Fresh Fish Preservation

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Contributor: Jorge Saraiva

Fresh fish is a highly perishable food characterized by a short shelf-life, and for this reason, it must be properly handled and stored to slow down its deterioration and to ensure microbial safety and marketable shelf-life. Modern consumers seek fresh-like, minimally processed foods due to the raising concerns regarding the use of preservatives in foods, as is the case of fresh fish. Given this, emergent preservation techniques are being evaluated as a complement or even replacement of conventional preservation methodologies, to assure food safety and extend shelf-life without compromising food safety.

Keywords: fresh fish ; spoilage ; shelf-life ; chilling/refrigeration ; freezing ; edible coatings ; hyperbaric storage

1. Introduction

Fish is a highly demanded and nutritious food product, yet perishability remains the biggest challenge for its preservation [1]. This food must be stored refrigerated or frozen, and, even under those conditions, it has a very short shelf-life, particularly for refrigeration (5–7 days and 9–12 months under refrigeration and frozen conditions, respectively) [2]. The deterioration of fresh fish during storage is attributed to different damage mechanisms, like microbiological spoilage, autolytic degradation, and lipid oxidation [3].

Fish products contain important nutritional and digestive proteins, including essential amino acids, lipid soluble vitamins, micronutrients, and highly unsaturated fatty acids. The muscle is mostly composed of water (75–85%), and it has a high water activity (0.98–0.99) [4]. Protein represents 20–22% of the muscle [5], while many types of lipids with different chemical composition, such as neutral/non-polar (triglycerides, diglycerides, etc.) and polar (free fatty acids, phospholipids, etc.) lipids, are also present [6]. Fish can be divided in four basic groups regarding its fat content: lean (<2% fat), low-fat (2–4% fat), medium-fat (4–8% fat), and high-fat (>8% fat) [7].

Fish Spoilage

After fish are caught, spoilage starts rapidly, and rigor mortis is responsible for changes in the fish after its death. A breakdown of various components and the formation of new compounds are responsible for the alterations in odor, flavor, and texture that happen throughout the spoilage process, and deterioration occurs very quickly due to various mechanisms triggered by the metabolic activity of microorganisms, endogenous enzymatic activity (autolysis), and by the chemical oxidation of lipids [1][8].

2. Chilling, Superchilling, and Freezing

The preservation of food products without using preservatives or additives has been increasingly demanded among consumers, and has brought additional challenges, especially to highly perishable foods, such as meat or fish. Low temperatures during the capture, transportation, and storage of the fish are of major importance worldwide. Chilling, superchilling, and freezing techniques allow for the preservation of fish for longer periods without major changes in quality, and assure economic benefits for the fish companies [9]. Therefore, chilling is one of the most used methods for fish preservation, along with freezing and, recently, superchilling.

2.1. Chilling

Chilling is the process of cooling fish or fish products to a temperature approaching that of melting ice, using, for example, ice. Chilling promotes an increase of shelf-life by slowing physical and chemical reactions and the action of deteriorative microorganisms and enzymes [9][10].

Chilled fish can keep a high organoleptic quality, being highly attractive for consumers, however, it is susceptible to microbial safety problems due to the temperature range at which it is kept, since psychrotrophic pathogens can grow and proliferate without an obvious sensorial impact [11].

Usually done with ice, chilling can maintain the fish at temperatures close to 0 °C and extend the shelf-life up to 30 days (in fatty fish, this can be up to 40 days), depending on several factors, such as the water temperature (temperate or tropical waters) and the type of species (marine or freshwater species) [9]. The shelf-life of different fish species stored in ice in shown in Table 1. However, temperatures close to 0 °C are not easily possible at retail and consumer houses, and, therefore, refrigeration (storage above 0 °C and up to 5 °C), the most usual storage process for fresh fish, results in a much shorter shelf-life [12].

Table 1. Shelf-life of different fish species stored in ice. Adapted from [9][13].

Fish Species	Temperate Waters (Days)	Tropical Waters (Days)
Marine Species	2–24	6–35
Cod (*Gadus morhua*)	9–15	na
Hake (*Merluccius merluccius*)	7–15	na
Catfish	Na	16–19
Batfih (*Ogcocephalus darwini*)	Na	21–24
Halibut (*Hippoglossus stenolepis*)	21–24	na
Sardine (*Sardina pilchardus*)	3–8	9–16
Freshwater species	9–17	6–40
Catfish (*Silurus glanis*)	12–13	15–27
Trout (*Oncorhynchus mykiss*)	9–11	16–24
Perch (*Perca* spp.)	8–17	13–32
Tilapia (*Oreochromis niloticus*)	Na	10–27
Corvina (*Argyrosomus regius*)	Na	30

2.2. Superchilling

Superchilling, also known as partial freezing or deep chilling, is characterized by low temperatures (between conventional chilling and freezing), in which a decrease of 1–2 °C occurs below the initial freezing point of the food product [10][14][15]. Most foods have a freezing point that varies from −0.5 to −2.4 °C and, specifically for fishery products, this parameter is between −0.8 and −1.4 °C [16][17].

