Review Article

QUALITY AND SAFETY CONCERNS OF FARMED TILAPIA FISH DURING FREEZING AND FROZEN STORAGE: REVIEW.

quality and safety of fresh

Abstract.

This study addresses the growing concern over the quality and shelf life of farmed fish products in the market due to the increasing demand in the international market. Various preservation methods are necessary to ensure food safety and extend the shelf life of fish products. Freezing and chilling are still considered the most reliable methods for preserving farmed fish. The study reviews techniques for extending the shelf life of frozen farmed fish, with a focus on the most common species in the international market. Results suggest that good frozen storage conditions and the method of preservation are critical factors in reducing post-harvest losses and extending the shelf-life of farmed fish in the market. The study recommends adopting freezing and frozen storage principles for farmed fish species, prioritizing quality concerns post-harvest, and paying close attention to optimal frozen storage conditions.The study also recommends adopting freezing and frozen storage principles to preserve and maintain the quality of farmed fish species, such as Nile Tilapia, carp, trout, and catfish. Fish farmers should prioritize quality concerns post-harvest to ensure safety and conforming products, reduce losses and extend shelf-life. Optimal frozen storage conditions must be maintained for high-quality and safe products. Further research is required to compare the effect of prolonged freezing and frozen storage on farmed and captured fishes and factors related to fish species, habitat, and food should be considered when optimizing storage conditions.

Keywords: *Frozen fish, shelf life, fish quality, fish spoilage, Rigour mortis*

1. INTRODUCTION

The demand for farmed Tilapia fish products in the global market has increased significantly, highlighting the importance of ensuring their quality and shelf life. Unfortunately, the quality of frozen fisheries products from marine and freshwater sources has been declining steadily and has become a subject of debate among consumers. As the second most traded farmed fish species globally, Tilapia frozen products are common in the market, and quality concerns related to frequent freezing and thawing have emerged. Mehta et al., (2014)observed that ice storage and subsequent frozen storage of Indian carp gutted fish led to an increase in gelation rate and changes in protein composition, similar to slow-frozen whole Tilapia fishes(El-Sayed, 2020). Similarly, Jiang et al., (2022) also observed that the quality of bigeye tuna flesh deteriorated during slow frozen storage after light salting due to its high dimethylamine and formaldehyde content. However, Subbaiah et al., (2015), noted that no comprehensive research has been conducted to explain the deterioration process of quick-frozen Tilapia under frozen storage.

The primary cause of deterioration in fresh fish over a long period is due to microbial activity(Zhan et al., (2018). Fish muscles contain highly soluble nitrogen components which are linked to rapid bacterial deterioration (Boziaris& Parlapani, 2017). Psychrophilic bacteria are present in frozen fish products during the chilling and freezing process, and they intensify the rate of deterioration. According to IWAMOTO et al., (1987),Gram-negative bacteria are more prevalent in cold-water fish during chilling and slow freezing, while Gram-positive bacteria are associated with tropical water fishes like Tilapia. To ensure sustainable freezing and frozen storage of Nile tilapia, the ambient temperature should be below 0°C.(Jessen et al., 2014) to eliminate the Gram-positive bacteria which are more abundant in tropical areas where Tilapia fish farming is common. According to Lakshmisha et al., (2008), the recommended temperature for freezing and frozen storage of fresh fish is between –15°C to –30°C. Alsailawi et al., (2020) also observed that deterioration of fish products under freezing is also caused by enzymes produced by the fish itself or by external pathogens on the fish's body. Similarly, Intrinsic enzymatic activity in fish packed for freezing and frozen storage causes significant quality degradation(Nikkilä& Linko,1956). Therefore, Enzyme protease activities in packed fish during frozen storage lead to significant quality variations in fresh marine fish products. Pre-heating treatment can denature some intrinsic enzymes in fish, which can prolong the shelf life of the fish product during frozen storage.

According to Boziaris, (2014), During the heating stage in seafood processing, the fish flesh becomes soft due to the denaturation of proteins and enzymatic activities in the muscles. The author noted that the shear force value decreased during the observation due to protein hydrolysis during alkaline protease action. However, the degradation of the quality of fish products during frozen storage, including changes in texture, appearance, and odour, remained a mystery(Sikorski &Kołakowska, 1994).

Chen et al., (2022) observed alterations in the texture of frozen sea bass during frozen storage, which raised concerns about a fresh gram-positive bacterial infestation on fish products like Nile Tilapia, Carp, and catfish freeze frozen storage products.Shi et al., (2018) found a significant relationship between the textures of pre-frozen perch fillets and their mince, as well as the ratio of dissolved proteins in the brine solution. They suggested an approach for evaluating frozen fillets and frozen mince based on soluble and total proteins. Wang et al., (2022) developed a topological dimensional quality evaluation approach for frozen tilapia fillets kept at various temperatures, which established composite qualities by distinguishing their units and relevance to assessing the unit's level of acceptance and tilapia fillet quality.

By prolonging chemical alteration and variations, impeding enzyme action, and eradicating microbial proliferation, nutrition-related fish quality, such as flavour, colour, and texture, can be preserved(Bland et al., 2018). The characteristics of each component can provide information about the overall nutritional value of the freeze-frozen storage fish since each component's quality parameters can be easily monitored and altered autonomously.

The cause of quality changes in farmed fish such as Nile Tilapia (*Oreochromis niloticus*) during the process of freezing and frozen storage is not well understood. This lack of understanding is due to a dearth of knowledge regarding the underlying causes of immediate deterioration associated with the frozen storage of farmed fish products. Farmed fish have a high level of bacterial loads that can trigger fish spoilage even before the fish reaches the Rigormortis stage, which is at the pre-rigor stage(Zhan et al., 2018). Therefore, there is an urgent need for coherent research to predict the properties or rate of deterioration of farmed fish products during freezing and frozen storage.

This research requires the collaboration of food scientists, food technologists, chemists, and bacteriologists to investigate methods to maintain the quality of frozen farmed fish products. With this broad vanguard of intellectuals consisting of scientists in the field of fish processing technologies, the right findings are bound to be obtained in due time.Previous research has focused on quality changes in frozen marine fish products and other seafood such as shrimps(Boziaris, 2014). One way to preserve the muscle of farmed Nile tilapia fish for an extended period is to freeze it(Kobayashi et al., 2017). However, chemical and physical changes to the fish occur during the freezing and frozen storage process(Bilbao-Sainz et al., 2020). The protein composition of the fish muscles undergoes selective dehydration during the freezing period, (Bilbao-Sainz et al., 2020)and the protein's freeze occurs as a result of the freezing of inorganic compounds such as mineral salts. This can lead to concerns about the quality of the frozen fish product in the eyes of consumers, especially when it is subjected to multiple freezing and thawing cycles.

