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Ice crystal development in pre-rigor Atlantic salmon fillets during superchilling process and following storage

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ABSTRACT

The objectives of this work were to compare ice crystal sizes of pre-rigor Atlantic salmon fillets subjected to two processes of superchilling and to assess the size changes during storage of superchilled samples at −1.7 ± 0.3 C. The fillets were superchilled in an impingement freezer at either a slow rate (−20 °C, 153 W/m^2 K, 4.2 min) which is referred to as process S or a fast rate (−30 °C, 227 W/m^2 K, 2.1 min) which is referred to as process F before storage for 29 days. Significantly smaller ($p < 0.05$) equivalent diameters of ice crystal occurred at faster superchilling rate when compared to slower superchilling rate. The influence of these processes on the microstructure of pre rigor salmon fillets was studied. The equivalent diameter of the intracellular ice crystals formed were 60 ± 5 and 23 ± 1 μm for the samples subjected to processes S and F, respectively. Significant differences were observed between the size of ice crystals formed during the superchilling process and during storage of superchilled samples. The formation of ice crystals within salmon muscle regardless of the superchilling rates was an important factor in reducing cell structure damage.

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1. Introduction

1.1. Superchilling process

Superchilling is the process of partial ice-crystallization from supercooled water in food products. During this process, a thin frozen layer of about 1–3 mm thick is achieved on the surface of food product depending on degree of superchilling required. The degree of superchilling is the amount of water (5–30%) which is partially frozen inside the food product and is one of the most important parameters which define the quality of the superchilled food product. Magnussen, Haugland, Torstveit Hemmingsen, Johansen, and Nordtvedt (2008), Stevik and Claussen (2011) and Stevik et al. (2010) have reported that the amount of ice crystals stored inside a superchilled product is one of the most important parameters which determine the quality of the end product. Also, it has been reported that a degree of superchilling between 5 and 30% is accepted and that a degree of superchilling higher than 30% will cause higher drip loss in food products (Stevik & Claussen, 2011).

1.2. Ice crystal formation in pre-rigor muscle

The quality of superchilled foods is mainly related to the properties of the ice crystals, such as their size, location (i.e. extracellular and intracellular) and shape during the superchilling process (Alizadeh, Chapleau, Lamballerie, & Bail, 2009; Martino, Otero, Sanz, & Zaritzky, 1998; Martino & Zaritzky, 1986; Petzold & Aguilera, 2009). These properties are influenced by the rate of superchilling, storage time, temperature fluctuation and physiological status of the muscle foods, i.e. pre-, in- or post-rigor muscle (Shenouda, 1980). Slow partial freezing/superchilling rates in post-rigor muscle usually cause texture damage due to the formation of large and extracellular ice crystals (Kaale, Eikevik, Bardal, Kjorsvik, & Nordtvedt, 2013; Shenouda, 1980) probably because the extracellular fluid has a lower osmotic pressure than the intracellular fluid. Rapid superchilling of post-rigor muscle also results in the initial formation of extracellular ice (Chevalier, Sequeira-Munoz, Bail, Simpson, & Ghoul, 2001; Dincer, 1997; Fernandez, Otero, Martino, Molina-Garcıá, & Sanz, 2008; Kiani & Sun, 2011; Martino et al., 1998; Martino & Zaritzky,

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1986; Petzold & Aguilera, 2009). However, the extracellular crystals formed during rapid superchilling are much smaller and more finely distributed than those in slow superchilling (Kaale, Eikevik, Bardal, & Kjorsvik, 2013; Kaale, Eikevik, Bardal, et al., 2013). The formation of extracellular ice still dehydrates the cells to some extent, but as the temperature decreases rapidly, the cells become supercooled and the remaining intracellular water freezes before it has time to diffuse out of the cell.

In pre-rigor muscle, the cell fluids are tightly bound to the intracellular proteins and the diffusivity from inside to outside the cell is therefore limited resulting in the formation of intracellular ice crystals independent of superchilling/partial freezing rates (Shenouda, 1980). A large number of smaller ice crystals are formed within the cell. If very slow superchilling/partial freezing rates are used, the muscle can go into *rigor mortis* during the superchilling process and ice crystal formation will be extracellular.

