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EXTENDING THE SHELF LIFE OF RAINBOW TROUT VIA APPLYING COLD TREATMENT PROCESSES: A REVIEW[1]

Vladimir Kitanovski[1*], Olga Popovska[1], Vesna Karapetkovska Hristova[2]

vladimir.kitanovski@unt.edu.mk,
[1]University "Mother Teresa" Skopje, Faculty of Technological Sciences – Skopje
[2]University "Kliment Ohridski", Faculty of Biotechnical Sciences – Bitola

ABSTRACT

- Cold treatment processes are very important in the field of food preservation, reliability of the product and extending shelf life. With different combinations and variations of temperatures, different cold treatments were developed. In this trend the superchilling process has been defined as a process were the temperature of food product is lowered somewhere close (1-2 °C) to the cryoscopic point. Storing food at superchilling temperatures can maintain food freshness, retain high quality and safety of products with suppressing growth of microorganisms. Nowadays large percentage of people have information about how important is healthy diet on general health, thus the demand of high quality food products is very high. Superchilling process is developed from this need for high quality and long shelf life products with initial quality parameters. In this point of view decisive are mechanism of ice crystal formation and modeling and optimizing of mathematical models of the variables in the system.

[1] review scientific paper

Key words: Cold treatments; Shelf life; Superchilling; Ice crystal formation

INTRODUCTION

- Fresh and high quality fish, especially nowadays is in great demand worldwide (Medina et al., 2009). This is due to the growing public and media popularity of nutritionists, linked with the growing desire of people to eat healthy and thus improve their general health. Nutritionists' advice to increase the percentage of fish meat intake in the human diet is mostly due to the nutritional and energy value of fish meat accompanied by its easy digestibility. All of these benefits of fish meat comes from the chemical composition of fish meat which is rich in proteins, the easy digestibility comes from absence of connective tissue, it contains very important micronutrients, and for what is most famous fish meat, it's the high amount of essential omega 3 fatty acids (Trumbo et al., 2002) in its fatty acid profile. We can say that the constant growth of demand for fresh fish on the market is directly linked nutritionists' advices and the popularity for healthy diet (Ghanbari et al., 2013) among people nowadays. Exactly - chemical composition of fish meat (Aubourg, 2008) and the presence of various enzymes and their activity, makes fish very unstable and perishable food product (Sampels, 2015). Thus, this leads to the need of new technologies for preserving and extending the shelf life of fresh fish on the market. Food technologist, engineers and scientist, offer a various range of methods and technologies for preserving the freshness of fish and extending the shelf life (Medina et al., 2009). This is very important for sustainable development of supply and demand because on one side the demand of freshness comes from the consumers and on the other side extending the shelf life will lead to financial benefit for the companies. It is important for this chain to have balance, and satisfaction on both sides. As we mentioned above that is task for food technologist and they manage it with application of many inventive and innovative methods and technologies. The biggest percent of these technologies for preserving the freshness of fish are based on lowering the temperatures, because the rate of food spoilage processes depends on temperature. To reduce spoilage and biochemical degradation, we need to lower the temperature. The

methods to which the fish are subjected, may include cold treatment immediately after catching or determination of temperature patterns during storage.

In this article we are focused on fresh fish meat, so the freezing methods and technologies that are used for preserving will be leaved aside. That means we will discuss for applying cold treatment processes covering regular flake ice chilling (Zakhariya et al., 2015), and more modern and more efficient method for preserve fresh fish, the “Superchilling method”.

As we mention above the people knowledge of quality food is constantly grooving so the demand for fresh refrigerated food grooving too. It can be said that this comes from the desire of people to improve general health by eating healthy products (Krstić et al., 2016). From the current trends comes and aim of this paper, and that is review the superchilling methods for fresh fish, and their link with improving the quality during storage and extending the shelf life of fresh golden rainbow trout.

COLD TREATMENTS APPLIED FOR EXTENDING THE SHELF LIFE AND PREVENT QUALITY OF RAINBOW TROUT

- In order to preserve the original quality of fresh fish, (Duun and Rustad, 2008) two modern technologies have been discussed, which allow the fish to be stored in a refrigerated or frozen state. Highly efficient techniques for fast cooling, ultra-fast cooling and freezing have been applied. The aim of all is to slow down the processes that lead to loss of quality in the period after the catch and during the transportation of fish to consumers.

