LWT - Food Science and Technology 55 (2014) 528–535

Contents lists available at ScienceDirect

LWT - Food Science and Technology

journal homepage: www.elsevier.com/locate/lwt

Changes in water holding capacity and drip loss of Atlantic salmon (*Salmo salar*) muscle during superchilled storage

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ARTICLE INFO

Article history:
Received 24 March 2013
Received in revised form
1 October 2013
Accepted 15 October 2013

Keywords:
Superchilled storage
Atlantic salmon (*Salmo salar*)
Liquid loss
Drip loss

ABSTRACT

Changes in water holding capacity and drip loss of Atlantic salmon (*Salmo salar*) fillets during superchilled storage were studied. Due to the significant differences in ice crystal sizes observed in our previous study, the liquid loss (LL) was analysed separately, at the surface and centre of the superchilled samples. No significant differences were found in LL between surface and centre parts of the superchilled samples. No significant difference in the LL was observed from surface samples between 1 and 14 days of storage. There was a significant difference in the LL at day 1 of the centre samples, but no significant differences were observed between 3 and 14 days of storage. In contrast, the LL was significantly decreased at day 21 both at the centre and the surface of the superchilled samples. No significant difference ($p < 0.05$) was found in drip loss between 1 and 14 days of storage for the superchilled samples. A significant increase in drip loss for the superchilled samples was observed at day 21. These findings are significant for the industry because it provides valuable information on the quality of food in relation to ice crystallisation/recrystallisation during superchilled storage.

1. Introduction

1.1. Superchilling process

Fresh and high quality food is becoming increasingly important. Many studies have been done to find the good preservation technologies. Superchilling technology is an alternative for preserving the freshness and maintaining the quality of food compared to conventional chilling and freezing technologies (Kaale, Eikevik, Rustad, & Kolsaker, 2011). Several different performances/definitions for superchilling are used, and have shown beneficial effects in storage of foods: Ando, Nakamura, Harada, and Yamane (2004) define it as the temperature zone below 0 °C but where ice crystals are not generated. Beaufort, Cardinal, Le-Bail, and Midelet-Bourdin (2009) defined superchilling as a technology where food is stored just below the initial freezing temperature. Bahuaud et al. (2008), Duun and Rustad (2008), Kaale, Eikevik, