. Atmospheric plasma inactivation of foodborne pathogens on fresh produce surfaces. *Journal of Food Protection*, vol. 70, no. 10, pp. 2290-2296. http://doi.org/10.4315/0362-028X-70.10.2290. PMid:17969610.

DABADÉ, D.S., AZOKPOTA, P., NOUT, M.R., HOUNHOUIGAN, D.J., ZWIETERING, M.H. and DEN BESTEN, H.M., 2015. Prediction of spoilage of tropical shrimp (*Penaeus notialis*) under dynamic temperature regimes. *International Journal of Food Microbiology*, vol. 210, pp. 121-130. http://doi.org/10.1016/j.ijfoodmicro.2015.06.010. PMid:26119189.

DARSANA, P., MARY, R. and BERNATH, N.A., 2021. A study on nutritional quality and identification of biogenic amine forming bacteria in marine edible species Sardinella longiceps and Loligo duvauceli from Tuticorin, Southeast coast of India. *International Journal of Fisheries and Aquatic Studies*, vol. 9, no. 2, pp. 277-279. http://doi.org/10.22271/fish.2021.v9.i2d.2464.

DEPAOLA, A., JONES, J.L., WOODS, J., BURKHARDT III, W., CALCI, K.R., KRANTZ, J.A., BOWERS, J.C., KASTURI, K., BYARS, R.H., JACOBS, E., WILLIAMS-HILL, D. and NABE, K., 2010. Bacterial and viral pathogens in live oysters: 2007 United States market survey. *Applied and Environmental Microbiology*, vol. 76, no. 9, pp. 2754-2768. http://doi.org/10.1128/AEM.02590-09. PMid:20190085.

DIMITRIJEVIĆ, M., GRKOVIĆ, N., BOŠKOVIĆ, M., BALTIĆ, M.Ž., DOJČINOVIĆ, S., KARABASIL, N., VASILEV, D. and TEODOROVIĆ, V., 2019. Inhibition of Listeria monocytogenes growth on vacuum packaged rainbow trout (*Oncorhynchus mykiss*) with carvacrol and eugenol. *Journal of Food Safety*, vol. 39, no. 1, e12553. http://doi.org/10.1111/jfs.12553.

EFFIONG, M.U. and CHRISTOPHER, E.U., 2020. Public health implication of microbial loads in smoked Mackerel, Scomber scombrus from major fish markets in Uyo, Akwa Ibom State, Nigeria. *South Asian Research Journal of Agriculture and Fisheries*, vol. 2, no. 4, pp. 126-131.

EIZENBERGA, I., TERENTJEVA, M., VALCIŅA, O., NOVOSLAVSKIJ, A., STRAZDIŅA, V., OŠMJANA, J. and BĒRZIŅŠ, A., 2015. Microbiological quality of raw fish at retail market in Latvia. *Food Quality and Safety*, vol. 6, pp. 16-18.

EKLUND, M.W., POYSKY, F.T., PARANJPYE, R.N., LASHBROOK, L.C., PETERSON, M.E. and PELROY, G.A., 1995. Incidence and sources of Listeria monocytogenes in cold-smoked fishery products and processing plants. *Journal of Food Protection*, vol. 58, no. 5, pp. 502-508. http://doi.org/10.4315/0362-028X-58.5.502. PMid:31137266.

ELHADI, N., ALJELDAH, M. and ALJINDAN, R., 2016. Microbiological contamination of imported frozen fish marketed in Eastern Province of Saudi Arabia. *International Food Research Journal*, vol. 23, no. 6, 2723.

EMIKPE, B.O., ADEBISI, T. and ADEDEJI, O.B., 2011. Bacteria load on the skin and stomach of *Clarias gariepinus* and *Oreochromis niloticus* from Ibadan, South West Nigeria: public health implications. *Journal of Microbiology and Biotechnology Research*, vol. 1, no. 1, pp. 52-59.

EMMANUEL, B.E., AKINNIYI, O.J. and UDEMEZUE, C.E., 2020. Microbiological analysis and organoleptic assessment of smoked *Sarotherodon melanotheron* from Retail Market in Lagos, Nigeria. *West African Journal of Fisheries and Aquatic Sciences*, vol. 1, no. 1, pp. 1-9.

ESPOSTO, E.M., SILVA, W.C.P., REIS, C.M.F., REIS, E.M.F., RIBEIRO, R.V., RODRIGUES, D.P. and LÁZARO, N.S., 2007. Bacterial enteropathogens from fishes of a nutrient recycle system and its ecosystem. *Pesquisa Veterinária Brasileira*, vol. 27, no. 4, pp. 144-148. http://doi.org/10.1590/S0100-736X2007000400003.

EZE, E.I., ECHEZONA, B.C. and UZODINMA, E.C., 2011. Isolation and identification of pathogenic bacteria associated with frozen mackerel fish (*Scomber scombrus*) in a humid tropical environment. *African Journal of Agricultural Research*, vol. 6, no. 7, pp. 1918-1922.

FERNANDES, D.V.G.S., CASTRO, V.S., CUNHA NETO, A.D. and FIGUEIREDO, E.E.S., 2018. Salmonella spp. in the fish production chain: a review. *Ciência Rural*, vol. 48, no. 8, e20180141. http://doi.org/10.1590/0103-8478cr20180141.

FOGARTY, C., WHYTE, P., BRUNTON, N., LYNG, J., SMYTH, C., FAGAN, J. and BOLTON, D., 2019. Spoilage indicator bacteria in farmed Atlantic salmon (Salmo salar) stored on ice for 10 days. *Food Microbiology*, vol. 77, pp. 38-42. http://doi.org/10.1016/j.fm.2018.08.001. PMid:30297054.

FRANCESCHELLI, L., BERARDINELLI, A., DABBOU, S., RAGNI, L. and TARTAGNI, M., 2021. Sensing technology for fish freshness and safety: a review. *Sensors*, vol. 21, no. 4, 1373. http://doi.org/10.3390/s21041373. PMid:33669188.

