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Using Various Fish Processing Techniques to Maintain Flesh Quality and Shelf Life, An Updated Review

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Abstract. fish and fish products are crucial for human health, providing high-quality proteins, essential vitamins, minerals, and healthy polyunsaturated fatty acids. Furthermore, the great nutritional importance of these substances has been linked to numerous health benefits extending from prenatal development of the fetus to puberty .However, fish can deteriorate quickly after harvesting due to external environmental factors such as water quality (waste that turns into ammonia, nitrate, nitrite, pH, amount of dissolved oxygen, and temperature) and internal physiological factors such as microbes and bacteria, which increases the chance of their deterioration and loss of nutritional value. Therefore, it is essential to use techniques for aquaculture fish that are constantly evolving, focusing on the type and condition of the fish and applying appropriate techniques for farmed fish, considering the duration of transport. In addition, there are various techniques used in the preservation of aquaculture fish, including traditional techniques such as salting, drying, smoking, and pickling or marinating; non-traditional fish processing techniques include cooling, freezing, and vacuum packaging. Also, to determine fish freshness such as sensory characteristics, microbial analyses, physical and chemical evaluations. Fish processing techniques include methodologies and procedures used from harvest until reaching the consumer in its final form. This review investigates the most important preservation techniques used for fish and their impact on overall quality. In addition, it aims to achieve sustainable production with nutritional content, improve profitable productivity, and reduce negative health impacts on consumers and fear about the nutritional safety of food to achieve human in line with the Kingdom's Vision 2030's two pillars of a thriving economy and society.

Keywords: fish processing, spoilage, preservation techniques, aquaculture farming, freshness, fish quality, shelf life.

1. INTRODUCTION:

Human fish consumption has increased globally by 3.2% annually since the 1970s (Mengistu et al., 2020). Also, the global population is projected to increase by 2-2.5 billion individuals by 2050. Consequently, there will be a need to ensure food and energy provision for this growing population. Additionally, a significant demand for power remains unmet, affecting approximately one billion people (Cosgrove & Loucks., 2015).

In line with a comparable global pattern, there has been a consistent rise in the demand for fish among consumers in the Kingdom of Saudi Arabia (KSA) throughout the previous few decades. According to Gomez et al. (2023), there has been a significant increase in per capita consumption, which has risen by 200% during a specific period. Specifically, the consumption has gone from 6.4 kg to 11.3 kg. This increase is accompanied by an annual growth rate of 2.9%, which surpasses the global, regional, and sub-regional averages.

As a result of the increase in population and the rising living standards of civil society, there is considerable pressure on fish consumption (Khan et al., 2018). However, many challenges are associated with this massive increase in water resource requirements. Such as high demand and higher efficiency of work to improve productivity (Kulat et al., 2019).

In addition, fish is a rich source of protein, minerals, vitamins, and essential nutrients for human nutrition (Abraha et al., 2018). Moreover, fish are a valuable dietary component due to their provision of essential amino acids, lipid-soluble micronutrients, and highly unsaturated fatty acids (Nie et al., 2022; Petsini et al., 2019; Yu et al., 2020). Furthermore, the significant nutritional significance of these substances has been linked to numerous health advantages spanning from prenatal development through adulthood (Rifat et al., 2023). In summary, a significant correlation exists between fish consumption and enhancing individual well-being and longevity (Rumape et al., 2022).

Given the continuous expansion of the global population and the imperative to effectively store and transport food to areas of demand, food preservation assumes a crucial role in extending its longevity while preserving its nutritional composition, texture, and taste (Ghaly et al., 2010).

Conversely, fish is often seen as a complex culinary commodity owing to its susceptibility to spoiling, oxidation, and the emergence of undesirable tastes resulting from inadequate handling or storage practices. Various factors, including the dietary composition of the fish, how it is handled, and the conditions in which it is stored, significantly influence the preservation of optimal nutritional value in fish (Rumape et al., 2022).

To be specific, fish is known to have a short shelf life after being caught, primarily because of its elevated moisture content, reliance on oxygenated blood supply for cell maintenance, neutral pH, and presence of numerous resident microbiotas. These factors collectively contribute to the spoilage of fish through microbial and biochemical processes (Amit et al., 2017; Odeyemi et al., 2020). The enzymatic and oxidative processes in fish following their harvest give rise to notable alterations in their sensory and nutritional characteristics. These changes have a detrimental impact on the shelf-life of fish and are commonly interpreted by customers as a decline in freshness (Duarte et al., 2020). The adverse effects linked to a decrease in freshness are caused mainly by the degradation of proteins and the oxidation of lipids. These processes result in undesirable alterations in the odor, flavor, and texture of fish and also give rise to significant concerns regarding food safety (Sheng & Wang, 2021).

