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Review

Effect of low and ultra-low temperature applications during freezing and frozen storage on quality parameters for fish

I. Tolstorebrov [a,*], *T.M. Eikevik* [a], *M. Bantle* [b]

[a] *Norwegian University of Science and Technology, Kolbjørn Hejes v 1B, Trondheim 7491, Norway*

[b] *SINTEF Energy Research, Kolbjørn Hejes v 1D, Trondheim 7491, Norway*

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ABSTRACT

The article reviews recent investigations in the application of ultra-low temperatures for high-quality long-term storage of fish. Changes in fish quality were discussed with respect to thermal events, which occur at low and ultra-low temperatures. Excellent stability of proteins was found at temperatures below the end of freezing point, when the unfrozen water content is at its minimum. Lipid oxidation was inhibited by preventing oxygen penetration to fish tissues rather than decreasing storage temperature. Thus, a significant part of fish oils remains unfrozen until temperatures of −110.0°C. The recommended storage temperature for high-quality long-term storage of fish is −35.0°C. Further decreasing storage temperature is unnecessary for industrial needs.

Effet des applications de basse et ultra basse température sur les paramètres qualitatifs du poisson lors de la congélation et de l'entreposage à l'état congelé

Mots clés : Poisson congelé ; Entreposage à long terme ; Ultra-basse température

1. Introduction

Freezing is a widely used and accepted technology for preserving fish and fish products in their natural states. Frozen food is defined as a product with a temperature of −10.0 °C or colder (Bøgh-Sørensen, 2006), which is maintained during storage and sales. Under such conditions, approximately 80.0% of the water in the product is converted into ice. Fish, with a temperature of less than −18.0 °C is considered to be "deep

* *Corresponding author.* Norwegian University of Science and Technology, Kolbjørn Hejes v 1B, Trondheim 7491, Norway. Tel.: +4796749192; Fax: +4773593580.

E-mail address: ignat.tolstorebrov@ntnu.no (I. Tolstorebrov).

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Nomenclature

ATP	adenosine triphosphate
DMA	dimethylamine
DSC	differential scanning calorimeter/ calorimetry
ESR	electron spin resonance
FA	formaldehyde
FFA	free fatty acid
LDPE	low-density polyethylene
PPP	product-process-package (factors)
PV	peroxide value, meq of O_2 kg^{-1} of fat
PUFA	polyunsaturated fatty acid
T	temperature [°C]
TAG	triacylglycerides
TBARS	thiobarbituric acid reactive substances, mg of malondialdehyde kg^{-1} of fish
TMAO	trimethylamine oxide
ULT	ultra-low temperature
ΔT	temperature difference [°C]
4-HNE	4-hydroxynonenal

Subscripts

g	glass transition
m	incipient of melting (end of freezing)

frozen" (Bøgh-Sørensen, 2006). Traditionally, the temperature of fish during storage is between −18.0 and −30.0 °C (Bøgh-Sørensen, 2006; Johnston et al., 1994; FAO and WHO, 2012). The shelf-life of fish is several months at these temperatures and depends on the type of fish and product–process–package factors (PPP). The production and storage of the high quality frozen fish is a process that demands a significant amount of energy and resources (energy losses, package, antioxidants, equipment, refrigerant, etc.). Thus, the industry requires efficient processes, where the balance between the long-term shelf-life and the resources used for its maintenance will be optimal. It should be noted that the meaning of "fish quality" varies depending on the aim of the scientific study. The recommendation of the International Institute of Refrigeration defines two levels of quality of frozen products, which are based on sensory assessment (Bøgh-Sørensen, 2006). Different studies point out various quality parameters for investigation: rancidity of fats in fish tissues, oxidation and/or denaturation of proteins, changes in color, texture of muscles, etc. Thus, the overall evaluation of influence of low temperatures on fish quality is complicated and in most R&D investigations limited to certain parameters.

The natural way to increase the stability of frozen products within storage is the decreasing of storage temperature. The shelf-life of frozen fish (both fatty and lean) increases exponentially from storage temperatures of −18.0 to −30.0 °C (Bengtsson et al., 1972). This trend could continue below the temperature of −30.0 °C. At the same time, several investigations that were devoted to the influence of low and ultra-low temperatures (ULT) on shelf-life of Atlantic salmon and Atlantic cod did not observe the difference in quality between storage temperatures of −40.0 and −70.0 °C (Burgaard and Jørgensen, 2011; Mørkøre and Lilleholt, 2007). This temperature range is far below eutectic points of most of electrolytes, which exist in fish tissues. Thus, this phenomenon cannot be explained by the "reversed stability" only. This review on recent investigations concerning a physical state of fish and its relations to biochemical changes in tissues may give information about the stability of the fish during storage at ultra-low temperatures below −30.0°C.

2. The state of water in fish at low temperatures

The state of the water in food products is one of the key questions for a complete explanation of the stability of the quality of frozen fish at low and ultra-low temperatures. Water is a good solvent and acts in many biochemical processes in foods. The concentration of liquid water in food systems determines the rate of deterioration (Guegov, 1981). All water in frozen food is classified into "freezable" and "unfreezable" water. The definition and explanation of "unfreezable water" strongly depends on the theory and applied methods (Reid and Fennema, 2007). Mostly, this "term" was applied to water, which is not frozen at temperatures below −40.0 °C (Chen, 1985; Kuntz and Kauzmann, 1974; Pham, 1987). A significant research work, which was devoted to determination of unfreezable water in fish, was done in the seventies and eighties of the 20th century. The freezing of free water was determined in the temperature range between −17.7 and −30.0 °C, depending on fish type and investigation method (Lebedev and Perelman, 1973; Shenouda, 1980; Sussman and Chin, 1966). The total constitution of bounded water was found ranging from 0.25 to 0.58 g H_2O g^{-1} dry protein in high moisture food such as fish (Kuntz, 1971; Reid and Fennema, 2007; Schwartzberg, 1976). At the same time, terms "bounded" and "unfreezable" water are not equal. Usually, "unfreezable" includes "bounded" water (Reid and Fennema, 2007).

The crystallization of water is a kinetic process and is limited by the formation of maximal freeze concentration, when the viscosity of the unfrozen system (mostly protein–water) exceeds 10^8 Pa s (Roos, 1995).The temperature, which refers to the formation of maximal freeze concentration, is the end of freezing point. The exact temperature of end of freezing (T_m) is essential, because it gives an opportunity to predict the temperatures when the fraction of unfreezable water will be relatively constant. The viscosity of the unfrozen system will increase with the decrease of the temperature below the end of freezing point (Champion et al., 2000).

Relatively new data concerning end of freezing point were obtained by various differential scanning calorimetry (DSC) techniques or/and cooling curve method (Rahman et al., 2002) in combination with the Clausius–Clapeyron equation modified for food by Chen (1986). All the DSC determinations of thermal properties use a heating rate between the range of 5.0 and 20.0°C min^{-1}. The incipient point of melting (T_m) can be detected by use of this method. This point is equivalent to the end of freezing, when system is in equilibrium. The amount of unfreezable water was detected in two ways: by a state