FRANZETTI, L. and SCARPELLINI, M., 2007. Characterisation of Pseudomonas spp. isolated from foods. *Annals of Microbiology*, vol. 57, pp. 39-47.

GALAVIZ-SILVA, L. and GOMÉZ-ANDURO, G., MOLINA-GARZA, Z.J. and ASCENCIO-VALLE, F., 2009. Food safety issues and the microbiology of fish and shellfish. In: N. HEREDIA, I. WESLEY and S. GARCÍA, eds. *Microbiologically safe foods*. Hoboken: John Wiley & Sons, pp. 227-254. http://doi.org/10.1002/9780470439074.ch11.

GHAFAR, R., SUMBUL, HASSAN, H.U., KAMIL, N., WATTOO, J., SULTANA, S., ABDALI, U., IMRANULLAH, SHAH, M.Z., SALEEM, M., SIDDIQUE, M.A.M., ZULFIQAR, T. and ARAI, T., 2024. Occurrence of new Philometra sp. in mangrove red snapper *Lutjanus argentimaculatus* from the Karachi coast, Pakistan. *Brazilian Journal of Biology = Revista Brasileira de Biologia*, vol. 84, e269504. http://doi.org/10.1590/1519-6984.269504.

GHALY, A.E., DAVE, D., BUDGE, S. and BROOKS, M.S., 2010. Fish spoilage mechanisms and preservation techniques. *American Journal of Applied Sciences*, vol. 7, no. 7, pp. 859.

GHANEM, N.A., SAMAHA, I.A. and NOSSAIR, M.A., 2019. Incidence of some pathogenic bacteria in smoked and salted fish products. *Alexandria Journal of Veterinary Sciences*, vol. 60, no. 2, pp. 104-109.

GIL, L., BARAT, J.M., ESCRICHE, I., GARCIA-BREIJO, E., MARTÍNEZ-MÁÑEZ, R. and SOTO, J., 2008. An electronic tongue for fish freshness analysis using a thick-film array of electrodes. *Microchimica Acta*, vol. 163, pp. 121-129.

GÓMEZ, B., MUNEKATA, P.E., GAVAHIAN, M., BARBA, F.J., MARTÍ-QUIJAL, F.J., BOLUMAR, T., CAMPAGNOL, P.C.B., TOMASEVIC, I. and LORENZO, J.M., 2019. Application of pulsed electric fields in meat and fish processing industries: an overview. *Food Research International*, vol. 123, pp. 95-105. http://doi.org/10.1016/j.foodres.2019.04.047. PMid:31285034.

GONÇALVES, A.A., 2009. Ozone: an emerging technology for the seafood industry. *Brazilian Archives of Biology and Technology*, vol. 52, pp. 1527-1539.

GOVARI, M., TRYFINOPOULOU, P., PARLAPANI, F.F., BOZIARIS, I.S., PANAGOU, E.Z. and NYCHAS, G.J.E., 2021. Quest of intelligent research tools for rapid evaluation of fish quality: FTIR spectroscopy and multispectral imaging versus microbiological analysis. *Foods*, vol. 10, no. 2, 264. PMid:33525540.

GRAM, L. and DALGAARD, P., 2002. Fish spoilage bacteria–problems and solutions. *Current Opinion in Biotechnology*, vol. 13, no. 3, pp. 262-266. PMid:12180103.

GRIGORAKIS, K., ALEXIS, M., GIALAMAS, I. and NIKOLOPOULOU, D., 2004. Sensory, microbiological, and chemical spoilage of cultured common sea bass (*Dicentrarchus labrax*) stored in ice: a seasonal differentiation. *European Food Research and Technology*, vol. 219, no. 6, pp. 584-587. http://doi.org/10.1007/s00217-004-1005-3.

GUFE, C., CANAAN ODOBO, T., MBONJANI, B., MAJONGA, O., MARUMURE, J., MUSARI, S., JONGI, G., MAKAYA, P.V. and MACHAKWA, J., 2019. Antimicrobial profiling of bacteria isolated from fish sold at informal market in Mufakose, Zimbabwe. *International Journal of Microbiology*, vol. 2019, 8759636. http://doi.org/10.1155/2019/8759636. PMid:31191658.

HAMIDIYAN, N., SALEHI-ABARGOUEI, A., REZAEI, Z., DEHGHANI-TAFTI, R. and AKRAMI-MOHAJERI, F., 2018. The prevalence of Listeria spp. food contamination in Iran: a systematic review and meta-analysis. *Food Research International*, vol. 107, pp. 437-450. http://doi.org/10.1016/j.foodres.2018.02.038. PMid:29580505.

HASSAN, H.U., ALI, Q.M., KHAN, W., MASOOD, Z., ABDEL-AZIZ, M.F.A., SHAH, M.I.A., GABOL, K., WATTOO, J., CHATTA, A.M., KAMAL, M., ZULFIQAR, T. and HOSSAIN, M.Y., 2021. Effect of feeding frequency as a rearing system on biological performance, survival, body chemical composition and economic efficiency of Asian Seabass *Lates calcarifer* (Bloch, 1790) reared under controlled environmental conditions. *Saudi Journal of Biological Sciences*, vol. 28, no. 12, pp. 7360-7366. http://doi.org/10.1016/j.sjbs.2021.08.031. PMid:34867038.

HASSAN, H.U., ALI, Q.M., SIDDIQUE, M.A.M., HASAN, M.R. and HOSSAIN, M.Y., 2022. Effects of dietary protein levels on growth, nutritional utilization, carcass composition and survival of Asian seabass *Lates calcarifer* (Bloch, 1790) fingerlings rearing in net cages. *Thalassas*, vol. 38, no. 1, pp. 21-27. http://doi.org/10.1007/s41208-021-00371-8.