The contemporary fisheries and aquaculture sectors function within a vast and international marketplace. Given the intensifying competition within the marketplace, the fisheries and fish farming sectors must investigate sophisticated technology interventions to enhance productivity and profitability (Liu et al., 2022).

Hence, fish Processing Technology (FPT) encompasses a range of methodologies and procedures employed in the post-harvest processing, handling, and commercialization of aquatic goods, spanning from the initial harvesting stage to the ultimate consuming phase (Tahiluddin & Kadak., 2022).

The main focus of applying processing technology to aquatic products is to avoid or slow down spoiling caused by bacteria, enzymes, and improper physical and mechanical handling (Kaminski et al., 2020). For these reasons, good food preservation techniques should prevent microbial spoilage of food without affecting its nutritional value and flesh quality to meet the nutritional needs of this enormous population.

2. Fish Processing Technology (FPT)

Fish Processing technologies have a significant relationship, and this affect the nutrients that fish offer for human health. Accordingly, FPT is crucial in ensuring food security, promoting economic development, and maximizing the nutritional content available to consumers (Tahiluddin & Kadak., 2022). The importance of ensuring the production of high-quality fish products is underscored by the fluctuating demands of consumers and the elevated costs associated with these items (Liu et al., 2022). Furthermore, fish processing processes can be categorized into two distinct groups: traditional methods and non-traditional ways. In summary, the Traditional Techniques (TTs) employed for fish processing are limited to smoking, drying, salting, and canning, whereas chilling, freezing, and vacuum packing are categorized as non-traditional techniques (NTTs) of fish processing (Guevara., 1980; Cain., 2019). Typically, TTs are implemented with limited infrastructure and resources, utilizing affordable equipment commonly found within small-scale fisheries' value chains. On the other hand, NTTs are commonly employed at processing facilities with significant investments and in the context of international trade (FAO, 2021).

Fish processing typically commences immediately following the capture of fish. The process encompasses several stages, including the capture of fish, bleeding, chilling, grading, beheading, scaling, filleting, skinning, trimming, portioning, mincing, by-product recycling, and packaging (Aldás, 2013; Buljo & Gjerstad, 2013; Einarsdóttir et al., 2022). The processing operations in question are essential as they encompass several vital procedures, including beheading, filleting, trimming, skinning, and portioning (Liu al., 2022).

2.1 Traditional Techniques

2.1.1 Salting

Salting is classified as one of TTs and is recognized as one of the first techniques employed to preserve fish and other fishery products (Samples., 2015). The preservation mechanism and underlying principles of salting are consistent across all fisheries products, irrespective of the specific method employed. Additionally, dry and wet salting of fish and fishery products is widely implemented globally (Tahiluddin & Kadak., 2022). Osmosis and diffusion are fundamental processes involved in reducing and removing moisture from fishery products, resulting in a decrease in enzymatic and bacterial activities. These ultimately extend salted products' shelf life (Espejo-Hermes., 1998; Erdem et al., 2015; Güngörmez et al., 2017). Dry salting, known as the Kench process, involves directly applying salt onto the fish through rubbing. On the other hand, wet salting, which includes brining and pickle curing, entails immersing the fish in a solution of salt and water prior to packaging. In the case of wet salting, each layer of fish is sprinkled with salt that has been previously used (Espejo-Hermes., 1998; Erdem et al., 2005; Güngörmez et al., 2017). according to Jiang et al.,(2023), salting at levels greater than 3% for 10 hours in *Oreochromis niloticus* caused myofibers deterioration, shrinking, and microstructure changes.