CHILLING COLD TREATMENT

By applying of this cold treatment, the original properties of the fish are preserved to the greatest extent. Disadvantage of cooling is the relatively short shelf life of the product. More precisely the term “cooling” refers to the process of lowering the temperature in the center of the fish from its initial value to final levels slightly higher than the so-called. “cryoscopic point”. In the traditional cooling process, the formation of ice crystals in the product is not allowed. Therefore, heat removal from fish is relatively slow (Magnussen et al., 2008).

Reducing the temperature to the cryoscopic point makes water difficult to reach for microorganisms. When lowering the temperature to a significant extent it reduces the rate of autolytic enzyme processes in fish (Dalgaard et al., 2006). These are the two main factors that contribute to the conservation effect of cooling (Sampels, 2015).

The most widely used method of chilling fish is considered to be the traditional cooling in a heterogeneous environment by covering the fish with flake ice (Zakhariya et al., 2015). In many cases, a combination of cooling in a liquid agent and flake ice accompanied by storage in air is also applied. Cooling by the traditional method has its advantages and disadvantages. Disadvantages of cooling fish with flake ice are: uneven cooling, mechanical damage to the fish, high ice costs, 2 times slower cooling compared to cooling in a liquid medium (Erikson et al., 2011).

Chilling is not able to completely stop the autolytic processes in the fish (Gandotra R., 2012). During chilling, the fish product is often influenced by environmental factors, such as light, oxygen, water, etc. In this sense, chilling protects the fish from decay only for a certain, relatively short period of time.

During cold storage of fatty fish such as silver salmon (Oncorhynchus kisutch) is, (Aubourg et al., 2005) found the development of a rancid odor. Compared to fresh fish, on the tenth day of refrigerated storage, sensory odor ratings were significantly reduced.

In terms of physicochemical properties, (Huidobro et al., 2001) found some better quality of sea bream (Sparus aurata) chilled in flake ice than chilling by immersion in slurry ice or by the commercial method by immersion in flake ice water.

FAST FREEZING OF FISH

- Short shelf life of the fish in refrigerated stage is the reason why so often the treatment of fast freezing is applied. The temperature method involves the use of temperatures below the cryoscopic point. Storage of the fish must be at temperatures below -18°C. This method is the most efficient way for long term storage of fish and preservation of the original properties in terms of

sensory, nutritional, functional and technological aspect (Ghaly et al., 2010). This is probably due to a 80-90% reduction of the initial microorganisms in fish, because the formation of ice crystals disrupts the normal life functions of a microorganisms .

In some cases, freezing can cause unwanted changes in the muscles, such as denaturation of muscle proteins, decreased water holding capacity, and secretion of meat juice during defrosting (Kaale et al., 2011).

Foegeding et al., (1996) reported that loose of quality during storage of frozen fish depends from the properties of the fish itself, precisely the water in fish has a relatively highest share (about 75%). In the process of freezing ice formation of 76% happens during the temperature interval of -1 to -5°C. This means that the way of freezing is very important because it also dictates the shape of the formed ice crystals. Upon slow freezing, large ice crystals are formed in the pericellular spaces, contrary fast freezing, a large number of crystals are formed, with small sizes, which are evenly distributed over the entire section of the muscle.

The percent of loosed quality in freezing treatment of fish is directly linked with the depth of autolytic changes of the fish at the time of freezing (Arannilewa et al., 2005). When the fish is undergoing a freezing process and is in early stage of autolysis small ice crystals are formed due to still very high water capacity and low permeability of sarcolemma, which prevent the water to came out from the cell. In advanced stage of autolysis, crystals are formed exclusively between the muscle fibers and this significantly reduces the quality of the fish.