HASSAN, H.U., MAWA, Z., AHMAD, N., ZULFIQAR, T., SOHAIL, M., AHMAD, H., YAQOOB, H., BILAL, M., RAHMAN, M.A., ULLAH, N., HOSSAIN, M.Y., HABIB, T. and ARAI, T., 2024. Size at sexual maturity estimation for 36 species captured by bottom and mid-water trawls from the marine habitat of Balochistan and Sindh in the Arabian Sea, Pakistan, using maximum length (Lmax) and logistic (L50) models. *Brazilian Journal of Biology = Revista Brasileira de Biologia*, vol. 84, e262603. http://doi.org/10.1590/1519-6984.262603. PMid:35857953.

HASSAN, M. and HUSSAM, S., 2020. Determination of histamine level in frozen fish in relation to bacterial contamination. *Benha Veterinary Medical Journal*, vol. 39, no. 2, pp. 105-110. http://doi.org/10.21608/bvmj.2020.51838.1307.

HASSOUN, A. and KAROUI, R., 2017. Quality evaluation of fish and other seafood by traditional and nondestructive instrumental methods: advantages and limitations. *Critical Reviews in Food Science and Nutrition*, vol. 57, no. 9, pp. 1976-1998. PMid:26192079.

HEIR, E., LILAND, K.H., CARLEHÖG, M. and HOLCK, A.L., 2019. Reduction and inhibition of Listeria monocytogenes in cold-smoked salmon by Verdad N6, a buffered vinegar fermentate, and UV-C treatments. *International Journal of Food Microbiology*, vol. 291, pp. 48-58. http://doi.org/10.1016/j.ijfoodmicro.2018.10.026. PMid:30445285.

HUANG, H.W., LUNG, H.M., YANG, B.B. and WANG, C.Y., 2014. Responses of microorganisms to high hydrostatic pressure processing. *Food Control*, vol. 40, pp. 250-259. http://doi.org/10.1016/j.foodcont.2013.12.007.

HUMAID, S., NAYYAR, D., BOLTON, J., PERKINS, B. and SKONBERG, D.I., 2020. Refrigerated shelf-life evaluation of high pressure processed, raw and sous vide cooked lobster. *High Pressure Research*, vol. 40, no. 3, pp. 444-463. http://doi.org/10.1080/08957959.2020.1774753.

HUSSAIN, M., HASSAN, H.U., SIDDIQUE, M.A.M., MAHMOOD, K., ABDEL-AZIZ, M.F.A., LAGHARI, M.Y., ABRO, N.A., GABOL, K., NISAR., RIZWAN, S. and HALIMA., 2021. Effect of varying dietary protein levels on growth performance and survival of milkfish *Chanos chanos* fingerlings reared in brackish water pond ecosystem. *Egyptian Journal of Aquatic Research*, vol. 47, no. 3, pp. 329-334. http://doi.org/10.1016/j.ejar.2021.05.001.

HYLDIG, G. and GREEN-PETERSEN, D.M., 2005. Quality Index Method: an objective tool for determination of sensory quality. *Journal of Aquatic Food Product Technology*, vol. 13, no. 4, pp. 71-80. http://doi.org/10.1300/J030v13n04_06.

IKPESU, T.O. and ARIYO, A.B., 2021. Seasonal variations in microbial loads and heavy metals concentrations in fish from Yenagoa Metropolis, Nigeria. *Journal of Applied Health Sciences and Medicine*, vol. 1, no. 1, pp. 13-29.

ILHAK, O.I. and GURAN, H.S., 2014. Combined antimicrobial effect of thymol and sodium lactate against Listeria monocytogenes and Salmonella Typhimurium in fish patty. *Journal of Food Safety*, vol. 34, no. 3, pp. 211-217. http://doi.org/10.1111/jfs.12115.

ILLIKOUD, N., ROSSERO, A., CHAUVET, R., COURCOUX, P., PILET, M.-F., CHARRIER, T., JAFFRÈS, E. and ZAGOREC, M., 2019. Genotypic and phenotypic characterization of the food spoilage bacterium *Brochothrix thermosphacta*. *Food Microbiology*, vol. 81, pp. 22-31. http://doi.org/10.1016/j.fm.2018.01.015. PMid:30910085.

ISLAM, S.I., MAHFUJ, S., BAQAR, Z., ASADUJJAMAN, M., ISLAM, M.J., ALSIWIEHRI, N., ALMEHMADI, M., SANJIDA, S. and AHAMMAD, F., 2024. Bacterial diseases of Asian sea bass (Lates calcarifer): A review for health management strategies and future aquaculture sustainability. *Heliyon*, vol. 10, no. 9, pp. e29793. http://doi.org/10.1016/j.heliyon.2024.e29793 PMid:38707314.

ITOH, D., KOYACHI, E., YOKOKAWA, M., MURATA, Y., MURATA, M. and SUZUKI, H., 2013. Microdevice for on-site fish freshness checking based on K-value measurement. *Analytical Chemistry*, vol. 85, no. 22, pp. 10962-10968. http://doi.org/10.1021/ac402483w. PMid:24206370.

JAN, A., HASAN, Z., SHAH, H., ULLAH, R., AHMAD, I. and YOUNAS, M., 2014. An investigation of the bacterial flora causing spoilage of fishes at board fish market, Peshawar, Pakistan. *Pakistan Journal of Zoology*, vol. 46, no. 5, pp. 1371-1375.

JIANADASA, B.K.K.K., GINIGADDARAGE, P.H. and ARIYAWANSA, S., 2014. A comparative quality assessment of five types of selected fishes collected from retail market in Sri Lanka. *American Journal of Food Science and Technology*, vol. 2, no. 1, pp. 21-27.

KAALE, L.D., EIKEVIK, T.M., RUSTAD, T. and KOLSAKER, K., 2011. Superchilling of food: a review. *Journal of Food Engineering*, vol. 107, no. 2, pp. 141-146. http://doi.org/10.1016/j.jfoodeng.2011.06.004.