There is pronounced interest for superchilling muscle in the pre-rigor state. Formation of the ice crystals within the cells regardless of the superchilling rates is the most important factor for reducing damage of food muscles and hence maintaining their quality. Freezing pre-rigor Atlantic salmon fillets has also been found to conserve more of the positive quality aspects than freezing of post-rigor muscle (Einen, Guerin, Fjæra, & Skjervold, 2002; Skjervold et al., 2001). An alteration of the freezing and thawing regime allowing for more rigor contraction might potentially conserve more of the positive quality aspects of pre-rigor muscle of the food products. The pre-rigor filleting allows the fish to be processed directly after slaughter; therefore no storage period before filleting is necessary (Bahuaud et al., 2008). Pre-rigor fillets reach the market 3–4 days fresher compared to post-rigor fillets and, as a matter of quality, show a reduction in the severity of gaping, firmer flesh texture, positive effect on color and increased thickness of the fillet (Bahuaud et al., 2008; Einen et al., 2002; Hansen, Mørkøre, Rudi, Langsrud, & Eie, 2009; Skjervold et al., 2001). This early processing also increases the fresh fillet value and reduces waste product transport by 20%, considerably decreasing transportation costs and energy wastage.

However, few studies have been conducted on how the superchilling rates and pre-rigor state will affect ice crystal sizes during the superchilling process and following storage. The size of ice crystals formed in pre-rigor fillets during the superchilling process and the change of the microstructure size during storage of superchilled samples should also be considered, as it is one of the main factors affecting the textural and physical properties of superchilled foods. Therefore, the objectives of this work were to compare the microstructure sizes of pre-rigor salmon fillets superchilled at slow and fast rates and to assess the change of these microstructure sizes during storage of superchilled products.

2. Materials and methods

2.1. Materials and superchilling process

Salmon fillets (0.9–1.2 kg) with thickness ranging from 26 to 28 mm were taken from the slaughtering plant, Salmar (Frøya, Norway). The fillets were vacuum packed and partially frozen pre-rigor (i.e. within 5–6 h of being caught) in an Impingement Advantec Lab Freezer (JBT Food - tech, Rusthållsgatan 21, SE-251 09, Helsingborg, Sweden) at NTNU Energy's laboratory in Trondheim, Norway. The samples were superchilled (partially frozen) at −20 °C, 153 W/m^2 K for 4.2 min (S) and at −30 °C and 227 W/m^2 K for 2.1 min, (F) to achieve an ice content of 20%. The previously developed model (Kaale, Eikevik, Kolsaker, & Stevik, 2012) was used to predict the degree of superchilling and superchilling time.

Once superchilled, the salmon samples were analyzed at day zero (superchilling process) and other samples were stored in a cold room at −1.7 ± 0.3 °C for 29 days. Three fillets were analyzed at each sampling time.

2.2. Measurement of the temperature during the superchilling process and following storage

The temperature was measured at three different locations on the samples during the superchilling process: at the surface, midway to the center and in the center. Three thermocouples were used at each location. The thermocouples were connected to a temperature recorder while the sample was cooled in the impingement freezer. The temperatures of the cool air and of the

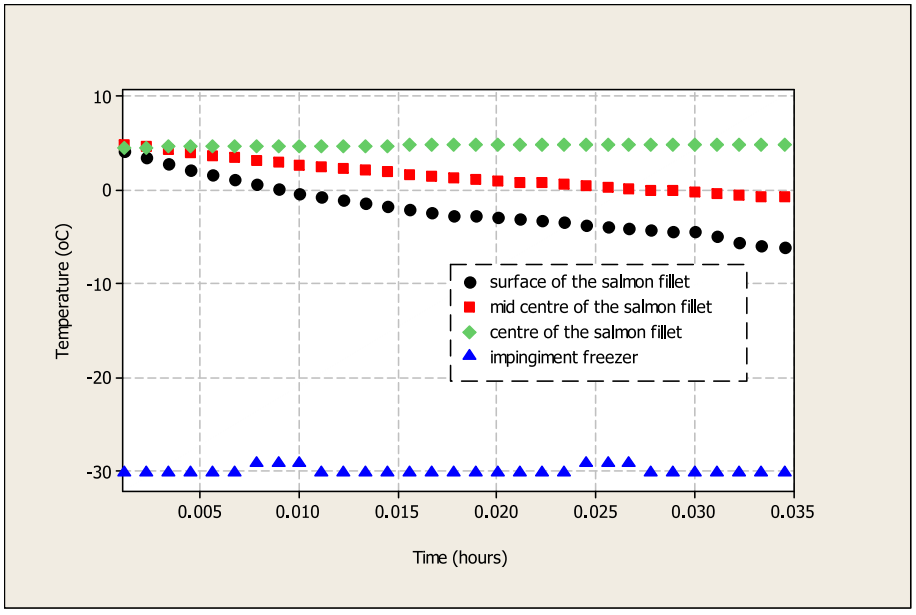

Fig. 1. Temperature–time profile at three places in the Atlantic salmon fillet and the air temperature in the impingement freezer during fast superchilling (−30 C, 227 W/m^2 K 2.1 min).

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