The primary objective of this review study is to analyze the available literature on the modifications that take place in farmed Nile tilapia (Oreochromis niloticus) and other related fish species, both freshwater and marine fishes, during the freezing and frozen storage period. This analysis will help to pave the way for further research in this important area since tilapia fish farming is increasing worldwide, and preserving fish through freezing and frozen storage methods is the best approach to minimize post-harvest losses and increase shelf life.

2. MATERIAL AND METHODS

For this review, a variety of secondary sources were utilized, including peer-reviewed journals, newsletters, reports, and relevant publications from both national and international sources. A total of 96 peer-reviewed journals were reviewed ranging from 1987 to 2023. Additionally, electronic media was also consulted, such as visits to the websites of fish processing companies in India, China, and Kenya. The collection and organization of this secondary information were done meticulously and systematically.

3. ANALYSIS OF THE LITERATURE FINDINGS

Farmed fish, similar to marine fish, necessitates advanced preservation techniques to guarantee quality is sustained throughout the value chain. The method of fish storage, shelf life, and original product quality are crucial factors that affect the quality of fish.

3.1. Coldstorage of fish

Cold storage techniques for preserving farmed Nile Tilapia are not new among major producers like China, India, Thailand, and Egypt (Macfadyen et al., 2012). Similar tofreshwatercapture fisheries and marine seafood, cold storage can be applied at any stage of the supply chain, from harvesting to consumption (Mehta et al., 2014). Fish farmers should store the fish in batches according to size grade, using either ice boxes or freezing and frozen storage facilities before transporting them to collection and distribution centres to meet the demand of clients at all levels. According to Xie et al., (2023), Cold storage is critical to controlling the temperature and preventing the fish from entering the rigour stage quickly, regardless of the quantity of fish produced. Many factories have cold chain facilities and transfer iced fish into frozen vehicles from collecting centres before entering the main freezing and frozen chamber in the factory for the case of India(Mehta et al., 2014). Quality assurance and HACCP measures are essential for transporting fish products (Boziaris, 2014)to and from frozen vehicles. According to Duarte et al., (2020) to ensure a quality supply of fish products in the market, big storage areas that can store refrigerated container loads with fish act as the link between fish processing factories and fishvehicles. Checking the ambient temperature of the fish product before accepting the container at the port of destination is necessary(Nakazawa & Okazaki, 2020). To reduce the loss of cold air during fish product movement, a 6kg box and standardized-tone pallet should be used for racking and shipping tilapia fish frozen products(Ólafsdóttir et al., 1997a).

3.2. The deterioration of fish freshness and shelf life

Compared to captured fish, farmed fish is considered highly perishable due to the presence of extrinsic pathogens on their body that can easily cause microbiological deterioration if not properly preserved.(Mzula et al., 2021; Opiyo et al., 2018) Therefore, efficient storage criteria must be adopted for farmed fish to ensure safety and extended shelf life for the benefit of fish farmers, stakeholders along the value chain, and consumers in the market. According to Dawson et al., (2018), The shelf life of fish is influenced by various factors, such as the storage period, temperature, fish species, and stress level during harvesting. And the amount of ice used during the chilling process(Mahmud et al., 2018; Mahmud et al., 2019). To address the need for better fish storage, Özyürt et al., (2015) reported recent advancements that have been made in contemporary fish storage methods, such as pressure processing, irradiation, and pulsed light technology. As well as pulsed electric field, microwave processing, radio frequency, and ultrasound, among others reported (Boziaris, 2014). These advancements are aimed at improving fish storage and reducing the risk of spoilage and contamination, thereby ensuring that the fish retains its quality and nutritional value for a longer period.

Despite the development of advanced technologies for fish processing and preservation, fish chilling and freezing remain the most commonly used preservation methods for farmed fish, such as Tilapia(Jessen et al., 2014). These techniques are used to preserve fish quality at low temperatures,(Wang et al., 2022) including refrigerated storage at 0°C to 4°C and frozen storage at 18°C to 40°C (Jiang et al., 2023). At the farm level, fish chilling is commonly achieved using ice, which may involve the use of super chilling technology. This technology freezes a small portion of the fish water content (4-35%), making the fish less susceptible to spoilage(Zhang et al., 2022). With this approach, there is no need for external ice around the fish product, which results in lower transit weight and expense, as well as a longer shelf-life than chilled fish due to reduced microbial activity(Jessen et al., 2014). However, it should be noted that these sophisticated methods are not commonly available to ordinary fish farmers. According toMiyawaki, (2018), super chilling technology can speed up self-autolytic reactions in fish, leading to enzymatic or chemical reactions that cause quick fish spoilage when thawed.

Fish freezing, on the other hand, is suitable for fish in the pre-rigour mortis stage, rather than the rigour mortis and post-rigour mortis stages(Lee et al., 1998; Roiha et al., 2018). This is because fish in the pre-rigor mortis stage have better quality characteristics and are less prone to degradation during storage(Dawson et al., 2018). Freezing prevents the growth of microorganisms, enzyme activity, and chemical reactions, which contribute to fish spoilage (Boziaris, 2014). However, it should be noted that freezing can cause changes in the texture and quality of fish(Boziaris& Parlapani, 2017) which can affect its sensory attributes and nutritional value. Therefore, proper freezing techniques must be used to minimize these effects and preserve the quality of the fish during storage.

To ensure the safety and extended shelf life of farmed fish, efficient storage criteria are needed due to the high extrinsic pathogens in their body that can easily cause microbiological deterioration if not properly preserved(Mahmud et al., 2018; Nagarajarao, 2016). Although sophisticated fish preservation methods such as pressure processing, irradiation, and pulsed light technology are available, fish chilling and freezing are still the most commonly preferred preservation methods, especially for farmed fish such as Tilapia. Fish chilling using ice (Diaoet al., 2021a)may entail the use of super chilling technology to freeze a small portion of the fish water content and reduce microbial activity, resulting in a longer shelf life than chilled fish. However, super chilling technology can speed up self-autolytic reactions in fish, leading to quick fish spoilage when thawed(Bouchendhomme et al., 2022; Jiang et al., 2023). Fish freezing should be done quickly rather than through the prolonged freezing process to enhance quality during freezing. To increase fish shelf-life and ensure its quality and safety, incorporation of freeze/chill temperature and duration, regulation of bleeding conditions, and fish preparation (whole, gutted, filleted) should be considered(Jiang et al., 2023; Zhang et al., 2022). The review paper focuses on traditional chilling and freezing methods for farmed fish, marine and freshwater capture fish species, and explores ways to increase the shelf-life of cooled and frozen fish, which is crucial for the quality assurance of farmed Tilapia fish. The review also discusses traditional sensory, physicochemical, biochemical, and microbiological approaches for assessing fish quality and explores mechanisms of fish deterioration and spoilage that can be learned and mirrored in Tilapia fish farming.

3.2.1. **Fish freshness deterioration and post-mortem changes**.