KARTHIGA RANI, M., CHELLADURAI, G. and JAYANTHI, G., 2016. Isolation and identification of bacteria from marine market fish *Scomberomorus guttatus* (Bloch and Schneider, 1801) from Madurai district, Tamil Nadu, India. *Journal of Parasitic Diseases*, vol. 40, no. 3, pp. 1062-1065. http://doi.org/10.1007/s12639-014-0634-0. PMid:27605837.

KERRY, J.P., O'GRADY, M.N. and HOGAN, S.A., 2006. Past, current and potential utilisation of active and intelligent packaging systems for meat and muscle-based products: a review. *Meat Science*, vol. 74, no. 1, pp. 113-130. http://doi.org/10.1016/j.meatsci.2006.04.024. PMid:22062721.

KHALID, S., KHAN, W., DAS, S.N., AHMAD, A., MEHMOOD, S.A., PAHANWAR, W.A., AHMED, S., KAMAL, M., WAQAS, M., WAQAS, R.M., HASSAN, H.U., ZAHOOR, S. and MAQBOOL, A., 2021. Evaluation of ecto and endo parasitic fauna of *Schizothorax plagiostomus* inhabitants of river Swat, Khyber PakhtunKhwa, Pakistan. *Brazilian Journal of Biology = Revista Brasileira de Biologia*, vol. 81, no. 1, pp. 98-104. http://doi.org/10.1590/1519-6984.222215. PMid:32578670.

KÖSE, S., 2010. Evaluation of seafood safety health hazards for traditional fish products: preventive measures and monitoring issues. *Turkish Journal of Fisheries and Aquatic Sciences*, vol. 10, no. 1, pp. 139-160. http://doi.org/10.4194/trjfas.2010.0120.

KUEBUTORNYE, F.K., ABARIKE, E.D., SAKYI, M.E., LU, Y. and WANG, Z., 2020. Modulation of nutrient utilization, growth, and immunity of Nile tilapia, Oreochromis niloticus: the role of probiotics. *Aquaculture International*, vol. 28, no. 1, pp. 277-291. http://doi.org/10.1007/s10499-019-00463-6.

KUMAR, R., DATTA, T.K. and LALITHA, K.V., 2015. Salmonella grows vigorously on seafood and expresses its virulence and stress genes at different temperature exposure. *BMC Microbiology*, vol. 15, no. 1, 254. http://doi.org/10.1186/s12866-015-0579-1. PMid:26531707.

KÜMMERER, K., 2009. Antibiotics in the aquatic environment–a review–part I. *Chemosphere*, vol. 75, no. 4, pp. 417-434. http://doi.org/10.1016/j.chemosphere.2008.11.086. PMid:19185900.

KUSWANDI, B., JAYUS, RESTYANA, A., ABDULLAH, A., HENG, L.Y. and AHMAD, M., 2012. A novel colorimetric food package label for fish spoilage based on polyaniline film. *Food Control*, vol. 25, no. 1, pp. 184-189. http://doi.org/10.1016/j.foodcont.2011.10.008.

LAWAL, A.T. and ADELOJU, S.B., 2012. Progress and recent advances in fabrication and utilization of hypoxanthine biosensors for meat and fish quality assessment: a review. *Talanta*, vol. 100, pp. 217-228. http://doi.org/10.1016/j.talanta.2012.07.085. PMid:23141330.

LI, Y., PEI, X., YAN, J., LIU, D., ZHANG, H., YU, B., LI, N. and YANG, D., 2019. Prevalence of foodborne pathogens isolated from retail freshwater fish and shellfish in China. *Food Control*, vol. 99, pp. 131-136. http://doi.org/10.1016/j.foodcont.2018.12.024.

LILTVED, H., VOGELSANG, C., MODAHL, I. and DANNEVIG, B.H., 2006. High resistance of fish pathogenic viruses to UV irradiation and ozonated seawater. *Aquacultural Engineering*, vol. 34, no. 2, pp. 72-82. http://doi.org/10.1016/j.aquaeng.2005.05.002.

LIU, C., MOU, J. and SU, Y.C., 2016. Behavior of Salmonella and Listeria monocytogenes in raw yellowfin tuna during cold storage. *Foods*, vol. 5, no. 1, 16. http://doi.org/10.3390/foods5010016. PMid:28231111.

LÓPEZ, M., CALVO, T., PRIETO, M., MÚGICA-VIDAL, R., MURO-FRAGUAS, I., ALBA-ELÍAS, F. and ALVAREZ-ORDÓÑEZ, A., 2019. A review on non-thermal atmospheric plasma for food preservation: mode of action, determinants of effectiveness, and applications. *Frontiers in Microbiology*, vol. 10, 622. http://doi.org/10.3389/fmicb.2019.00622. PMid:31001215.

MACÉ, S., CORNET, J., CHEVALIER, F., CARDINAL, M., PILET, M.F., DOUSSET, X. and JOFFRAUD, J.J., 2012. Characterisation of the spoilage microbiota in raw salmon (*Salmo salar*) steaks stored under vacuum or modified atmosphere packaging combining conventional methods and PCR–TTGE. *Food Microbiology*, vol. 30, no. 1, pp. 164-172. http://doi.org/10.1016/j.fm.2011.10.013. PMid:22265297.

MAHENDRAN, R., RAMANAN, K.R., BARBA, F.J., LORENZO, J.M., LÓPEZ-FERNÁNDEZ, O., MUNEKATA, P.E.S., ROOHINEJAD, S., SANT'ANA, A.S. and TIWARI, B.K., 2019. Recent advances in the application of pulsed light processing for improving food safety and increasing shelf life. *Trends in Food Science & Technology*, vol. 88, pp. 67-79. http://doi.org/10.1016/j.tifs.2019.03.010.