Superchilling has raised interest in its application to some food products, namely fishery products, due to the shelf-life extension and quality improvement, in comparison to traditional preservation methods. Table 2 presents the conditions for different superchilled fish species, including data from other preservation technologies and from combination with diverse packaging methods. Therefore, in general, the shelf-life is longer when superchilling technology is combined either with VP or MAP methods and when compared to the shelf-life obtained in each of these individually.

Table 2. The effect of superchilling, chilling, and/or freezing technologies and/or the synergistic effect with packaging (vacuum packaging or MAP: modified atmosphere packaging) on the quality and shelf-life of fish muscle foods.

Species (Scientific Name)	Storage Conditions	Main Results	References
Atlantic Salmon (*Salmo salar*)	Superchilling: −1.0 °C up to 16 days Chilling: +4.0 °C up to 16 days Freezing: −40.0 °C up to 30 days	Superchilled salmon for nine days, without salting, presented the best results when compared with ice-chilled and frozen samples due to the reduction of biochemical quality degradation and a low/less degree of protein denaturation and structural damage. The highest production yield of salted salmon (in the weight of the salmon) was observed for the superchilling method at the ninth day of storage.	[18]
	Superchilling: −1.4 °C and −3.6 °C up to 34 days Chilling: +4.0 °C up to 21 days Freezing: −40.0 °C up to 37 days Packaging: Vacuum	The storage time of vacuum-packed, superchilled salmon fillets can be doubled when compared to ice-chilled samples. The highest drip loss value and degree of protein and myosin denaturation for superchilled salmon stored at −1.4 °C. Better muscle hardness in superchilled samples stored at −3.6 °C and stable activity of cathepsins enzymes (B and B + L) in all salmon samples.	[19]
	Superchilling: −1.5 °C up to 28 days Chilling: +2.0 °C up to 21 days Packaging: MAP-CO_2, N_2 (CO_2 compositions: 25%, 40%, 60%, 75%, and 90% with different gas-to-product ratios).	Extension of shelf life for superchilled product (using 90% CO_2) salmon fillets, from 11 days to 22 days, compared to chilled/control samples.	[20]
	Superchilling: −2.0 °C air overwrap up to 24 days Chilling: +4.0 °C air overwrap up to 24 days Packaging: MAP—60% CO_2, 40% N_2	Spoilage of MAP and air-stored salmon fillets after 10 days and seven days, respectively. Good microbial and sensorial quality during 24 days of storage for superchilled MAP salmon, compared to 21 days of superchilled salmon with air overwrap.	[21]
	Superchilling: −1.5 °C up to 28 days Packaging: Vacuum	The liquid loss value of the superchilled salmon fillets was significant after one day of storage and not significant between three and 14 days of storage, and after 21 days, this parameter decreased. The drip loss parameter of the superchilled salmon fillets remained without significant differences between one and 14 days of storage, but increased after 21 days.	[22]