2.1.2 Drying

Another TTs known as drying. Drying has preserved fishing products since ancient times (Doe & Olley., 2020). Drying is extracting moisture from fishery products, typically accomplished through evaporation or alternative methodologies (Espejo-Hermes, 1998; Oğuzhan., 2012; Samples., 2015). Reducing the moisture content (MC) of fisheries products to below 15% has effectively prevented spoiling caused by various microorganisms. Additionally, drying the products to a moisture content of 10% has been observed to completely inhibit the formation of molds, resulting in a significant extension of the products' shelf-life (Espejo-Hermes., 1998). The drying rate of fishery products during the drying process is affected by several significant parameters, including the thickness of the product, its salt and fat content, the temperature at which drying occurs, the velocity of the surrounding air, and the relative humidity (Samples., 2015). Drying methods for fishery products include contact drying and air drying, also known as sun-drying. Contact drying involves cleaning the products and exposing them directly to sunlight for a specific period, which can range from hours to days, depending on the nature of the products. Alternatively, drying with salts can be employed, whereby the fishery products are cleaned, brined, or dry-salted and subsequently placed under the sun for a specified duration (Espejo-Hermes, 1998; Erkan, 2011; Oğuzhan, 2012). Sun drying *Alestes baremose* fish is a preservation method of creating good quality, quick, and straightforward procedure that yields an acceptable result (Modibbo et al., 2014). On the other hand, Delima et al. (2021), shows that salt amount varies depending on the fish species: two teaspoons for tilapia, one tablespoon for motan and lemongrass fish. Fish drying times are dependent on the intensity of the sun; cloudy weather prolongs drying times. When fish treated with salt were examined for research purposes, the fish's quality held up better than that of fish not treated with salt. Even in terms of flavor, fish prepared with salt is more appetizing or practical for eating. Because the salted fish already has a distinct flavor when cooked, it doesn't need any additional flavorings or seasonings.The flavor of the fish will be dull as opposed to unsalted fish (Table 1).

Table 1. Different fish with the addition of salt

NO	Type of fish	Drying Time	Add salt	Texture	Quality
1	Tilapia	Three days	2 tbsp	Dry	No fishy smell and long-lasting.
2	Motan Fish	Two days	1 tbsp	Dry	No fishy smell and durable
3	Lemongrass Fish	Two days	1 tbsp	Hard	No fishy smell and long-lasting.

In addition, long-term exposure of fish to sunlight can oxidize the lipids in the fish, reducing nutritional quality and raising consumer health risks (Smida et al., 2015). Furthermore, natural drying can dry fish faster and cause the flesh to become hard even though some moisture is still present, slowing down the drying process and promoting protein degradation (Abraha et al., 2018).

2.1.3 Smoking

Like smoking, preserving food through smoking has been widely employed in numerous underdeveloped nations (Samples., 2015; Espejo-Hermes., 1998). The preservation process of smoking involves the synergistic impact of salting, drying, heat treatment, and chemical deposition resulting from the combustion of wood (Espejo-Hermes., 1998). In general, smoked products acquire a desirable smoky aroma by the combustion of sawdust or wood during manufacturing and by the influence of volatile compounds. This process ultimately extends the shelf life of the smoked products. The process of smoking fish is commonly conducted within a smokehouse facility to effectively regulate the combustion of wood (Küçükgülmez et al., 2010; Espejo-Hermes., 1998). There are two distinct traditional smoking methods employed in the preservation of fishery goods: hot smoking, which involves subjecting the products to elevated temperatures ranging from 70 to 80 degrees Celsius. According to previous studies (Espejo-Hermes., 1998; Aydin & Yalçın., 2018), the final products typically exhibit qualities such as being cooked, juicy, and tasty. Cold smoking involves the process of smoking fishery items at a controlled temperature that does not exceed 30°C. According to previous studies (Espejo-Hermes., 1998; Emel., 2020), smoked items are typically uncooked and may necessitate an additional cooking step. Teklu & Lema., (2015), mentioned that for non-dried fish, *Oreochromis niloticus* was smoked at 80 ± 3°C for two hours, on the other hand, if the fish dried before, the smoke duration was about three hours at 80 ± 3°C. However, If the time, temperature, and wood type are not controlled and chosen in accordance with the regulations throughout the smoking protocol, the smoked fish products' chemical, physical, and nutritional contents will be impacted. Furthermore, the carcinogenic activity may increase and cause various disorders in consumers (Abraha et al., 2018). Fish quality that has been smoked will have a hard texture, turn black instead of golden brown, and lose nutrients that are sensitive to heat (Boonsumrej et al., 2007). Depending on the amount of heat produced during smoking, fish's protein and amino acid denaturation will occur. This changes the protein's chemical and physical characteristics and lowers its biological availability (Ihekoronye & Ngoddy, 1985). According to research by Abraha et al. (2018), overheating can happen in the majority of conventional smoking techniques for fish processing, which greatly lowers the availability of vital amino acids (lysine, tryptophan, and methionine). Chavan et al. (2008) report that smoking also raises the amount of insoluble protein and decreases the amount of more soluble protein, such as sarcoplasmic and myofibrillar contents.