Fish Freshness refers to unfrozen fish that has retained its sensory, chemical, and nutritional qualities since harvesting or capture. The loss of fish freshness due to fish deterioration begins immediately after harvesting from the pond at the pond site for farmed fish. The post-mortem changes show the need to cautiously handle fish well after harvesting and through the processing and marketing period to retain the quality of the end fish product. Fish handling will thematicallydetermine the enzymatic, bacterial, and oxidative activity that occursin the fish under storage. Similarly,Hematyar et al., (2018) reported that the working pace of thefish storage method used during the frozen storage of common carp (*Cyprinus carpio L.)* filletwasinfluenced by frozen storage temperature and period of treatment. This too can dependon the preservation methods used, as well as the fish species, size, catch method, temperature, storage type, and physical state before death(Esteves &Aníbal, 2021). Immediately after the fish die Sensory, physicochemical, and microbiological changes take place. Sensory alterations are linked to how the senses perceive insight, texture, odour, and taste.Examples of such change includemuscle browning anddarkening due to reactions that occur when temperatures are high, enzymatic activity in the body,and the production of mucus,especially mucin-type which is considered glycoprotein ideal for bacterial growth (Calanche et al., 2019). Similarly, the fish also starts to emit an odour when spoilage starts. Therefore, at the farm level, Tilapia fish farmers ought to be careful with fish handling and preservation measures at the pond site to protect fish from spoilage immediately after it is harvested the fact that could result in post-harvest losses.

Muscular withdrawal a conditioncalled gaping, as well as belly exploding,arealso sensory alterations induced by the activity of digestive enzymes contained in the fish gut as reported by (Ólafsdóttir et al., 1997b). Fish equally undergo chemical changes immediately after death. Chemical changes are identified through chemical analysis which is done toevaluate the extent to which fish muscles have undergone deterioration andthe resulting compoundformed and to evaluate the fish based on grade. Similarly, Physical changes, on the other hand, allow for the determination of additional deterioration characteristics, which include the measurement of tissue change in resistance and muscular stiffness. According to (Prabhakar et al., 2020a) in review fish muscles were observed to steadilydiminish until the fish reaches a critical stage of deterioration. These sorts of changes are caused by processes that compromise with pH, rigour mortisprocess, protein breakdown, and free amino acids and lipids.

Whenevera dead fish is placed in ice for 5 to 8 days, the bacteria load is present on the body under a delay-sensitive phase called the lag phase while adapting to the new environment on the dead fish. This is through the use of the modification of survival strategies owing to the lack of oxygen. In reality, when contrasted to autolytic activity, which is primarily for quality loss, bacterial action is the primary cause of fish degradation and deterioration. This is bolstered by the fact that self-autolysis begins in the digestive system truck and may be controlled through gutting ng ofthe fish at the pond site for the case of farmed Nile Tilapia before icing is done. when evisceration is done properly, the activity of proteolytic enzymes and bacterium movement from the intestinal flora to fish flesh is inhibited duringfreezing and frozen storage.(Kobayashi et al., 2017; Skjervold et al., 2001). Hence, post-mortem deterioration of fish can be divided into three stages: Rigormortis, autolysis, and bacterial spoilage.(Lee et al., 1998)

3.2.2. Rigor mortisprocess in farmed fish

Rigor mortis is a natural process that occurs in a fish, typically a few hours after death. It is the stiffening of the muscles in the fish body(Kobayashi et al., 2017), caused by a chemical reaction that occurs as the body begins to decompose. The process begins in the smaller muscles (IWAMOTO et al., 1987)and eventually spreads to the larger muscles in the body.

The onset and duration of rigor mortis can be affected by several factors, including the temperature of the environment, and the age of the fish (JERRETT et al., 1998).Rigor mortis typically begins to subside within 24-48 hours(Skjervold et al., 2001) immediately after fish death, as the body continues to decompose. Fish muscle contains glycogen, creatine phosphate, and adenosine triphosphate (ATP) which are responsible for maintaining the muscle's flexibility and stretchiness(IWAMOTO et al., 1987). However, once the fish dies after being harvested from the pond, these substances begin to deplete, and the muscle loses its flexibility and stretchiness after a few hours. At the same time, Lee et al., (1998) observed that the fish's blood circulation and defensive systems stop working, which leads to a lack of oxygen transport and the start of anaerobic glycogen respiration (glycolysis). The length of time that glycolysis occurs depends on the amount of glycogen stored in the fish(Wei et al., 2020). Which according to the authors is higher in well-fed fish and those that experienced a less violent death, resulting in a longer shelf-life.

As glycolysis progresses, the ATP concentration in the fish decreases, which leads to the generation of lactic acid and a decrease in pH. Additionally,Wang et al., (2022) and found that temperature changes can also affect rigour contractions in rested and partially exercised Tilapia fillets stored at different temperatures, with higher temperatures leading to faster rigour stages in the muscle. Therefore, it is important to maintain lower temperatures (Jarrett et al., 1998). This is to delay rigour and prevent post-harvest losses associated with poor storage of farmed fish products.

During the onset of rigour mortis, the drop in pH leads to a decrease in bacterial growth and the capacity of proteins to retain water(Kristoffersen et al., 2006). Similarly, accordingto Lee et al., (1998) during the rigour mortis stage, protein peptides form links between fish muscle collagen fibres, resulting in muscle contractions and rigidity. The restoration of rigor mortis can take hours or more than a day, depending on various factors, including the fish species, temperature, handling, size, physiological state, and stress level experienced by the fish before death.(JERRETT et al., 1998; Lee et al., 1998). When the rigour mortis process begins later and with less stress and lower temperatures, the flesh stiffness is better maintained, resulting in better-quality fish.Furthermore, IWAMOTO et al., (1987) found that storage temperature has a significant influence on rigor mortis and ATP deterioration in the muscle of plaice *Paralichthysolivaceus.* During the recovery of rigour mortis, autolytic activities begin, which leads to fish deterioration immediately. Therefore, to extend the shelf life of farmed Nile tilapia, it is important to chill and freeze the fish quickly after harvesting from the pond site to delay the rigour mortis process. This biosecurity quality assurance approach is crucial in ensuring that the fish is of good quality for human consumption.

3.2.3. **Autolysis and Bacterial Spoilage**

Autolysis refers to the process of self-digestion that occurs in fish after death, which leads to the breakdown of cell structures and the release of enzymes that contribute to fish spoilage. Bacterial spoilage, on the other hand, refers to the growth of bacteria on the surface and inside of the fish,(Mahmoud et al., 2004). According to the author this results in the production of harmful toxins that can cause foodborne illnesses in humans who consume fish. Boziaris&Parlapani, (2017)also reported that both autolysis and bacterial spoilage are important factors to consider in preserving the quality and safety of fish for human consumption. Proper handling, storage, and processing techniques can help minimize the extent of these processes and prolong the shelf life of the fish(Prabhakar et al., 2020b).When fish die, they undergo a process called autolysis which is the hydrolysis of proteins and fats in fish by proteolytic and lipolytic enzyme reactions(Nie et al., 2022). This process is mainly caused by lysosomal and cytosolic enzymes' systematic reactions within the cells of the fish muscle. Erkmen&Bozoglu, (2016) found that the breakdown of myosin-heavy chains and myofibrillar proteins by these enzymes leads to changes in the texture and softening of the fish muscle structure. This makes the fish vulnerable to bacterial attack,(Sheng & Wang, 2021a) which causes spoilage. Therefore, to improve the quality and shelf life of farmed Nile tilapia *(O. niloticus*), immediate chilling and quick freeze-frozen storage should be done at the pond site right after harvesting.