SUPERCHILLING OF FISH COLD TREATMENT

- Short shelf life of fish in refrigerated storage and sometimes the undesirable effects caused by the fast freezing method such as protein denaturation, reduced WHC, and some sensory deterioration of appearance, are some of the reasons for searching new models for cold treatment of fish. Applying temperatures somewhere a little below the cryoscopic point, precisely in the interval between -1 and -4°C, has shown big advantages in fish storage (Fagan et al., 2003). This method is called superchilling.

During the process of superchilling, combination of the inhibitory effect of low temperature and the partial crystallization of water increases the ability to slow down the natural processes of deterioration (Aparicio et al., 2008). In the temperature interval between -1°C and -4°C only part of the water in fish is frozen, the other part is in liquid state, that is the explanation why the temperature of fish is below zero and ice crystals in the muscle tissue are not formed.

IMPACT OF SUPERCHILLING ON QUALITY AND SHELF LIFE OF FISH

- It is to expect that as the storage temperature decreases, the rate of biochemical processes caused by microbiological and enzymatic factors will progressively decrease. It is this slowing down of the processes that is the reason for extending the shelf life of the fish (Hansen et al., 2009). With lowering the storage temperature it is normal to expect a progressive slowdown in the biochemical processes caused from microbiological and enzymatic factors. It can be said that this is the reason for the extension of the shelf life.

The elementary disadvantage of the superchilling process from a from a technical point of view is the necessary need to maintain a constant temperature, pre and during storage. The stable temperature, without significant fluctuations is elementary for reducing the possibilities of ice crystal formation (Magnussen et al., 2008). In laboratory conditions the needs of constant temperature are reachable, but this is a really big challenge when considering the application of superchilling in industrial conditions.

In recent years, a number of studies have been conducted on the benefits of superchilling cold treatment and storage of fish. Bao et al., (2007) investigated the influence of different cooling techniques and storing temperatures (-2 ° C and + 3 ° C) on the shelf life extension, of Arctic trout (Salvelinus alpinus). It has been found that the effect of temperature is stronger than the influence of different cooling agents, and the storage temperature of -2°C shown prolongation of shelf life, with 12 days compared to traditional storage temperature of +3°C. Best temperature regimes for superchilling of golden rainbow trout were reported by (Kitanovski et al., 2017) who investigate the physicochemical parameters and sensory parameter skin appearance. Obtained data are presented on the graph below.

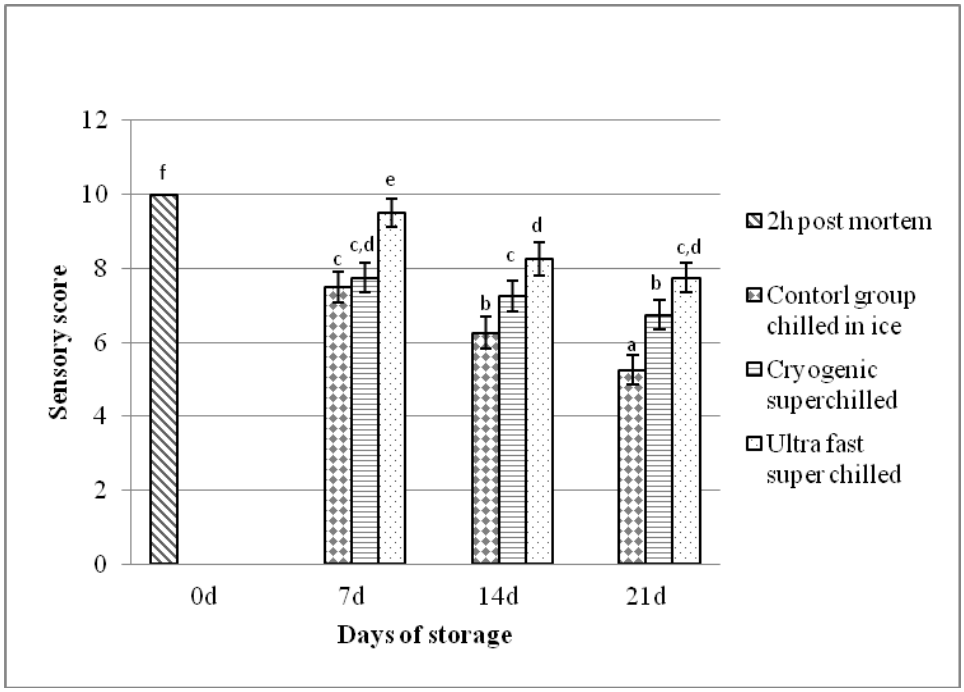

Fig. 1. Skin appearance sensory evaluation of golden rainbow trout **(***Oncorhynchus mykiss***)** stored and chilled in different ways. *Data were expressed as Mean ± SD (n = 7).* $^{a, b, c, d, e, f}$ - different letters indicated that values of the means in the rows are significantly different ($p^* < 0.05$).