2.1.4 Pickling or Marinating

The preservation actions of pickling or marinating are due to the combined effects of salt and vinegar/acetic acid (Espejo-Hermes, 1998; Sampels, 2015; Kadak & elik., 2015; Cetinkaya, 2017). The presence of vinegar or acetic acid reduces the pH of the product, thereby inhibiting the proliferation of microorganisms that cause spoilage (Sampels., 2015). In addition, higher concentrations of these substances have increased inhibitory effects on enzymes and bacteria (Espejo-Hermes., 1998; Cetinkaya., 2017). However, pickled/marinated products generally have a short shelf life and are therefore considered semi-preserved unless stored in a chilled environment, where they can last for several months. (Espejo-Hermes, 1998; Sampels, 2015); (Espejo-Hermes, 1998; Sampels, 2015). An investigation showed that marinating rainbow trout fillets extended their shelf life at 4 ˚C by delaying microbiological spoiling and avoiding deterioration (Maktabi et al., 2016).

2.2 Non- Traditional Techniques

Rumape et al. (2022) advised initiating the cooling process promptly after harvesting the fish. However, Jeyasanta et al. (2013) observed that delaying the application of icing for varying durations of 4, 6, 8, or 10 hours resulted in a decrease in the storage life of Malabar trevally. Specifically, the shelf life was lowered to 14, 10, 6, and 3 days, respectively, compared to the 18-day shelf life observed when icing was applied immediately. The study conducted by Rumape et al. (2022) revealed that the shelf life of rainbow trout *Oncorhynchus mykiss* experienced a reduction from the initial range of 9-11 days to a new range of 5-7 and 1-3 days, respectively, when the process of icing was delayed by either 4 or 8 hours after the fish were captured.

2.2.1 Cooling

Fresh fish is commonly transported and sold on a bed of crushed ice, maintaining a temperature of approximately zero degrees Celsius. The preservation of freshness can be achieved using refrigeration or cooling methods; however, it is important to note that these methods do not possess the capability to eliminate or eradicate microorganisms, nor can they halt enzymatic activity. According to Yu et al. (2019), most biological deterioration processes exhibit a deceleration rate. In a study conducted by Melgosa et al. (2021), it was observed that the rate of hydrolysis in cod exhibited a threefold increase at a temperature of 20°C compared to 0°C. Additionally, microbial growth decelerates at lower temperature conditions. The rate at which food is cooled has a crucial role in determining the overall quality of the final product, encompassing factors such as oxidation, spoilage, and texture. In order to achieve the intended duration of shelf life, it is imperative to maintain sufficient refrigeration throughout transportation and storage (Alice et al., 2020). Shelf-life of *Oreochromis niloticus* after being stored at +1.0 ◦C for 23 days, the microbiological quality of tilapia fillets was still good for eatable. Nonetheless, certain adverse impacts were noted in the samples' texture, color, and drip loss. According to sensory assessment and microbiological counts, the ideal storage periods were 13–15 and 21 days .

2.2.2 Freezing

Freezing has been widely regarded as a viable method for prolonging meat preservation over extended durations (George, 1993). However, it is essential to note that freezing can significantly affect muscle's chemical and structural properties, including the generation of lipid oxidation products (Zhan et al., 2018). According to Yu et al. (2020), freezing is more successful than cold storage in reducing enzymatic and microbiological activity retaining flavor and nutritional properties. The formation of ice crystals during the freezing process is a critical event. It is important to note that larger ice crystals provide a higher risk of membrane rupture and textural damage, which might result in increased oxidation (Sikorski & Kolakowska, 2020). The generation of small ice crystals during the freezing process is crucial in preventing increased oxidation and deterioration in texture after thawing (Rumape et al., 2022). In a study conducted by You et al. (2021), it was observed that a decrease in the freezing rate resulted in the formation of larger ice crystals, leading to pronounced damage to muscle fibers. According to Sigurgisladottir et al. (2000), the size and uniformity of the ice crystals can be enhanced by increasing the speed and homogeneity of the freezing process. It was also noted that the color and texture of the *Oreochromis niloticus* muscles fish did not change when ice was applied immediately after harvesting. As a result, the shelf life was increased, and the general characteristics and nutritional value were maintained. (Figures 1,2 and 3). However, understanding the impact of freezing and thawing on frozen fish's muscle is essential for choosing the best preservation conditions and maintaining the product's texture, which will ultimately determine whether or not consumers will accept it (Dıaz-Tenorio et al., 2007). Additionally, he noted in his research that freezing and thawing conditions as well as holding temperature can have an impact on fish muscle qualities, including their edibility. Freezing can keep a product as fresh as when it was first stored and prolong its shelf life, but it depends on a number of variables, including the fish species' initial condition and the amount of time that passes between harvest and freezing. It can also result in protein denaturation and texture defects (Abraha et al., 2018). Protein denaturation may happen during the freezing fish treatment method (Yerlikaya & Gokoglu., 2010). Since muscle protein is the primary source of textural distinctive features, denatured protein affects the water-holding capacity, flavor, color, and texture of frozen fish and fish products (Abraha et al., 2018). Consequently, there is an increased risk of damage to proteins and loss of important amino acids (Chavan et al., 2008). Yerlikaya & Gokoglu (2010), have reported that the freezing time has an impact on the final quality of frozen fish. According to Lakshmanan et al. (2003), the number of freeze-thawing periods has a direct impact on the nutritional losses of aqua foods. Free fatty acid can have indirect effects on texture changes and flavor deterioration of frozen fish by promoting protein denaturation and enhancing lipid oxidation, respectively. Fish that has been frozen for 180 days can have less crude protein and fat, according to research by Foruzani et al. (2015) (Fig 4A) (Fig 4B).