However, it's essential to note that decreasing enzymatic activities and reaction rates in fish muscle at 0°C restricts storage time (Getu&Misganaw, 2015; Mahmud et al., 2018b)both in non-fatty and fatty fish due to mainly lipids and protein autolysis at freezing temperature (–18°C). Therefore, quality improvement of Nile tilapia *(O. niloticus*) should be done by first chilling using ice at the pond site immediately after harvesting, which should then be followed by quick freezing during frozen storage. This approach will limit the rate of autolysis and bacterial spoilage, which ultimately will increase the shelf life and quality of the fish as reported by (Mahmoud et al., 2004).The right quantity of ice to fish ratio should be observed while chilling tilapia fish in preparation for freeze frozen storage process as in figure 1

*Figure 1 Chilling of Nile Tilapia (Oreochromis niloticus) using Clean ice.**(photo adapted from.istockphoto.com/photo/tilapia-fish-in-market***

3.2.4. **Lipid Oxidation**

Lipid oxidation is a significant concern in fish and seafood products as it results in the development of off-flavours, rancidity, and reduced shelf life. According to Ghanbari et al., (2013), reported that the process of lipid oxidation is initiated by the presence of free radicals, which can be generated through a variety of mechanisms, including exposure to heat, light, and oxygen. These free radicals then react with unsaturated fatty acids in the fish lipids, leading to the formation of lipid hydroperoxides.(Duarte et al., 2020b).Therefore the rate of lipid oxidation is influenced by several factors, including the lipid composition of the fish, the presence of antioxidants, and storage conditions such as temperature and light exposure(Sheng & Wang, 2021b). Fish with higher levels of polyunsaturated fatty acids (PUFAs) are more prone to lipid oxidation than those with lower levels of PUFAs, especially in farmedrainbow trout (*Oncorhynchus mykiss*) (Nikoo et al., 2021). Therefore, to prevent lipid oxidation in fish and seafood products, various methods are used, including the addition of antioxidants such as vitamins E and C, (Syanya et al., 2023)vacuum packaging, and the use of modified atmosphere packaging(Kontominas et al., 2021). These methods can slow down the rate of lipid oxidation and improve the shelf life and quality of fish products.In ideal situations lipid oxidation is a significant concern in fish and seafood products as it results in off-flavours, rancidity, and reduced shelf life. Preventive measures such as the addition of antioxidants and modified atmosphere packaging can help slow down the rate of lipid oxidation (Kontominas et al., 2021; NIKKILÄ & LINKO, 1956)and improve the quality of fish products.The belly and caudal region of farmed Nile tilapia (*O. niloticus)* have a considerable amount of lipids that are vulnerable to oxidation during storage, despite the fish being generally low in lipid content. This is a major quality concern because unsaturated lipids, such as polyunsaturated fatty acids (PUFA's),(Ghaly et al., 2010a) are highly susceptible to oxidation, resulting in changes in taste and the production of peroxides in the fish muscle. It is essential to practice proper care to minimize the lipid oxidation process.

(HEARN et al., 1987) also observed that fatty fish, such as sardines (*Sardinapilchardus*) and horse mackerel (*Trachurustrachurus*), contain the highest percentage of unsaturated lipids, making them more prone to oxidation. The oxidation process in fish begins with hydroperoxides,(Everson et al., 2021) which cause the fish tissue to turn brown or yellow, and further spoilage leads to an unpleasant rancid flavour especially in rainbow trout, (*Oncorhynchus mykiss)*. The presence of extrinsic bacteria on farmed fish, such as Nile Tilapia (*O. niloticus*), combined with traces of lipids, leads to higher spoilage rates caused by lipid oxidation and bacterial spoilage.

To ensure good quality frozen Nile tilapia *(O. niloticus)* in the market, a series of chilling, fast freezing, and frozen storage at ambient temperatures ranging from -18^{oc} to -35 ^{oc} are essential (Jessen et al., 2014; Löndahl& Nilsson, 2003). It is crucial to note that exposure of frozen fish to light, particularly ultraviolet, organic, and inorganic substances such as copper and iron, can initiate and accelerate the lipid oxidation process in farmed fish, leading to spoilage(Jiang et al., 2023),especially in Tilapia fillets.

These findings suggest that the quality of farmed Nile Tilapia (*O. niloticus*) and other farmed fish can be improved by proper packaging to prevent sun exposure and ultraviolet light before being considered for freezing and frozen storage. In addition, fish farmers should be cautious of veterinary medicines used in aquaculture such as copper (II) sulphate and potassium permanganate (VII) which contain copper and iron elements respectively. According to Shaw & Handy, (2006)These inorganic chemicals have been found to accelerate the lipid oxidation process in fish during freezing and frozen storage, leading to spoilage. Therefore, regulations should be put in place to control the use of such chemicals in aquaculture to ensure quality preservation.Furthermore, the findings reported by the majority of authors emphasize that bacterial spoilage is a more serious concern. Once the fish dies after harvesting, the body becomes a favourable environment for bacterial pathogens. (Ghanbari et al., 2013; Mahmoud et al., 2004). Similarly, Boziaris& Parlapani (2017) support this claim, suggesting that bacterial spoilage is a major contributor to the deterioration of fish quality. Therefore, it is crucial to adopt proper storage methods and hygiene practices to minimize the growth of bacterial pathogens and prevent spoilage of farmed fish.The quantity and distribution of bacteria present in different parts of a fish can vary depending on the state of the fish(Mahmoud et al., 2004). For instance, the author observed that the number of bacteria per square centimetre before decay is lowest on the skin of the fish, with a range of 100 to 10,000, while the gills have a range of 1,000 to 1,000,000 and the digestive tract has 1,000 to 100,000,000. However, after decay, the number of bacteria on the skin can increase dramatically from1,000,000 to 100,000,000(Mahmoud et al., 2004). This shows that bacterial growth can rapidly multiply in a decaying fish. To control this, specific temperature measures should be taken such as chilling, super chilling, freezing, and frozen storage, which can be easily managed and regulated.