MHANGO, M., MPUCHANE, S.F. and MPUCHANE, B.A., 2010. Incidence of indicator organisms, opportunistic and pathogenic bacteria in fish. *African Journal of Food, Agriculture, Nutrition and Development*, vol. 10, no. 10, pp. 4202-4218. http://doi.org/10.4314/ajfand.v10i10.62898.

MIAN, G.F., GODOY, D.T., LEAL, C.A.G., YUHARA, T.Y., COSTA, G.M. and FIGUEIREDO, H.C.P., 2009. Aspects of the natural history and virulence of S. agalactiae infection in Nile tilapia. *Veterinary Microbiology*, vol. 136, no. 1-2, pp. 180-183. http://doi.org/10.1016/j.vetmic.2008.10.016. PMid:19042097.

MOLINARI, L.M., SCOARIS, D.D.O., PEDROSO, R.B., BITTENCOURT, N.L.R., NAKAMURA, C.V., NAKAMURA, T.U. and DIAS FILHO, B.P., 2003. Bacterial microflora in the gastrointestinal tract of Nile tilapia, *Oreochromis niloticus*, cultured in a semi-intensive system. *Acta Scientiarum. Biological Sciences*, vol. 25, no. 2, pp. 267-271.

MORALES-DE LA PEÑA, M., WELTI-CHANES, J. and MARTÍN-BELLOSO, O., 2019. Novel technologies to improve food safety and quality. *Current Opinion in Food Science*, vol. 30, pp. 1-7. http://doi.org/10.1016/j.cofs.2018.10.009.

MOSTAFA, A.M., 2020. Chemical quality of some fresh water fish in Egyptian markets. *Benha Veterinary Medical Journal*, vol. 39, no. 1, pp. 141-145. http://doi.org/10.21608/bvmj.2020.39495.1250.

MUHAMMAD, K., KIMAN, S.H., MUHAMMAD, K., JESSE, I. and MOHAMMED, S., 2020. Isolation and identification of pathogenic bacteria from fresh fish organs. *International Research Journal of Advanced Science*, vol. 1, no. 2, pp. 42-46.

MUSTAFA, F. and ANDREESCU, S., 2018. Chemical and biological sensors for food-quality monitoring and smart packaging. *Foods*, vol. 7, no. 10, 168. http://doi.org/10.3390/foods7100168. PMid:30332833.

NAKAZAWA, N. and OKAZAKI, E., 2020. Recent research on factors influencing the quality of frozen seafood. *Fisheries Science*, vol. 86, no. 2, pp. 231-244. http://doi.org/10.1007/s12562-020-01402-8.

NEETHIRAJAN, S. and JAYAS, D.S., 2011. Nanotechnology for the food and bioprocessing industries. *Food and Bioprocess Technology*, vol. 4, no. 1, pp. 39-47. http://doi.org/10.1007/s11947-010-0328-2. PMid:32215165.

NILAVAN, E., VAIYAPURI, M., SADANANDAN SHEELA, G., NADELLA, R.K., THANDAPANI, M., KUMAR, A. and MOTHADAKA, M.P., 2021. Prevalence of Vibrio mimicus in fish, fishery products, and environment of South West Coast of Kerala, India. *Journal of AOAC International*, vol. 104, no. 3, pp. 790-794. http://doi.org/10.1093/jaoacint/qsab001. PMid:33484252.

NOORLIS, A., GHAZALI, F.M., CHEAH, Y.K., TUAN ZAINAZOR, T.C., PONNIAH, J., TUNUNG, R. and SON, R., 2011. Prevalence and quantification of Vibrio species and *Vibrio parahaemolyticus* in freshwater fish at hypermarket level. *International Food Research Journal*, vol. 18, no. 2, pp. 689-695.

OKONKO, I.O., OGUNJOBI, A.A., FAJOBI, E.A., ONOJA, B.A., BABALOLA, E.T. and ADEDEJI, A.O., 2008. Comparative studies and microbial risk assessment of different Ready-to-Eat (RTE) frozen sea-foods processed in Ijora-olopa, Lagos State, Nigeria. *African Journal of Biotechnology*, vol. 7, no. 16, pp. 2898-2901.

OLOFSSON, T.C., AHRNÉ, S. and MOLIN, G., 2007. The bacterial flora of vacuum-packed cold-smoked salmon stored at 7°C, identified by direct 16S rRNA gene analysis and pure culture technique. *Journal of Applied Microbiology*, vol. 103, no. 1, pp. 109-119. http://doi.org/10.1111/j.1365-2672.2006.03216.x. PMid:17584457.

OLUWAGUNKE, T.O., OLAJUYIGBE, O.O. and AMUSAN, E.E., 2019. Bacterial pathogens isolated from *Pseudotolithus senegalensis* and *Micromesistus poutasou* sold in some markets in Lagos state. *FUDMA Journal of Sciences*, vol. 3, no. 3, pp. 275-280.

ONYANGO, D.M., WANDILI, S., KAKAI, R. and WAINDI, E.N., 2009. Isolation of Salmonella and Shigella from fish harvested from the Winam Gulf of Lake Victoria, Kenya. *Journal of Infection in Developing Countries*, vol. 3, no. 2, pp. 99-104. http://doi.org/10.3855/jidc.56. PMid:19755738.

ÖZOGUL, Y., ÖZOGUL, F. and KULAWIK, P., 2021. The antimicrobial effect of grapefruit peel essential oil and its nanoemulsion on fish spoilage bacteria and foodborne pathogens. *LWT*, vol. 136, 110362. http://doi.org/10.1016/j.lwt.2020.110362.

PARLAPANI, F.F., HAROUTOUNIAN, S.A., NYCHAS, G.J.E. and BOZIARIS, I.S., 2015. Microbiological spoilage and volatiles production of gutted European sea bass stored under air and commercial modified atmosphere package at 2 °C. *Food Microbiology*, vol. 50, pp. 44-53. http://doi.org/10.1016/j.fm.2015.03.006. PMid:25998814.