Note. Reprinted from J Aquac Res Development 4, Extension the Shelf-Life of Fresh Golden Rainbow Trout via Ultra-Fast Air or Cryogenic Carbon Dioxide Super Chilling by Kitanovski VD, Vlahova-Vangelova DB, Dragoev SG, Nikolov HN, Balev DK., Pp 481-491., 2017.

COOLING EQUIPMENT, AGENTS AND TECHNIQUES IN SUPERCHILLING PROCESS

- The cooling equipment for superchilling process mainly is divided in three main groups: Mechanical, Cryogenic and Impingement freezers. (Kaale et al., 2011).These three types of technological equipment for superchilling of food

products, have different advantages and disadvantages. Therefore, the selection of appropriate equipment for superchilling processing of fish, helps to, optimize product quality, allows operational, technological and market flexibility, and largely ensures a return on investment, minimizing refrigeration losses, processing time and financial costs per unit of finished product (Lee and Sahm, 1998).

Impingement freezers are more modern more sophisticated version of mechanical freezers in sort of way. They both use cooling agent and air velocity to reach the results, opposite the cryogenic freezers that have no requires for mechanical refrigeration equipment and they can offer shorter freezing time due to big temperature differences between cryogen (nitrogen liquid -196°C or solid carbon dioxide -78°C) and the product. Despite all this advantages low temperatures of the cryogen may affect on the sensory features such as appearance (Zhou et al., 2010). If we take the fact that the skin, on big percent of favorable fish is thin and tender, the unintended consequences will be an integral part. Therefore, we can agree that looking into impingement air jet freezers, as compatible equipment for superchilling process, is the right choice (Sarkar et al., 2004). The advantages of air jet impingement freezers over the cryogenic are almost in all points of interest. Freezing times and weight losses are similar but at significantly lower operating cost, also they better preserve quality of product because of reduced freezing time and enhanced heat transfer (Salvadori and Mascheroni, 2002). Having all the advantages mentioned above air jet superchilling maybe can give best way of preserving food, if we take the fact that this method extend the shelf life and at same time improve product quality (Dirita et al., 2007; Garimella and Schroeder, 2002; Soto and Bórquez, 2001)..

CHALLENGES IN SUPERCHILLING COLD TREATMENT

- The greatest benefit of applying the process of superchilling is extending the shelf life of fresh food products (Kilcast and Subramaniam, 2000) and at the same time improving their quality propositions during cold storage. To be sure that we will get these benefits we need to overlook more aspects of the process itself.

Table 1. Changes of physicochemical quality parameters in muscle tissue of super chilled golden rainbow trout *(Oncorcynchus mykiss)* during 21 d of storage