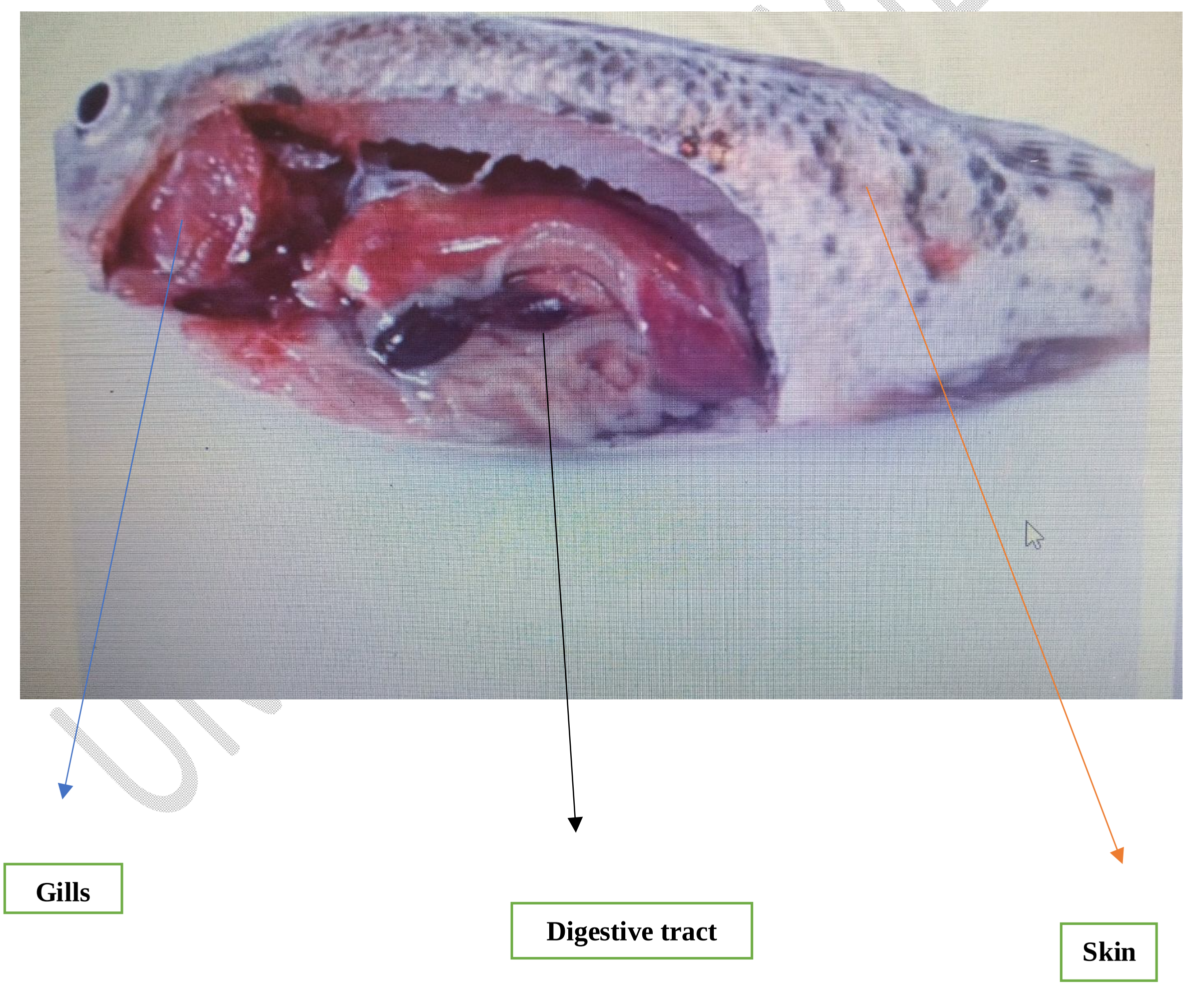

Figure 2. opportunistic parts of farmed tilapia for bacterial spoilage

3.2.5. Effects of changes in storage temperature on the quality and shelf life of farmed fish.

Temperature is by far the most significant factor in determining how quickly fish spoil.

The higher the temperature, the faster the chemical dissolves and the commencement of autolysis and bacterial degradation.Each bacterial species has a temperature range in which it grows best.There is also a minimum temperature below which bacteria cannot grow and a maximum temperature over which bacteria cannot grow. According to Boziaris& Parlapani, (2017)Bacteria that like cold temperatures - Psychrophilic (0-20°C) Choose 15°C, for example. *Psuedomonas,*Mesophilic bacteria -(20-45°C) -Optimum temperature 37°Ce.g. Salmonella(45-70°C) thermophilic bacteria Optimal temperature is 55°Ce.g. Clostridium botulinum is a kind of bacteria.82°C-110°C-Optimum 105°C - Pyrodictiumhyperthermophile. Based on these findings farmed fish such as Nile Tilapia are prone to nearly all these bacterial deterioration effects. Therefore, proper storage and handling parameters must be observed at all times within the value chain to reduce fish spoilage which may result in post-harvest losses to fish farmers. However, Gaping" in fish is temperature dependent; the higher the temperature of the fish during the start of the rigour mortis phase, the greater will be the gaping of the muscle.

Gaping is muscle separation in fish fillets that occurs during frozen storage and is regarded as a quality flaw.As a result, during rigour mortis, the temperature of the fish should be kept as low as possible.The temperature of the fish determines the onsetand length of the rigour mortis phase in both marine and farmed fish. The higher the temperature, the faster it starts and the faster it stops. According to Kobayashi et al., (2017)Rigor mortis,in Nile Tilapia fish for example, begins 24 hours after death and lasts 72-80 hours when the fish is kept under chilling at 0°C. Concerningthe findings of these authors farmed Nile Tilapia should be kept under ice immediately after harvesting from the pond site to prolong the rigour mortis process especially when the fish is destined for factory processing and export to the global market.

This isspecially controlled by enzymatic processes that accelerate with increasing temperature, *figure 3.*At high temperatures, the enzymatic reactions cause more modifications in proteins, resulting in greater loss of tissue fluids during processing.Typically, the later rigour mortis begins and the longer it lasts, the longer the fish's storage life and usage for consumption.Therefore,for farmed Tilapia fish, itis believed that Chilling and freezing fish is an efficient approach to reduce spoiling if done swiftly, correctly, and hygienically right away from the pond site.

Based on the findings of Lee et al., (1998) in their work on Differences in Progress of Rigor Mortis between Cultured Red Sea Bream and Cultured Japanese Flounder, The greater the storage temperature, the shorter the shelf life of the fish. Fish with a 15-day storage life at 0°C will keep for 6 days at 5°C and just around 2 days at 15°C. they further observed that When the same species are stored at 35°C, it starts 20-30 minutes after death and ends around 3 hours later.This is too demonstrated by enzymatic processes that accelerate with increasing temperature. Since At high temperatures, the reactions cause further changes in proteins, resulting in significant loss of tissue fluids during processing.
Typically, the later rigour mortis begins and the longer it lasts, the longer the fish's storage life and usage for consumption.