PARLAPANI, F.F., MALLOUCHOS, A., HAROUTOUNIAN, S.A. and BOZIARIS, I.S., 2014. Microbiological spoilage and investigation of volatile profile during storage of sea bream fillets under various conditions. *International Journal of Food Microbiology*, vol. 189, pp. 153-163. http://doi.org/10.1016/j.ijfoodmicro.2014.08.006. PMid:25150673.

PERINBAN, S., ORSAT, V. and RAGHAVAN, V., 2019. Non-thermal plasma–liquid interactions in food processing: a review. *Comprehensive Reviews in Food Science and Food Safety*, vol. 18, no. 6, pp. 1985-2008. http://doi.org/10.1111/1541-4337.12503. PMid:33336960.

PRIDGEON, J.W. and KLESIUS, P.H., 2012. Major bacterial diseases in aquaculture and their vaccine development. *CABI Reviews*, vol. 7, pp. 1-16. http://doi.org/10.1079/PAVSNNR20127048.

PROVINCIAL, L., GUILLÉN, E., GIL, M., ALONSO, V., RONCALÉS, P. and BELTRÁN, J.A., 2013. Survival of Listeria monocytogenes and Salmonella Enteritidis in sea bream (*Sparus aurata*) fillets packaged under enriched CO2 modified atmospheres. *International Journal of Food Microbiology*, vol. 162, no. 3, pp. 213-219. http://doi.org/10.1016/j.ijfoodmicro.2013.01.015. PMid:23454810.

RAHIMI, E., SHAKERIAN, A. and RAISSY, M., 2012. Prevalence of Listeria species in fresh and frozen fish and shrimp in Iran. *Annals of Microbiology*, vol. 62, no. 1, pp. 37-40. http://doi.org/10.1007/s13213-011-0222-9.

RAISSY, M., RAHIMI, E., AZARGUN, R., MOUMENI, M., RASHEDI, M. and SOHRABI, H.R., 2015. Molecular detection of Vibrio spp. in fish and shrimp from the Persian Gulf. *Journal of Food Biosciences and Technology*, vol. 5, no. 2, pp. 49-52.

RATTANACHAIKUNSOPON, P. and PHUMKHACHORN, P., 2010. Potential of cinnamon (*Cinnamomum verum*) oil to control Streptococcus iniae infection in tilapia (*Oreochromis niloticus*). *Fisheries Science*, vol. 76, no. 2, pp. 287-293. http://doi.org/10.1007/s12562-010-0218-6.

RAUFU, I.A., LAWAN, F.A., BELLO, H.S., MUSA, A.S., AMEH, J.A. and AMBALI, A.G., 2014. Occurrence and antimicrobial susceptibility profiles of Salmonella serovars from fish in Maiduguri, sub-Saharah, Nigeria. *Egyptian Journal of Aquatic Research*, vol. 40, no. 1, pp. 59-63. http://doi.org/10.1016/j.ejar.2014.01.003.

RAVINDRAN, R. and JAISWAL, A.K., 2019. Wholesomeness and safety aspects of irradiated foods. *Food Chemistry*, vol. 285, pp. 363-368. http://doi.org/10.1016/j.foodchem.2019.02.002. PMid:30797358.

REZAI, R., AHMADI, E. and SALIMI, B., 2018. Prevalence and antimicrobial resistance profile of Listeria species isolated from farmed and on-sale rainbow trout (*Oncorhynchus mykiss*) in Western Iran. *Journal of Food Protection*, vol. 81, no. 6, pp. 886-891. http://doi.org/10.4315/0362-028X.JFP-17-428. PMid:29714625.

RHEA, F., 2009. *Microbiology handbook: fish and seafood*. Surrey: Leatherhead Food International Ltd.

ROCHA, R.S., LEITE, L.O., SOUSA, O.V. and VIEIRA, R.H.S.F., 2014. Antimicrobial susceptibility of Escherichia coli isolated from fresh-marketed Nile Tilapia (*Oreochromis niloticus*). *Journal of Pathogens*, vol. 2014, 756539. http://doi.org/10.1155/2014/756539. PMid:24808957.

ROWAN, N.J., 2019. Pulsed light as an emerging technology to cause disruption for food and adjacent industries–quo vadis? *Trends in Food Science & Technology*, vol. 88, pp. 316-332. http://doi.org/10.1016/j.tifs.2019.03.027.

SABO, S.S., VITOLO, M., GONZÁLEZ, J.M.D. and OLIVEIRA, R.P.S., 2014. Overview of Lactobacillus plantarum as a promising bacteriocin producer among lactic acid bacteria. *Food Research International*, vol. 64, pp. 527-536. http://doi.org/10.1016/j.foodres.2014.07.041. PMid:30011684.

SABRY, M.A., MANSOUR, H.A.E.A., ASHOUR, R.M. and HAMZA, E., 2019. Histamine-producing bacteria and histamine induction in retail sardine and mackerel from fish markets in Egypt. *Foodborne Pathogens and Disease*, vol. 16, no. 9, pp. 597-603. http://doi.org/10.1089/fpd.2018.2616. PMid:31009260.

SEKER, D. and OCAK, F., 2016. Isolation of the Pseudomonas spp. to cause of microbial spoilage of fishes. *Journal of Applied Biological Sciences*, vol. 10, no. 1, pp. 22-25.

SHENG, L. and WANG, L., 2021. The microbial safety of fish and fish products: recent advances in understanding its significance, contamination sources, and control strategies. *Comprehensive Reviews in Food Science and Food Safety*, vol. 20, no. 1, pp. 738-786. http://doi.org/10.1111/1541-4337.12671. PMid:33325100.