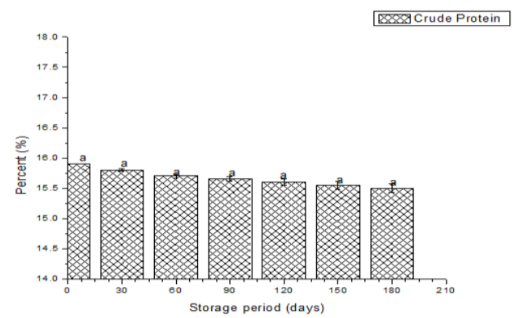

Fig 4A: Effect of storage period on crude protein content of *Lutjanus johnii* during 180dayes of preservation in freezer (Foruzani et al., 2015).

Fig 2. Freezing technique used for *Oreochromis niloticus* aquaculture.

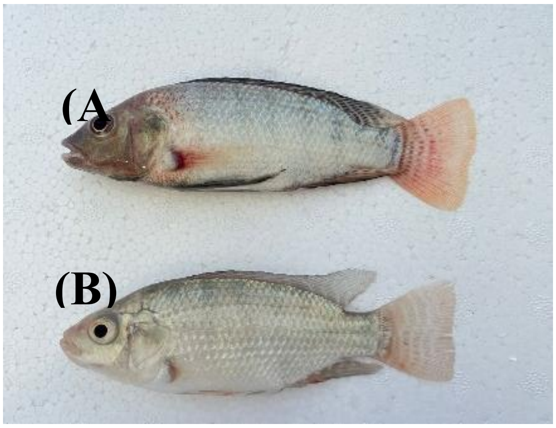

Fig 1. A) None of the techniques were applied to *Oreochromis niloticus* aquaculture. B) Freezing technique was applied using cold water and small pieces

Fig 3. Freezing technique used for *Oreochromis niloticus* aquaculture.

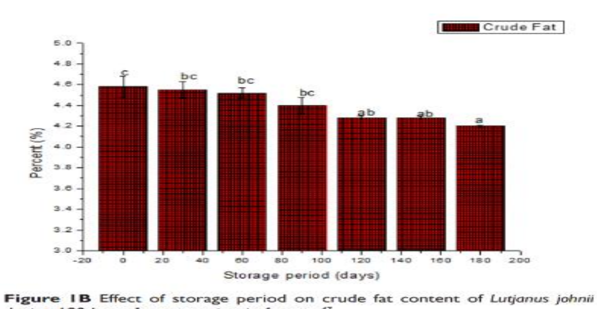

Fig 4B: Effect of storage period on crude fat content of *Lutjanus johnii* during 180dayes of preservation in freezer (Foruzani et al., 2015).

2.2.2.1 Slurry ice

Slurry ice has become a viable method in the post-capture, onboard handling, storage, and transporting of fish (Ntzimani et al., 2023). According to previous studies conducted by Huidobro et al. (2001), Losada et al. (2005), and Rodríguez et al. (2004), it has been observed that slurry ice exhibits the ability to inhibit microbial development and extend the shelf life of many marine species, including salmon, seabream, horse mackerel, and pink shrimp. Additionally, slurry ice can be defined as a biphasic system wherein small spherical ice particles are enveloped by seawater at temperatures below zero degrees Celsius (Cakli et al., 2006). The purported benefits of using cryogenic ice, compared to conventional freshwater ice forms, including flake, tube, and block ice, encompass several aspects. These include a lower temperature, resulting in faster chilling owing to enhanced heat exchange, a reduced likelihood of physical damage, and the presence of spherical tiny particles (Bellas & Tassou, 2005; Kauffeld et al., 2010). According to Kauffeld et al. (2010), the ice slurry's ice concentration can be adjusted to a maximum of 60%, while the salt content can range from 2% to 3%. This adjustment is crucial in achieving optimal preservation outcomes for sensitive fish, as it prevents any potential injury and excessive salt absorption by the fish. Furthermore, the comprehensive application of the slurry ice mixture to the fish surface protects fish tissues against the detrimental effects of oxygen, including lipid oxidation and dehydration (Huidobro et al., 2002).