Similarly, observations were made by Tolstorebrov et al., (2016); Wei et al., (2020) that The greater the storage temperature, the shorter the shelf life of the fish. Fish with a 15-day storage life at 0°C will keep for 6 days at 5°C and just around 2 days at 15°C.
Boran et al., (2006) also observed that as a general rule, for every hour the fish are kept at room temperature, the equivalent of one day's storage life is lost, and for every 5°C and 0°C they are held, the storage life in ice is cut in half.Therefore,Freezing is by far the most effective way of removing heat from fish. The quicker the freezing process, the less spoilage is recorded. As a result,for commercial purposes farmed fish need to undergo freeze and frozen storage just like captured fishes from marine and freshwater systems. fast freezing is used is therefore recommended the suggested temperature for lowering the temperature of the fish is -30°C, with the inside of the fish being -20°C(Malik et al., 2021; Moody, 2003; Xie et al., 2023).

3.2.6. **Effect of Super chillingprocess between (0°C to -4°C) on fish quality**

Super chilling, also known as partial freezing, involves storing fish at temperatures between 0°C and -4°C immediately after leaving the pond. This technique can increase the shelf life of many types of fish and shellfish by preserving their freshness(Gökoğlu&Yerlikaya, 2015). Fish products that have been superchilled have a longer shelf life than those that have not. However, a study by (Roiha et al., 2018) found that Atlantic cod stored at -2°C for 10 days had a less appealing appearance and texture than fish kept on ice at 0°C. Additionally, when super-chilled fish is stored at -3°C, it has a higher drip rate and an unsatisfactory texture for filleting.(Skjervold et al., 2001).This is due to the production of large ice crystals, protein denaturation, and increased enzymatic activity in partially frozen fish. This negative impact on the appearance and texture of sea bream fillets was also noted by(Diop et al., 2016). Despite these limitations, super chilling is used commercially for some fish species, such as tuna and salmon, and can also be used for farmed fish, including Nile Tilapia, as a quality control measure.

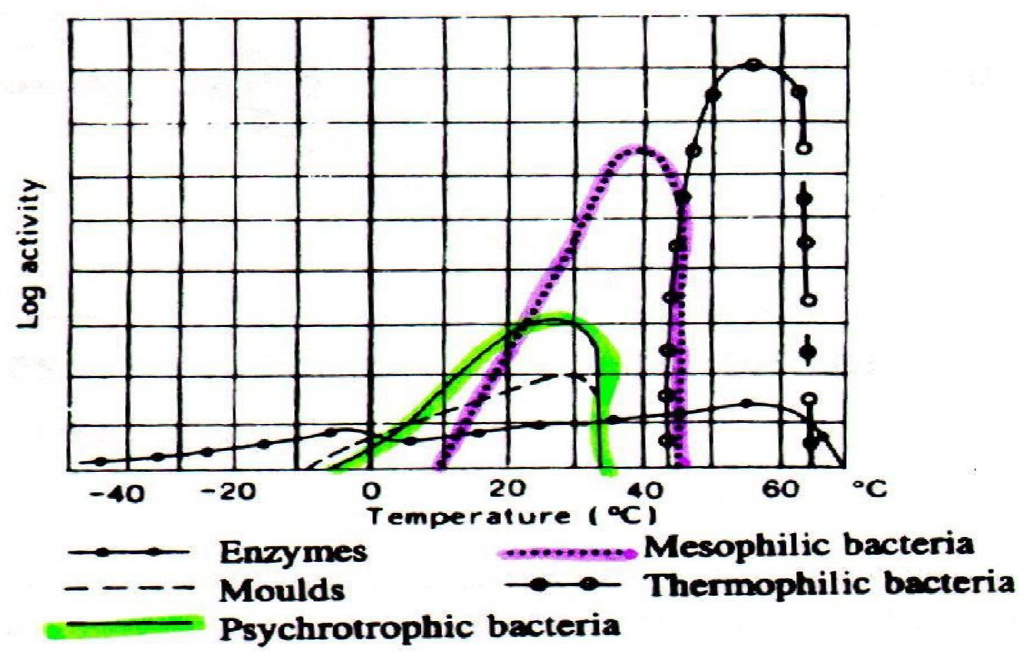

Figure 3. Relative enzyme activity and growth rate of bacteria in relation to temperature (Andersen et*al.,*1965).

3. 2.7. Fish quality evaluation process and its pros

The fish quality evaluation is an important process that involves assessing the condition, freshness, and safety of fish products. fish quality evaluation is linked to several benefits to the consumerswhich include but are not limited to: Ensures safety(Duarte et al., 2020b): Fish quality evaluation ensures that fish products are safe for human consumption by detecting any harmful substances or contaminants present.Maintains freshness(Nakazawa & Okazaki, 2020) the authors reported that evaluating the quality of fish products helps to maintain the freshness and flavour of the fish for longer periods.It Determines market value:(Xie et al., 2023) Fish quality evaluation helps to determine the market value of fish products based on their quality, which is important for both the producers and consumers.

According to Nakazawa & Okazaki, (2020) it Improves quality control: Fish quality evaluation helps to improve quality control by providing a standard for evaluating fish products and ensuring consistency in their quality.Assessing fish quality goes beyond just its appearance and freshness; it also involves checking for harmful microorganisms and chemicals, as well as examining its moisture, acidity, colour, feel, and macro-nutrient composition(Nie et al., 2022). Evaluating fish quality requires a combination of techniques such as sensory analysis, physical chemistry, biochemistry, and microbiology. One commonly used technique for evaluating fish quality is sensory analysis, which assesses people's perceptions of a product through their five senses - sight, smell, touch, taste, and hearing(Esteves &Aníbal, 2021). The Quality Index Method (QIM) (Esteves &Aníbal, 2021)is often used in this technique to assess the quality of raw fish by measuring variations in key criteria and converting them into equivalent days of storage and shelf-life. The Torry scheme, evaluation (Jahan et al., 2017)on the other hand, is used to evaluate the freshness of cooked fish fillets from the sensory evaluation. The QIM scheme is highly recommended for evaluating the quality and freshness of farmed fish products like Nile Tilapia. The QIM scale ranges from 0-10, with 10 being "very fresh taste and odour," 5.5 being the limit for consumption, 3 for spoiled fish, and lower scores indicating that the fish is unfit for human consumption(Duarte et al., 2020b). This scale is easy to use in a regular setting and can be adopted by fish farmers to conduct preliminary fish quality checks.

