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REVIEWARTICLE

Quality measurements affected by frozen storage of fishes

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ABSTRACT

Fish is a very perishable food and therefore several storage strategies need to be employed to increase its shelf-life, guaranteeing its safety and quality from catch to consumption. Despite the advances in modern fish storage technologies, chilling and freezing are still the most common preservation methods used onboard. The present review aims to summarize strategies to increase the shelf-life of fresh (chilled) and frozen fish. Although there are other factors that influence the fish shelf-life, such as the fish species and the stress suffered during catch, storage time and temperature and the amount of ice are some of the most important. In addition, the way that fish is stored (whole, fillet, or gutted) also contributes to the final quality of the product. A major problem with food storage, whether refrigeration or freezing, is quality degradation. Major physical and chemical attributes affected in fish are color, texture, enzymatic activity, lipid oxidation, and ice crystal structural damage. Storage time, whether that is short or long term, affects these quality attributes in different ways.

Keywords: Freezing, fish,water holding capacity,color, texture, crystallization

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INTRODUCTION

Most studies on fishes show more physical changes during freezing (short-term effects), such as weight loss, color change, and structural/texture changes as a result of ice crystal nucleation and growth (Ottestad, 2011, Zhu, 2004). During longer term storage physical attributes continue to slowly deteriorate, however, chemical characteristics such as enzymatic activity, lipid oxidation, and microbial growth become increasingly important factors affecting meat quality (Heldman, 1998, Strasburg, 2008, Bahececi, 2005). Because of the difference in quality that short and long-term freezing effects can have on products, studying both of these phases of freezing are necessary in determining the effects on fishes.

Different forms of preservation have become available to fish industries. Freezing fish is an efficient way to store and distribute high quality seafood products. There have been numerous studies reporting the long-term impact of freezing fish on a commercial scale (Abdel-Kader, 1996, Chevalier, 2000, Woinet, 1998). Freezing rate can be controlled by the base temperature of the freezer as well as airflow rate and freezing medium. Commercial freezing methods such as high pressure and air blast freezing have been used to supercool food products to maintain high standards of quality. Air blast freezing uses

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low temperatures ranging between -30°C(-22°F) and -52°C(-62°F) and air speed, regulated by internal fans, to freeze products over a 24 to 48 hour time period (Alizadeh, 2007). Pressure shift freezing depresses the freezing point of water, allowing for ice crystallization to occur at lower temperatures. Ice crystal nucleation occurs most readily in intracellular regions of food products as a result of the rapid growth that occurs once these sub cooling temperatures are reached (Petzold, 2009). High pressure freezing and thawing reduces quality loss in food storage and is at the forefront of commercial storage research (Alizadeh, 2007). Faster freezing rates maintain physical and chemical quality attributes within different types of fish such as Atlantic sea bass, Atlantic salmon, and hake (Zhu, 2004). Longer term freezing storage contributes to chemically induced quality loss in color, texture, structure, and microbial activity (Heldman, 1998, Strasburg, 2008). However, there is a threshold where the energy efficiency related to lower temperatures provides a diminishing rate of return on product quality (Farouk, 2003). Research for freezing fish and other forms of meat has focused on commercial freezing using rapid and low temperature freezing, therefore examining differences in quality deterioration at the higher temperatures used in consumer home freezers is an important field to research (Tolstorebrov et al., 2016).

Heavy metals are found in abundance in nature. Their numbers, on the other hand, have been steadily increasing as the world has become more industrialized. Heavy metals like cadmium (Cd), lead (Pb), and zinc (Zn) are plentiful in agricultural soils. Plant growth is hampered by metal toxicity. Metal poisoning affects crop output while also posing a threat to the food chain (Poschenrieder and Bercelo, 1999). Excessive levels of heavy metals in soil has harmed not only natural aquatic bodies but also terrestrial ecosystems. Cadmium (Cd) among the other heavy metals is the most reactive and persistent heavy metal contaminants, as well as one of the most prone to buildup due to poor agricultural practices (Gardea- Torresdey et al.,1996; Meagher, 2000). Under many agricultural systems, environmental pressures can result in significant yield losses. The pernicious issue involving both productivity and quality of economically valuable crops is a source of diverse stress (Wanger, 1993). Excessive levels of heavy metals in soils can have detrimental effects on biomass production, seed germination, root growth , morphological characteristics and architecture(Kukkola et al., 2000,Arduini et al., 1995). Heavy metal toxicity is a concern for ecological, evolutionary, and environmental factors (Nagajyoti et al., 2008). Heavy metals like lead and cadmium are extremely harmful contaminants that are released into the environment by vehicular exhaust (Lagerwerffand Specht,1970).