Examined parameter	Base data	Cryogenic super chilled golden rainbow trout (*Oncorhynchus mykiss*) by dry carbon dioxide at -78°C with flow 0.5 m/s, and stored at -2 to -3°C			Ultra-fast super chilled golden rainbow trout (*Oncorhynchus mykiss*) by cold air at -20°C with flow 3.0 m/s, and stored at -2 to -3°C		
	0 d	7d	14d	21d	7d	14d	21d
pH value	6.76 [a] ± 0.03	6.85 [b] ± 0.02	6.92 [b,c] ± 0.03	6.99 [d] ± 0.03	6.83 [b] ± 0.02	6.91 [b,c] ± 0.02	7.01 [d] ± 0.04
Free fatty acids, % Oleic acid	0.02 [a] ± 0.01	0.04 [a,b] ± 0.01	0.05 [a,b] ± 0.02	0.05 [b,c] ± 0.01	0.04 [a,b] ± 0.01	0.05 [a,b] ± 0.02	0.05 [b,c] ± 0.01
Peroxide value, $\mu eqO_2/kg$	0.45 [a] ± 0.07	1.03 [d] ± 0.01	1.10 [e] ± 0.01	1.15 [e,f] ± 0.02	0.85 [b] ± 0.06	0.98 [c] ± 0.01	1.10 [e] ± 0.08
TBARS, mg MDA/kg	0.10 [a] ± 0.02	0.17 [a,b] ± 0.03	0.25 [b,c] ± 0.05	0.35 [c] ± 0.04	0.12 [a] ± 0.04	0.20 [b] ± 0.04	0.30 [c] ± 0.06
α-Amino nitrogen, mg/100 g	15.98 [a] ± 0.22	16.77 [b] ± 0.34	17.17 [b] ± 0.59	18.02 [c] ± 0.13	16.81 [b] ± 0.52	17.16 [b] ± 0.31	17.97 [c] ± 0.32
TVB-N, mg N_2/100 g	13.96 [a] ± 1.25	24.43 [b] ± 0.91	35.16 [c] ± 1.12	45.54 [d] ± 1.14	24.21 [b] ± 0.98	34.59 [c] ± 0.95	45.38 [d] ± 1.11

Data were expressed as Mean ± SD (n = 7). [a, b, c, d, e, f, g, h, i] - different letters indicated that values of the means in the rows are significantly different ($p^* < 0.05$).

Note. Reprinted from J Aquac Res Development 4, Extension the Shelf-Life of Fresh Golden Rainbow Trout via Ultra-Fast Air or Cryogenic Carbon Dioxide

Super Chilling by Kitanovski VD, Vlahova-Vangelova DB, Dragoev SG, Nikolov HN, Balev DK., Pp 481-491., 2017.

In the table above, obtained data from the research of (Kitanovski et al., 2017) are presented. They investigated changes of physicochemical quality parameters in muscle tissue of super chilled golden rainbow trout (Oncorcynchus mykiss) during 21 d, in different cold storage regimes. In that point of view first we need to optimize process conditions such as temperature and velocity of the cooling air in the superchilling unit. Time needed to reach the desired temperature in the center of the product. Also if the product is packed when undergoing the process the material and thickness of the layer is very important. To be able to say that the freezing process has achieved the expected specifications, our strategy for dealing with the challenges mention above is very complex.

OPTIMIZATION AND MODELING

- For successful applying of the superchilling process, as we say, it's very important to settle and optimize the settings of the superchilling unit (Erdogdu et al. 2005), and packaging if any. The best solution is preparing statistical experiment design with two or more factors each with discrete possible values or "levels", so we can encompass all possible combinations of these levels across all factors. In statistics this is so called full factorial experiment.

The design of the full factorial experiment combined with analyzes that will follow, relate to quality and safety of food products (Anderson et al. 2006), will give the final decision of the success of applied superchilling process. The examined parameters divided in: sensory properties, changes in physicochemical composition of the ingredients like lipids and proteins, microbiological and microstructure analyzes of superchilled food products, will provide the necessary data to estimate the quality and percent of success of the process.

CONCLUSIONS

- Superchilling process and further storage at superchilling temperatures, give the benefit of extending the shelf life and maintaining the quality of fresh food. To be sure that we will get all the positive effects from the process we

need to ensure required items from all points of interests. Most important is correct and sequential setting of the process itself from the aspect of mathematical statistical modeling of a full-factorial experiment, and from the aspect of evaluating the food quality, all parameters that need to be examined, which indicate safety and quality state of food product and it's ingredients.

FUTURE TRENDS

- First statement of conclusions indicates that equally important as the superchilling process itself is, also the storage at superchilled temperatures. Precisely this means that the maintenance of cold chain, from the beginning of process till the end (purchase) of product life, must be guaranteed. Many of the food products found in the markets today are packaged in individual packages. High quality trout is no exception. In collaboration with industries that produce food packages a specific patent system may arise that will monitor, shows and guarantee the specifications of cold chain.

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