3.3. The trend in Deterioration levels offarmed fish stored under ice conditions

Farmed fish just like captured fish is a perishable food product that is susceptible to spoilage and decay, which can lead to quality deterioration, food safety risks, and economic losses. According to (Ghaly et al., 2010a) the rate of deterioration of fish depends on several factors, including the initial quality of the fish, the storage temperature, the storage time, and the presence of microorganisms.Storing fish under ice conditions is a common method used to preserve the quality and freshness of fish(Sheng & Wang, 2021b). Ice helps to maintain a low temperature and slows down the rate of bacterial growth, which can extend the shelf life of the fish. However, Natseba et al., (2005) reported that the effectiveness of ice storage depends on several factors, such as the quality of the ice, the thickness and coverage of the ice layer, and the temperature and humidity conditions in the storage area from his study onicing duration on quality changes in frozen Nile perch (Lates niloticus). Therefore, to ensure the safety and quality of farmed fish stored under ice conditions, it is important to follow best practices for handling, storing, and transporting fish. This includes proper cleaning and handling of the fish before storage, using high-quality ice, maintaining a consistent and appropriate storage temperature, and monitoring the fish for any signs of spoilage or deterioration(Karungi et al., 2004). In general,the trend in deterioration levels of farmed fish stored under ice conditions depends on several factors and can vary based on the specific conditions of storage and handling. It is importanttherefore to follow best practices and guidelines for fish storage and handling to ensure the safety and quality of the fish.

According toDuarte et al.,(2020c)When fish is stored on ice, it undergoes a process of deterioration that can be divided into four stages. The first two stages involve quality loss due to self-autolysis processes, while the last two stages involve degradation caused by microbial activity within the fish's body. Initially, the fish and shellfish exhibit high levels of freshness, with a water scent and pleasant flavour (Ashie et al., 1996). However, in the second stage, there is a loss of taste and odour, though the texture remains good and there is no growth of disagreeable taste (Duarte et al., 2020c; Najam ul Hasan et al., 2012). The third stage is characterized by the emergence of odour signals, including the creation of a "fishy smell," ammonia, and certain sulphuric molecules, with a slightly vinegary flavour. (Freitas et al., 2021; Najam ul Hasan et al., 2012) The fourth stage signifies that the fish deteriorates and rancid Boziaris& Parlapani, (2017) . Therefore, it is recommended that fresh farmed or captured fishery products (excluding live fish) be chilled as soon as possible after harvesting, with a maximum delay of 3 hours, and kept at temperatures close to the melting ice rate while considering the requirements for microorganism survival. These recommendations are in accordance withJessen and others' work(Jessen et al., 2014).

The importance of temperature in fish storage is supported by Boran et al., (2006); Tolstorebrov et al., (2016). Namulema et al., (1999)found that frozen Nile perch (*Lates niloticus*) stored at -13 and -27°C recorded extended shelf life. While (Boran et al., 2006) reported a shelf-life of 8 days for fish stored on ice at 5°C. These temperatures can also be applied to the cold storage of farmed fish products, such as Tilapia, and Rainbow Trout (*Salmo gairdneri*) Cultured in Brackish Water to extend their shelf-life (Teskeredzić& Pfeifer, 1987). It is crucial to maintain these temperatures using ice or a refrigerator, as demonstrated by (Diao et al., 2021b) in their study on grass carp during frozen storage. The authors evaluated changes in fish quality with different storage methods, including immersion freezing. They found that fish stored on ice had higher levels of Trimethylamine and pH compared to refrigerated fish. A similar study by (Özyürt et al., 2015) on Frozen farmed Rainbow Trout (*Oncorhynchus mykiss)* Fillets found that texture and firmness decreased throughout storage time. The authors attributed the decrease in pH to lactic acid formation and ATP decomposition, followed by an increase due to alkaline compound build-up. In their research on Nile tilapia fillet,(Xie et al., 2023) found that gutting the fish before frozen storage increased the initial microbial load due to increased fish flesh surface contact with the surroundings and the gutting process and tools used. The authors also observed that Pseudomonadaceae were the most dominant bacteria in both gutted and non-gutted fish samples, with lower levels in gutted fish increasing rapidly throughout the investigation. Despite the lower beginning levels seen in gutted fish, the researchers found that this treatment stimulated Pseudomonadaceae development and altered the fish microbiome loads. Based on these findings, it can be concluded that maintaining freshness through careful handling requires quick chilling at the pond harvesting stage for farmed fish and capture for wild fisheries. Similarly, Ghaly et al., (2010b); Rivai et al., (2019) observed that it is important to avoid temperature alterations and maintain a high level of cleanliness at the pond working site for farmed fish and the boat's working surface for captured fish to reduce fish spoilage. The most crucial operation in the fish handling process on board is chillingwith ice made from pure potable water(Han et al., 2015) used to maintain the fish as close to the freezing point (0°C) as possible. Saeed et al., (2022); Senapati &Sahu, (2020) observed that Refrigeration during processing from the farm of capture should be done with cool water at 0 to 3°C, and the fish thermal centre (spine) should be kept at 0 to 2°C in an industrial situation.

3.4. The trend in Deterioration levels of farmed fish under freeze and frozen storage.

When farmed fish are stored under freeze and frozen storage, their deterioration levels can vary depending on several factors such as the species of fish, storage temperature, and storage duration. Here are some general considerations: fish species (Ghaly et al., 2010c) reported that different species of fish have varying levels of tolerance to freeze and frozen storage. For example, fatty fish such as salmon and mackerel tend to deteriorate more quickly than lean fish such as cod and haddock. Similarly,(Gökoğlu&Yerlikaya, 2015). Observed Storage temperatureasa factor influencing fish deterioration. The authorsreported thatstorage temperature is a critical factor that affects the deterioration rate of farmed fish. Generally, the colder the storage temperature, the slower the deterioration Mahmud et al., 2018b). Fish that are stored at temperatures below -18°C (-0.4°F) are usually safe from bacterial growth and spoilage for extended periods (Sheng & Wang, 2021a).Storage duration has also been reported to affect fish quality changes under freezing and frozen storage. The duration of storage is another essential factor that determines the deterioration rate of farmed fish under freeze and frozen storage as reported by (Obiero et al., 2019). Generally, the longer the storage period, the higher the chances of quality deterioration(Novoslavskij et al., 2016). This is due to pathogenic actions. Therefore, it's recommended to use the fish within the recommended storage time.Therefore, farmed fish deteriorate less under freeze and frozen storage, with lower temperatures and shorter storage times. Proper handling, packaging, and storage conditions can help to minimize quality loss. It's important to follow the recommended guidelines for storage time, temperature, and handling to ensure the safety and quality of the farmed fish(Tamiru et al., 2023).