Water Holding Capacity

Weight loss in fish is directly related to the water holding capacity of each fillet. Depending upon distribution and handling post mortem, water-holding capacity within fish can change overtime (Offer, 1988). Weight loss during distribution and storage can be attributed to evaporation from freezing storage, as well as drip loss from thawed meat preparation. Drip loss within meat contains water, but also water-soluble proteins, sarcoplasmic proteins (myoglobin), depleting the weight and therefore value of the meat (Offer, 1988). Drip loss increases when additional processing is preformed on fish, such as filleting or mincing. To maintain water-holding capacity and deplete the opportunity for dehydration of meat, acid and salt treatments to adjust the pH and ionic strength between filament lattices within fish muscle. As a result of acid and salt treatments, there is more room for water molecules to bind within muscle filament (Offer, 1988).

Color

Color or appearance is a physical attribute that can change during freezing resulting from deterioration at the food surface; although changes in pigment appearance can be due to both chemical and biological actions. Color can effect product perception without affecting nutrition or flavor (Santos-Yap, 1996). Different forms of color analysis of food products are available to predict consumer acceptance and track color changes in frozen products (Pomeranz, 1987). Fish appearance and

color originates from meat-water binding properties and pigmentation within the skin or meat surface. Depending on the fish species, pigmentation can be oxidized resulting in darkening or fading. Salmon meat has a pink pigmentation in its natural state and with freezing; the pink color tends to fade (Santos-Yap, 1996). Ottestad et al. (2011) found that fading or increase in lightness is related to ice crystal formation during freezing. Higher freezing rates form small, more numerous ice crystals within salmon, which then reflect light more intensely. Slower freezing rates form larger and fewer ice crystals in salmon, resulting in light refraction and a darkening effect of the meat surface. To analyzecolor changes in products the International Commission of Illumination (CIE) proposed a universal method in 1931 to be used in analyzingcolor. This method distinguishes color into three different tristimulus values. More recently the Munsell system simplifies quantifying color even further through a multi-dimensional method. L, a, b, h, and C readings can be quantified and compared. L represents the overall lightness of a sample. The a value denotes redness or greenness in a sample, while the b value denotes yellowness and blueness. Hue (h) and Chroma (C) values are derived from a and b values with hue expressed in radians or degrees of the angle within the color space and chroma as a measure of intensity as distance from the achromatic center of the color space. Color analysis can indicate surface degradation of product and color difference value (ΔE) can be helpful in distinguishing the difference between storage treatments. Equation 1 below shows the equation used to calculate color difference (∆E). The number generated from this equation can be used as a comparative value against a control sample and utilizes L, a and b values to express sample color difference. Studies on freezing Atlantic salmon and other varieties of fish have shown similar results with a relationship between freezing rate and color change (Alizadeh, 2007, Zhu, 2004). Lightness values (L) are seen to increase with freezing rate, while a and b values tended to vary (Zhu, 2004, Alizadeh, 2007). Zhu et al. (2004) studied how color difference (∆E) was affected by freezing rate more so than the freezing, thawing, or cooking methods.

$$\Delta E_{ab} = [(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2]^{1/2}$$

Ice Crystallization

Another effect of freezing foods is ice crystal nucleation and morphology. Ice crystallization and recrystallization affect food structure and food texture. There are three main steps to ice crystallization 1) nucleation of the crystalline lattice 2) crystal growth and continuation of ice crystal nucleation and 3) recrystallization (Hartel, 2001). Freezing rate affects crystal formation and uniformity. Slow freezing leads to larger crystal formation in the extracellular areas of food products, especially within different species of meat and fish. Large crystals as well as small thermodynamically unstable crystals form during the nucleation process and any fluctuation in temperature after freezing causes ice to melt and refreeze, a process also known as recrystallization. Recrystallization during slow freezing causes larger, irregularly spherulite, ice spear-like ice crystals to form. The irregular and extracellular nature of crystals formed from recrystallization damages muscle structure, especially in meat and fish, as connective tissue surfaces deteriorate. Rapid freezing results in ice nucleation within the intracellular areas of food products. These ice crystals are smaller and more uniform, therefore creating a more structurally stable product (Petzold, 2009). For example, different freezing rates affected cell wall structure in blueberries (Figure 1.4). Images “b” and “c” were both subjected to faster freezing methods as compared to images “a” and “d”, which were frozen raw and more slowly. As a result of different freezing rates, especially shown in image “b”, there is less cell wall damage (Petzold, 2009).