2.2.3 Vacuum Packing

High pressure's potential to eliminate germs was first documented in 1899. However, scientific investigations into applying high pressure for food preservation did not commence until the late 1980s and early 1990s. According to Rastogi et al. (2007), bacteria and enzymes respond similarly under high-pressure conditions. Conversely, elevated pressure levels may lead to cellular harm and distortion, causing structural modifications and impairments. It has been shown that alterations in pressure within the range of 100-300 MPa are generally reversible in most food products, in contrast to modifications induced by variations in temperature. In certain instances, such as with bacterial spores, it has been observed that they can endure elevated pressures, necessitating a minimum of 1,200 MPa for deactivation (Abera., 2019). Consequently, applying high pressure can influence various aspects of food quality, including proteolysis, myofibrillar proteins, and muscle enzymes. Additionally, it is imperative to consider the effects on sensory perception and texture. The relationship between high pressure and color changes and meat tenderization has been shown. (Figure 5). The quality of aquatic goods can be influenced by each stage of the process and any additional components introduced. Customizing the preservation technique according to the specific requirements of a perishable item such as fish, which is vulnerable to bacterial decay and oxidative processes, is imperative. The study conducted by Rumape et al. (2022) highlights the importance of preserving the overall quality, sensory attributes, and textural properties of food products while also maintaining their nutritional value. The findings suggest that employing a combination of storage and preservation techniques in a thoughtful and innovative manner can produce high-quality goods with favorable nutritional characteristics.

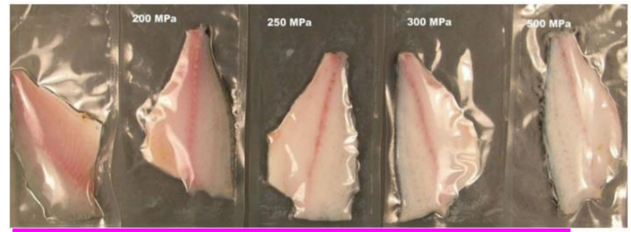

Fig 5. Changes in sea bream (Sparus aurata L.) fillets. (Rumape et al., 2022).

3. Determination of Fish Freshness

The freshness of fish is an important factor to consider due to its limited shelf life as a highly perishable food item. This attribute is important in ensuring safety, nutritional content, availability, and edibility.

It is well acknowledged that not only one method can be deemed entirely dependable in assessing the freshness or quality of fish goods (Martinsdottir., 2010). The assessment of fish freshness and the decision to accept or reject it based on this criterion may be the sole requirement for the industry (Freitas et al., 2019).

The post-mortem changes in fish encompass a range of physical, chemical, sensory, and microbiological features that contribute to the deterioration of food quality. These changes are species-specific and can be influenced by factors such as fishing processing technique, handling practices, and storage temperature (Freitas et al., 2019). Substantial elements serve as indicators of product spoiling (Balino-Zuazo & Barranco, 2016; Shumilina et al., 2016). Nevertheless, due to the absence of the capture date on fish sold by vendors, consumers lack a dependable means of ascertaining the true freshness of the product. Moreover, the existing regulations do not mandate the inclusion of an expiration or "best before" date for fresh fish (Freitas et al., 2019).

3.1 Sensory Characteristics:

Sensory character is crucial in determining food quality, influencing consumer acceptance, food selection, and market value. The assessment of aquaculture product quality based on production and post-production characteristics is consistently regarded as a matter of utmost significance (Goncalves., 2010). Sensory analysis demonstrates adaptability across several stages of the supply chain, hence proving its significance in assessing the freshness of fish at different junctures of transactions (Freitas et al., 2019). Sensory analysis tools can significantly improve the overall perception of products in today's highly competitive markets (Bernardi et al., 2013). Also, it is widely recognized as a highly effective method for adequately assessing the freshness and grading of fish or fish products (Freitas et al., 2019).

In sensory evaluation, olfaction played a significant role in discerning the extent of degradation. According to the study by Freitas et al. (2019), the initial characterization of skin and gill odors in cod was classified as reminiscent of seaweed or fresh. However, starting from day 3 of the experiment, these aromas transitioned to a neutral state. Moreover, the perception of unpleasant scents linked to decay was observed on the 11th day; however, the intensity necessary for rejection was only reached on the 12th day. The primary cause of this phenomenon can be attributed to the notable presence of strong scents on both the skin and gills, characterized explicitly by rancidity.