SILBANDE, A., CORNET, J., CARDINAL, M., CHEVALIER, F., ROCHEFORT, K., SMITH-RAVIN, J., ADENET, S. and LEROI, F., 2018. Characterization of the spoilage potential of pure and mixed cultures of bacterial species isolated from tropical yellowfin tuna (*Thunnus albacares*). *Journal of Applied Microbiology*, vol. 124, no. 2, pp. 559-571. http://doi.org/10.1111/jam.13663. PMid:29222941.

SKOWRON, K., GRUDLEWSKA, K., GRYŃ, G., SKOWRON, K.J., ŚWIECA, A., PALUSZAK, Z., ZIMEK, Z., RAFALSKI, A. and GOSPODAREK-KOMKOWSKA, E., 2018. Effect of electron beam and gamma radiation on drug-susceptible and drug-resistant Listeria monocytogenes strains in salmon under different temperature. *Journal of Applied Microbiology*, vol. 125, no. 3, pp. 828-842. http://doi.org/10.1111/jam.13902. PMid:29727511.

SMOLANDER, M. 2008. Freshness indicators for food packaging. In: J. KERRY and P. BUTLER, eds. *Smart packaging technologies for fast moving consumer goods*. Chichester: John Wiley & Sons, pp. 111-127. http://doi.org/10.1002/9780470753699.ch7.

SORSA, M., MAMO, G. and ABERA, L., 2019. Major fish-borne bacterial and parasitic zoonoses in Ethiopia: a review. *International Journal of Fauna and Biological Studies*, vol. 6, no. 4, pp. 50-58.

STANBOROUGH, T., FEGAN, N., POWELL, S.M., TAMPLIN, M. and CHANDRY, P.S., 2017. Insight into the genome of *Brochothrix thermosphacta*, a problematic meat spoilage bacterium. *Applied and Environmental Microbiology*, vol. 83, no. 5, e02786-16. http://doi.org/10.1128/AEM.02786-16. PMid:27986732.

STERNIŠA, M., KLANČNIK, A. and SMOLE MOŽINA, S., 2019. Spoilage Pseudomonas biofilm with Escherichia coli protection in fish meat at 5 °C. *Journal of the Science of Food and Agriculture*, vol. 99, no. 10, pp. 4635-4641. http://doi.org/10.1002/jsfa.9703. PMid:30895626.

TAOKA, Y., MAEDA, H., JO, J.Y., KIM, S.M., PARK, S.I., YOSHIKAWA, T. and SAKATA, T., 2006. Use of live and dead probiotic cells in tilapia *Oreochromis niloticus*. *Fisheries Science*, vol. 72, no. 4, pp. 755-766. http://doi.org/10.1111/j.1444-2906.2006.01215.x.

TASSOU, C.C., LAMIBROPOULOU, K. and NYCHAS, G.J., 2004. Effect of prestorage treatments and storage conditions on the survival of Salmonella enteritidis PT4 and Listeria monocytogenes on fresh marine and freshwater aquaculture fish. *Journal of Food Protection*, vol. 67, no. 1, pp. 193-198. http://doi.org/10.4315/0362-028X-67.1.193. PMid:14717374.

TAVARES, J., MARTINS, A., FIDALGO, L.G., LIMA, V., AMARAL, R.A., PINTO, C.A., SILVA, A.M. and SARAIVA, J.A., 2021. Fresh fish degradation and advances in preservation using physical emerging technologies. *Foods*, vol. 10, no. 4, 780. http://doi.org/10.3390/foods10040780. PMid:33916441.

TERENTJEVA, M., EIZENBERGA, I., VALCIŅA, O., NOVOSLAVSKIJ, A., STRAZDIŅA, V. and BĒRZIŅŠ, A., 2015. Prevalence of foodborne pathogens in freshwater fish in Latvia. *Journal of Food Protection*, vol. 78, no. 11, pp. 2093-2098. http://doi.org/10.4315/0362-028X.JFP-15-121. PMid:26555535.

THAMPURAN, N., SURENDRARAJ, A. and SURENDRAN, P.K., 2005. Prevalence and characterization of typical and atypical Escherichia coli from fish sold at retail in Cochin, India. *Journal of Food Protection*, vol. 68, no. 10, pp. 2208-2211. http://doi.org/10.4315/0362-028X-68.10.2208. PMid:16245731.

THIRUMDAS, R., KOTHAKOTA, A., ANNAPURE, U., SILIVERU, K., BLUNDELL, R., GATT, R. and VALDRAMIDIS, V.P., 2018. Plasma activated water (PAW): chemistry, physico-chemical properties, applications in food and agriculture. *Trends in Food Science & Technology*, vol. 77, pp. 21-31. http://doi.org/10.1016/j.tifs.2018.05.007.

TILAHUN, A. and ENGDAWORK, A., 2020. Isolation, identification and antimicrobial susceptibility profile of E. coli (O157: H7) from fish in lake Hawassa, southern Ethiopia. *Life Science Journal*, vol. 17, pp. 64-72.

TOSUN, Ş.Y., ALAKAVUK, D.Ü. and MOL, S., 2016. Isolation of Salmonella spp. and other members of Enterobacteriaceae from horse mackerel (*Trachurus trachurus*), sold in public markets of Istanbul, Turkey. *Food and Health*, vol. 2, no. 2, pp. 82-89. http://doi.org/10.3153/JFHS16009.

TOSUN, Ş.Y., ÜÇOK ALAKAVUK, D., ULUSOY, Ş. and ERKAN, N., 2018. Effects of essential oils on the survival of Salmonella enteritidis and Listeria monocytogenes on fresh atlantic salmons (*Salmo salar*) during storage at 2±1 °C. *Journal of Food Safety*, vol. 38, no. 1, e12408. http://doi.org/10.1111/jfs.12408.

TSIRONI, T., HOUHOULA, D. and TAOUKIS, P., 2020. Hurdle technology for fish preservation. *Aquaculture and Fisheries*, vol. 5, no. 2, pp. 65-71. http://doi.org/10.1016/j.aaf.2020.02.001.