Sayamaladevi et al. (2012) found that temperature fluctuations and ice recrystallization damage occurs readily in Atlantic salmon muscle structure (Figure 1.5). Image “a” shows small ice crystals formed uniformly throughout the fish tissue directly after freezing. Immediately after freezing, a sample would not be subjected to recrystallization due to temperature fluctuations, therefore resulting in smaller, more uniform ice crystal pores. Images “b” and “c” represent samples exposed to an increase in their core temperature close to a glassy state and the onset temperature of ice crystals melting. Image “b” has larger ice

crystal pores that are still uniform as compared to image “a”. This shows that samples are more structurally stable at a -27°C(-17°F) glassy state. Image “c” shows the ice crystal pores growing larger and varying in uniformity, at a temperature range between -27°C(-17°F) and -17°C(1°F), which allows for ice crystals to melt and recrystallize. Finally image “d” shows a sample when the temperature surpassed the onset temperature of ice crystal melting with the largest, most irregular ice crystal pores from the whole study. Temperatures above -17°C(1°F) did not provide the most ideal atmosphere for Atlantic salmon during long-term storage. This study shows the physical damage that can occur to samples frozen to different core temperatures, an area where increased research is needed in the frozen products industry (Sayamaladevi, 2012).

Singh (2001) sounds that thawing allows intracellular water to become permanently extracellular; thus incurring greater cell wall or muscle damage during freezing will increase water relocation during thawing. Measuring ice crystal pore damage is a good indicator of structural damage imposed by freezing foods. After samples are frozen they can be subjected to freeze-drying, freeze concentration, or free substitution to isolate the pores left behind by ice crystal growth (Chevalier, 2000). Freeze drying has proven to be an effective method although it is slower and more expensive than others methods, mainly because ice crystals are vaporized leaving behind a physical pore that emulates the ice crystal’s shape (Petzold, 2009). After the pore has been stabilized different techniques can be used to examine pore morphology. Arnaud 1998 used optical microscopy to study pore structure and size in ice cream. Fractal, environmental scanning electron microscopy, CT X-ray, and cold stage scanning electron microscopic analysis techniques have been used on different types of fish including Atlantic salmon and sea bass (Chevalier, 2000, Petzold, 2009, Syamaladevi, 2012). With all of these techniques micrograph images can be used to quantify and qualify ice crystal frequency and size. These studies support the objective of the current research; as increasingly more evidence needs to be collected about different freezing rates and how they affect the physical integrity of Atlantic salmon.

Texture

As a result of ice crystal growth and recrystallization, another quality parameter that is compromised in fish is texture. Alizadeh et al. (2007) found that freezing storage affects texture quality in Atlantic salmon fillets more than thawing techniques. They found that control of pressure and temperature affected ice crystal growth and distribution. Toughness is related to protein and fat content and properties within fish meat. Texture analysis of fish meat differs from other meat types because of variability in muscle structure (Listrat, 2016). There are also added variables such a species, composition, seasonality that make texture a more challenging attribute to measure. However, trends such as higher resistance and toughness in fish that are in frozen storage for extended periods of time at higher temperatures have been established (Barroso, 1998). Texture changes during frozen storage have also been directly linked to protein denaturation within fish (Shenouda, 1980). Salt-water fish, such as Atlantic salmon, may contain higher levels of trimethylamine oxides (TMAO) within red muscle as compared to fresh water fish (Yamada, 1967). TMAO degrades in the presence of TMAase, an enzyme located within fat tissue. The products dimethylamine and formaldehyde are then susceptible to form both intra- and intermolecular crosslinks with protein side chains (Jebson, 1978). The aggregation of these cross linkages causes toughness in fish (Alizadeh, 2007). Slow freezing could also cause for a tougher sample, as larger ice crystals tend to break down protein structure within fish (Santos-Yap 1996).

Different texture analyses methods include the Kramer Shear Cell method, Warner-Bratzler shear cell method; puncture test, and texture profile analysis (TPA). Each of these methods uses a blade or probe to measure a maximum force for food samples. The Kramer Shear and puncture method can test multiple locations per sample unlike the Warner-Bratzler and TPA methods, which only allow for one or two maximum force readings per sample (Barroso, 1998).

CONCLUSION

Generally, the stability of fish and shellfish meat is lower than that of livestock meat, and the concept of T-TT (time–temperature-tolerance), including frozen storage temperature and storage period, is more important for maintaining quality of fish and shellfish meat. Protein denaturation before and during freezing and frozen storage greatly affects the quality. When fish meat is stored at a sufficiently low temperature (−40 °C), protein denaturation of the frozen fish meat is suppressed and the tissue of the meat reabsorbs water. Ice crystal formation in frozen seafood significantly affects the quality properties by changing the structure of tissues and other properties. However, the effects of ice crystals on the quality of thawed fish meat differ based on the fish species, post-mortem stages, protein denaturation of frozen fish meat, and processing conditions of frozen fish meat.

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