3.1.1 Quality Index Method QIM:

Quality Index Method (QIM) is a grading method used to evaluate the freshness of fish. It is characterized by its efficiency, simplicity, nondestructiveness, and descriptive nature. The integration of fish species differences is achieved through an objective assessment of fish features, such as gill odor (Nollet & Toldra., 2010). Additionally, it offers a dependable and standardized approach to users, including manufacturers, customers, merchants, and resellers. This methodology comprises clear directions and easily comprehensible illustrative materials. This approach is very suitable for instructing individuals with limited expertise and providing training or overseeing the performance of panelists (Bernardi et al., 2013). Attributes are assessed using a scoring system that assigns demerit points ranging from 0 to 3. Additionally, as time elapses, punctuation is more emphasized, resulting in higher scores (Martinsdottir., 2010). However, it is frequently observed that one or more traits do not attain the maximum demerit points due to the lack of significant changes throughout the storage period, which prevents them from achieving such scores (Sant'Ana et al., 2011).

3.1.2 Quality Index (QI):

Quality Index (QI) is derived by aggregating all ratings to predict shelf-life. The possibility of making a forecast relies on establishing a linear correlation between the variable of interest, namely QI, and the duration of storage. However, novel QIM schemes are developed in conjunction with other methodologies. The fish muscle assessment is conducted using the Torry Scale (Freitas et al., 2019). According to Lauteri et al. (2023), the Torry scheme was utilized, and each sample was given a score based on a structured scale ranging from 10 to 3. Absolute freshness is indicated by a score of 10–9; good quality is indicated by an 8; tastelessness or neutrality is indicated by a 7–6; slight extraneous odors and tastes (initial state of alteration) is indicated by a 5–4; and severe extraneous odors and tastes (putrid product) are indicated by a 3 . When the product's flavor and odor received a sensory QIM score of less than six overall, the samples were declared unfit for consumption.

3.1.3 Quantitative Image Analysis (QIA):

Quantitative Image Analysis (QIA) methods were developed using exterior characteristics such as skin, texture, odor, and the look of eyes, gills, and anus (Freitas et al., 2019).

3.2 Microbiological Analysis:

The presence of microorganisms in aquatic species indicates the bacterial composition of the surrounding environment and the circumstances experienced during handling or processing. In the case of recently processed fish, Single Species Organisms (SSOs) are observed in minimal quantities and represent a minor portion of the microbial community associated with the fish. Under specific storage conditions, such as a particular temperature, SSOs' growth rate is higher than other microflora. This increased growth leads to the production of metabolites that are responsible for off-flavors in the product. Ultimately, these off-flavors result in sensory rejection of the product (Freitas et al., 2019; Oehlenschlager., 2014). The prevailing SSOs found in aquatic species inhabiting temperate seas and subjected to ice preservation at a temperature of 0 °C in the presence of oxygen are *Shewanella* spp and *Pseudomonas* spp. These substances are linked to odors characterized by ammoniacal spoilage and hydrogen sulfide (Sant'Ana et al., 2011).

3.3 Physical Evaluation:

The physical evaluation is a comprehensive assessment of an individual's physical health and well-being. It involves the systematic examination of one often employed method for evaluating electrical measures in fish based on the observation that the cell membranes in fish muscle tissue undergo a gradual disruption caused by autolytic enzymatic degradation and subsequent microbial activity anus (Freitas et al., 2019). This process ultimately results in a reduction in electrical resistance and capacity. Hence, over time, there will be a decrease in the magnitude of the electric impulse recorded (Oehlenschlager., 2014). The alteration in gradient is a result of the dual-phase quality deterioration process elucidated by two distinct degradation mechanisms, namely enzymatic autolysis and microbial activity (Freitas et al., 2019).

3.4 Chemical Analysis: concentration of hydrogen ions, commonly known as pH measurement (Lanzarin et al., 2016). The pH levels of live fish exhibit variation across different species. Thus, the occurrence of a low value, indicated by the QI, signifies an aberrant alteration and elucidates the rapid deterioration of the fish (Freitas et al., 2019).