The quality of fish, when stored in freezing and frozen conditions, depends on various factors such as the rate of freezing, storage temperature, oxygen content, temperature fluctuations(Mei et al., 2019a; Supartini et al., 2018), and how the fish is transported. If the fish is frozen slowly, large ice crystals form(Mei et al., 2019b), which can cause protein denaturation, damage the cell membrane and result in moisture loss during thawing, resulting in a poor-quality frozen fish product. In contrast, (Chen et al., 2022) reported that quick freezing results in smaller ice crystals, less water loss during thawing, and a better-quality frozen sea bass fish product. According to Khan, (2021)Food industries, while resistant to technology, can sustain themselves independently. However, increasing competition in the agricultural and food processing sectors has made it necessary to embrace technology for faster, more efficient distribution, packaging, and testing within strict cost constraints.This technology needs to be adopted in aquaculture fish products in the market as well. In absentia of advanced technology in place,It is therefore recommended to quickly freeze fish products to improve their quality during freeze and frozen storage, especially during thawing. Temperature changes are another critical factor that can affect the quality of frozen fish products. A study by Aune et al., (2014) showed that temperature changes can cause recrystallization, reducing the quality of the fillet to that of a slowly frozen product during the rigour mortis phase of Atlantic cod fillets.The authors observed changes in frozen fish quality, such as colour changes due to deterioration at the surface of the fillet's food and chemical and biological activities during rigour mortis. Boran et al., (2006). Also reported a weight decrease caused by crystalline ice that enhanced enzymatic activity and alterations in fish oil quality due to holding temperature and time. The causes of textural changes in frozen fish, particularly Nile Tilapia, are unclear, but it is believed to be caused by structural modification of protein structures in the fish flesh, water retention ability, and the formation of formaldehyde and dimethylamine compounds. Jia et al.,(2022); Lakshmisha et al., (2008) both observed that Freezing fish prevents compounds from the blood, such as myoglobin and haemoglobin, from contributing to lipid oxidation in fish, which varies among species under storage. However, freezing does not improve or fully maintain the quality of the product(Sánchez-Alonso et al., 2012), and some deterioration occurs even when frozen. Lowering the storage temperature reduces the rate of deterioration in fish. Wang et alSánchez-Alonso et al., (2012); Tolstorebrov et al., (2016) both observed that a shelf life of 23 weeks was achieved by freezing fish fillets at 20°C, but the thawing process was not investigated in this study. The stiffness of frozen carp fillets decreased due to the freezing process(Diao et al., 2021b), but not due to the storage time. The authors also noted a correlation between lipid oxidation and sensory characteristics.

To reduce post-harvest losses, it is advisable to freeze and freeze-store farmed fish products before releasing them to the market. However, the type of fish that is freeze-frozen and stored can significantly affect the rate of deterioration during storage. Aune et al., (2014); Wang et al., 2022) Studies have shown that low storage temperatures can increase the rate of deterioration in fish, so it is important to maintain very low temperatures that can deter micro-bacterial growth to improve the quality of farmed Nile Tilapia fish during freeze-frozen storage. The recommended temperature for frozen storage is -18°C (Jiang et al., 2022), for Tuna. But certain fish species, such as fatty fish, should be stored at lower temperatures between -23°C and -29°C. (Stien et al., 2005; Tolstorebrov et al., 2016). Protein denaturation in certain frozen farmed fish, such as Tilapia and carp fillets, can occur due to physical conditions such as the size of the fish and environmental temperature during slow freezing. Namulema et al., (1999) reported that Rancidity can also cause poor taste in frozen Nile perch fishes and loss of colourin otherfreshwater fishes, indicating that physical conditions are key agents for fish spoilage under freeze and frozen storage.
Nikkilä&Linko, (1956)proposed the time-temperature tolerance hypothesis to maintain the quality of frozen and refrigerated food products by considering the relationship between storage temperature and time and how it affects the quality of frozen products. The changes in quality during storage and distribution at different temperatures are irreversible and progressive throughout the storage period as reported by (Freitas et al., 2021). Due to protein denaturation, 0°C is the critical temperature zone for deterioration in fish, and therefore, it is recommended that all fish should be frozen from 0°C within two hours or less(Hematyar et al., 2018). The ambient temperature should be lowered repeatedly until an average storage temperature of -30°C is achieved at the peak of the freezing process, and the hottest part of the fish should be cooled to -20°C at the end of the treatment. When this temperature level is reached, the coldest parts of the fish will be close to or at the freezing equipment temperature of -35°C, (Freitas et al., 2021)resulting in an average temperature of -30°C, which is a rapid freezing standard that ensures high-quality for farmed fish products.Similarly, farmed fish with essential fish additive that promote growth may enhance spoilage during freeze-frozen storage (Syanya et al., 2023).A similar finding was reported by,Sikorski &Kołakowska, (1994) who observed that without enzymatic oxidation, rancidity causes poor taste in frozen marine fishes as well as loss of colour in freshwater fishes. This is an indication that physical conditions such as the size of the fish, and environmental temperature are key agents for fish spoilage under freeze and frozen storage.

4. CONCLUSIONS.

From the review articles the following conclusion can be derived:

The quality of farmed fish products must be considered from the moment of harvesting to ensure that it is maintained throughout the entire supply chain. The chilling process should only be used as a preliminary step to the freezing and frozen storage processes.

Proper frozen storage conditions are critical in maintaining the quality of farmed fish products and reducing post-harvest losses. By implementing optimal frozen storage conditions, it is possible to achieve the right quality parameters and sell conforming fish products, as well as extend the shelf life of the farmed fish products.

It is also observed that the quality and safety of farmed fish products depend on post-harvest handling practices such as chilling and freezing. The optimization of cooling and freezing conditions varies depending on the fish species and howthe fish is stored for sale. Storage temperature is critical in determining the shelf-life of fish, as well as the method of preservation.

Intact fish had longer shelf lives than gutted fish under freezing and frozen storage. Filleted fish stored in plastic bags at 20°C for 24 months had a shelf-life of 24 months during freezing and frozen storage.

Further,the optimization of fish freezing and frozen storage conditions is critical to maintain the quality and increase the shelf life of farmed fish products. The method of preservationand the storage temperature are key factors that affect the shelf-life of fish.

5. RECOMMENDATIONS:

Based on the views of different authors, we recommend the adoption of the freezing and frozen storage principle in the preservation and quality storage of farmed fish species such as Nile Tilapia, carps, Trouts species, Catfish fishes and other marine and brackish water farmed fish species.

Fish farmers should ensure that quality concerns are in place immediately after the fish is harvested, as this determines the quality and safety of the farmed fish product that comes into the market. With optimal conditions, it will be possible to sell conforming fish products, reduce post-harvest losses, and extend the shelf-life of farmed fish products in line with captured fish products on the market.

It is also recommended that fish farmers and those involved in the supply chain of farmed fish products pay close attention to maintaining optimal frozen storage conditions to ensure the highest quality and safety of the products reaching the market and consumers' plates.

This study equally recommends the adoption of the freezing and frozen storage principle in the preservation and quality storage of farmed fish species, particularly Nile tilapia.

Further research is needed to compare the effect of prolonged freezing and frozen storage on farmed fishes and captured fishes from wild water systems. Factors related to the biochemical and behavioural composition of fish, such as species, habitat, and food, should also be considered when optimizing fish freezing and frozen storage conditions.

In general, this review paper provides useful insights for determining the best storage conditions for farmed fish species under freezing and frozen storage, and it highlights the importance of cold storage settings in maintaining and preserving the quality of farmed fish products.

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