Species (Scientific Name)	Storage Conditions	Main Results	References
Cod (*Gadus morhua*)	Superchilling: −1.5 °C up to 15 days Chilling: +0.5 °C up to 15 days	The shelf-life of superchilled cod fillets increased by three days when compared to the chilling process, resulting in a total of 15 days of shelf-life. The shelf-life of cod samples stored at a chilled temperature (+0.5 °C) only increased from 12.5 to 14 days.	[23]
	Superchilling: −1.0 °C up to 42 days Chilling: +4.0 °C up to 37 days Freezing: −21.0 °C for 36 days or −40.0 °C for 43 days Packaging: Vacuum	The superchilling technology combined with vacuum packaging prolonged the shelf-life of the cod fillets by several weeks when compared to the traditional chilling method. Drip loss and liquid loss parameters of superchilled cod fillets decreased and increased, respectively, compared to the chilled samples.	[16]
	Superchilling: −0.9 °C up to 21 days Chilling: +1.5 °C up to 21 days Packaging: MAP—50% CO_2, 45% N_2, 5% O_2	The shelf-life of fresh cod loins has been extended from nine days for ice-chilled storage to 16 or 17 days by superchilled storage. In addition, MAP combined with chilling and superchilling methods increased the shelf-life to 14 and 21 days, respectively. The superchilled MAP cod loins after seven days showed significant differences in muscle texture when compared to other storage methods due to the formation of ice crystals, when the storage temperature reached the freezing point of the fish.	[24]
	Superchilling: −2.0 °C or −3.6 °C up to four weeks Chilling: +0.0 °C up to four weeks Packaging: MAP—50% CO_2, 45% N_2, 5% O_2	The effect of brine (2.5 ± 1.0% NaCl) on cod loins was evaluated using the combined superchilling/MAP technology. The synergistic effect of superchilling/MAP extended the shelf-life of unbrined cod loins by 21 days (at −2.0 °C) instead of 14 to 15 days (at −2.0 °C) of the superchilled samples. The brined samples showed a shorter shelf-life compared to unbrined samples, especially in superchilling/MAP cod loins.	[25]
Tilapia (*Oreochromis niloticus*) fillets	Superchilling: −1.0 °C Chilling: +1.0 °C Packaging: MAP—50% CO_2, 50% N_2	The MAP tilapia fillets remained good for consumption at the microbiological level, even after 23 days of storage at both temperatures (−1.0 °C and +1.0 °C). However, some detrimental effects were observed in color, drip loss, and texture of samples. The best storage conditions, considering both sensorial evaluation and microbial counts, were 13–15 and 21 days for the chilled and superchilled tilapia fillets, respectively.	[26]

2.3. Freezing

Of all of the low-temperature preservation methods used, freezing (frozen storage) is the one that can maintain fish and fish products conserved for longer periods, but some quality parameters can be affected. It is typically applied at temperatures between −18 to −40 °C depending on the type of fish stored, and, contrary to what happens with chilling, for frozen storage, most deteriorative and pathogenic microorganisms are unable to proliferate at temperatures below −10 °C [10][27]. At this temperature, approximately 80% of the water is converted to ice, decreasing the water activity, which inhibits microbial activity [28][29].

The shelf-life of the frozen fish depends on several factors, such as the initial quality, storage conditions, and fish species, while the quality depends mainly on the storage temperature and temperature fluctuations [27][30]. Table 3 presents the shelf-life of some fish species stored at different freezing temperatures, according to fat content and fish size and shape. Notwithstanding the advantage over chilling regarding the inhibition of microbial growth, the impact of freezing temperatures in quality parameters is quite important when choosing the preservation technique. Some textural changes take place due to the formation of ice crystals that damage the tissues (mainly related to protein denaturation), which promotes dryness and toughness, and occurs more frequently in lean fish than in fatty or semi-fatty fish species. This can be minimized by fast-freezing processes, leading to smaller ice crystals and lower cell wall rupture and drip loss during the thawing process [27][28].

Table 3. Shelf-life of fish species stored at different freezing temperatures. Adapted from [31].

Type of Fish	Storage Time (Months)		
	−18 °C	−25 °C	−30 °C
Fatty fish (sardines, salmon)	4	8	12
Lean fish (cod, haddock)	8	18	24
Flat fish (flounder, plaice)	9	18	24

3. Conclusions

As stated, fish is a highly perishable food characterized by a short shelf-life. Refrigeration is probably one of the most used methods for fish preservation, along with freezing, and, more recently, superchilling. However, several deteriorative fish quality changes occur during refrigerated storage, particularly in texture, color, and flavor, limiting shelf-life. Frozen storage can avoid these changes (except for texture), but freezing/thawing largely alters the fish fresh-like characteristics. Emerging food packaging techniques, such as the use of edible films and coatings, also meet consumer demands due to their biodegradability and sustainability, while improving the safety and extending the shelf-life of fish and fishery products. Other emergent technologies are arising, as in the case of hyperbaric storage. This methodology uses different pressure and temperature conditions applied at subzero, low, and room temperatures, and has shown the possibility to increase fish shelf-life by microbial inhibition/inactivation, maintaining textural, sensorial, and nutritional characteristics when compared to conventional methods of storage, with the additional advantage of potentially high energy savings, especially when performed at naturally variable/uncontrolled room temperatures. However, currently available high pressure equipment was designed to operate at very high pressure (up to 600 MPa for short minutes), and not to perform hyperbaric storage (up to a maximum of 200 MPa, but for weeks/months), and so specific pressure requirements for hyperbaric storage are of interest to be built.

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