In addition, the generation of volatile amines, including ammonia, trimethylamine (TMA), dimethylamine (DMA), and methylamine (MA) (Sadok, Uglow, & Haswell, 1996), is sometimes referred to as total volatile basic nitrogen (TVB-N). These organic molecules are formed by bacterial or enzymatic processes, utilizing trimethylamine-n-oxide (TMAO) as a precursor (Dyer & Mounsey., 1945a). The assessment of spoilage in fish products often relies on the measurement of TVB-N, a crucial characteristic. TVB-N is widely recognized as the predominant chemical indicator for evaluating the spoilage of marine fish (Amegovu et al., 2012; Wu & Bechtel., 2008). Nevertheless, the conventional approach to quantify its concentrations in tissue samples is time-consuming due to the need for meticulous extraction procedures (Esposito et al., 2018).

TMA alone can indicate fish freshness because its level is directly related to product deterioration. The official method for determining the concentration of the substance.

Chemical analysis is a scientific technique used to determine the composition and properties of substances and characteristics of the chemical changes that occur in fish muscle during rotting.

3.4.1 Potential of Hydrogen (pH):

The assessment of deterioration process in fish products can be achieved by measuring pH the despite its limited accuracy and harmful solvents, it is predominantly the analytical approach based on Dyer's method (Dyer., 1945b).

4. Conclusion

Currently, fish farms and aquaculture in the Kingdom of Saudi Arabia operate in a global and competitive market due to increasing human consumption of aquatic resources. To maintain this competitive level, fish processing techniques are integral to reducing concerns about food safety, maintaining the country's economic development, and achieving consumer satisfaction. However, it is hard to harvest and transport due to its rapid susceptibility to spoilage and rot. Therefore, it is suggested to choose one of the fish processing techniques with high precision according to the type and condition of the fish and the way that reaches the consumer, considering the duration of transportation. In addition, it is possible to combine more than one technique to obtain results with long shelf life, abundant nutritional value, and better flesh quality. Furthermore, there are many ways to determine the freshness of fish, ranging from experienced people to less ones.

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استخدام تقنيات مختلفة للحفاظ على جودة اللحم ومدة صلاحيته، دراسة مرجعية محدثة

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مستخلص. تعتبر الأسماك والمنتجات السمكية ضرورية لصحة الإنسان، حيث توفر بروتينات عالية الجودة وفيتامينات أساسية ومعادن وأحماض دهنية صحية متعددة غير مشبعة. علاوة على ذلك، فقد ارتبطت الأهمية الغذائية الكبيرة لهذه المواد بالعديد من الفوائد الصحية التي تمتد من نمو الجنين قبل الولادة وحتى البلوغ. ومع ذلك، يمكن أن تتدهور الأسماك بسرعة بعد الحصاد بسبب عوامل بيئية خارجية مثل نوعية المياه (النفايات التي تتحول إلى أمونيا ونترات ونتريت، ودرجة الحموضة، وكمية الأكسجين المذاب ودرجة الحرارة) والعوامل الفسيولوجية الداخلية مثل الميكروبات والبكتيريا، مما يزيد من فرصة تدهورها وفقدان قيمتها الغذائية. ولذلك، من الضروري استخدام تقنيات تربية الأحياء المائية التي تتطور باستمرار، مع التركيز على نوع وحالة الأسماك وتطبيق التقنيات المناسبة للأسماك المستزرعة، مع الأخذ في الاعتبار مدة النقل. بالإضافة إلى ذلك، هناك تقنيات مختلفة تستخدم في حفظ الأسماك بما في ذلك التقنيات التقليدية مثل التمليح، التجفيف، التدخين والتخليل أو التتبيل، وتشمل تقنيات معالجة الأسماك الغير التقليدية التبريد، التجميد والتعبئة المفرغة من الهواء. وأيضا لتحديد مدى نضارة الأسماك مثل الخصائص الحسية والتحليلات الميكروبية وتقييمات التحليل الفيزيائي والكيميائي. تشمل تقنيات تجهيز الأسماك المنهجيات والإجراءات المستخدمة منذ الحصاد حتى وصولها إلى المستهلك في شكلها النهائي. تتناول هذه المراجعة أهم تقنيات حفظ الأسماك المستخدمة وتأثيرها على الجودة الشاملة. بالإضافة إلى تحقيق إنتاج مستدام ذو محتوى غذائي وتحسين الإنتاجية المربحة، وكذلك للحد من الآثار الصحية السلبية على المستهلكين والخوف على السلامة الغذائية للغذاء لتحقيق رفاهية الانسان وفقاً لمحوري اقتصاد مزدهر ومجتمع لرؤية المملكة ٢٠٣٠.

الكلمات المفتاحية: تقنيات معالجة الأسماك، الفساد، الطازجة، تقنيات الحفظ، الاستزراع السمكي، جودة الأسماك، مدة الصلاحية.