TSOGAS, A., VATAVALI, K., DIMITRIOU, E., BADEKA, A., KONTAKOS, S. and KONTOMINAS, M.G., 2019. Combined effect of light salting and vacuum packaging on the microbiological, chemical, and sensory attributes of mullet fillets (*Mugil cephalus*) during refrigerated and frozen/refrigerated storage. *Journal of Food Processing and Preservation*, vol. 43, no. 8, e14009. http://doi.org/10.1111/jfpp.14009.

UEDEME-NAA, B. and JOHN-AMADI, V.S., 2022. Characterization and isolation of bacteria from adult African catfish (*Clarias gariepinus*) in selected fish farms of Rivers State, Nigeria. *Asian Journal of Fisheries and Aquatic Research*, vol. 19, no. 3, pp. 19-36. http://doi.org/10.9734/ajfar/2022/v19i330476.

VALDÉS, A., RAMOS, M., BELTRÁN, A., JIMÉNEZ, A. and GARRIGÓS, M.C., 2017. State of the art of antimicrobial edible coatings for food packaging applications. *Coatings*, vol. 7, no. 4, 56. http://doi.org/10.3390/coatings7040056.

VAN, T.T.H., CHIN, J., CHAPMAN, T., TRAN, L.T. and COLOE, P.J., 2008. Safety of raw meat and shellfish in Vietnam: an analysis of Escherichia coli isolations for antibiotic resistance and virulence genes. *International Journal of Food Microbiology*, vol. 124, no. 3, pp. 217-223. http://doi.org/10.1016/j.ijfoodmicro.2008.03.029. PMid:18457892.

WANG, H., LIU, X., ZHANG, Y., LU, H., XU, Q., SHI, C. and LUO, Y., 2017. Spoilage potential of three different bacteria isolated from spoiled grass carp (*Ctenopharyngodon idellus*) fillets during storage at 4° C. *Lebensmittel-Wissenschaft + Technologie*, vol. 81, pp. 10-17. http://doi.org/10.1016/j.lwt.2016.11.010.

WU, Q., SABOKROO, N., WANG, Y., HASHEMIAN, M., KARAMOLLAHI, S. and KOUHSARI, E., 2021. Systematic review and meta-analysis of the epidemiology of vancomycin-resistance Staphylococcus aureus isolates. *Antimicrobial Resistance and Infection Control*, vol. 10, no. 1, pp. 101. http://doi.org/10.1186/s13756-021-00967-y PMid:34193295.

XIE, T., WU, Q., XU, X., ZHANG, J. and GUO, W., 2015. Prevalence and population analysis of Vibrio parahaemolyticus in aquatic products from South China markets. *FEMS Microbiology Letters*, vol. 362, no. 22, fnv178. http://doi.org/10.1093/femsle/fnv178. PMid:26424767.

YAGOUB, S.O., 2009. Isolation of Enterobacteriaceae and Pseudomonas spp. from raw fish sold in fish market in Khartoum state. *Journal of Bacteriology Research*, vol. 1, no. 7, pp. 85-88.

YAN, Z., NIU, Q., MOU, M., WU, Y., LIU, X. and LIAO, S., 2017. A novel colorimetric method based on copper nanoclusters with intrinsic peroxidase-like for detecting xanthine in serum samples. *Journal of Nanoparticle Research*, vol. 19, no. 7, 235. http://doi.org/10.1007/s11051-017-3904-9.

YANESTRIA, S.M., RAHMANIAR, R.P., WIBISONO, F.J. and EFFENDI, M.H., 2019. Detection of invA gene of Salmonella from milkfish (*Chanos chanos*) at Sidoarjo wet fish market, Indonesia, using polymerase chain reaction technique. *Veterinary World*, vol. 12, no. 1, pp. 170-175. http://doi.org/10.14202/vetworld.2019.170-175. PMid:30936672.

YANG, Y., XIE, J., LI, H., TAN, S., CHEN, Y. and YU, H., 2017. Prevalence, antibiotic susceptibility and diversity of Vibrio parahaemolyticus isolates in seafood from South China. *Frontiers in Microbiology*, vol. 8, 2566. http://doi.org/10.3389/fmicb.2017.02566. PMid:29326682.

YORDANOV, D.G. and ANGELOVA, G.V., 2010. High pressure processing for foods preserving. *Biotechnology, Biotechnological Equipment*, vol. 24, no. 3, pp. 1940-1945. http://doi.org/10.2478/V10133-010-0057-8.

YOUSUF, A.H.M., AHMED, M.K., YEASMIN, S., AHSAN, N., RAHMAN, M.M. and ISLAM, M.M., 2008. Prevalence of microbial load in shrimp, Penaeus monodon and prawn, *Macrobrachium rosenbergii* from Bangladesh. *World Journal of Agricultural Sciences*, vol. 4, no. 5, pp. 852-855.

ZHANG, K., SHI, H., PENG, J., WANG, Y., XIONG, X., WU, C. and LAM, P.K., 2018. Microplastic pollution in China's inland water systems: a review of findings, methods, characteristics, effects, and management. *The Science of the Total Environment*, vol. 630, pp. 1641-1653. http://doi.org/10.1016/j.scitotenv.2018.02.300. PMid:29554780.

ZHANG, Y., LI, Q., LI, D., LIU, X. and LUO, Y., 2015. Changes in the microbial communities of air-packaged and vacuum-packaged common carp (*Cyprinus carpio*) stored at 4 °C. *Food Microbiology*, vol. 52, pp. 197-204. http://doi.org/10.1016/j.fm.2015.08.003. PMid:26338135.

ZHANG, Z.H., WANG, L.H., ZENG, X.A., HAN, Z. and BRENNAN, C.S., 2019. Non-thermal technologies and its current and future application in the food industry: a review. *International Journal of Food Science & Technology*, vol. 54, no. 1, pp. 1-13. http://doi.org/10.1111/ijfs.13903.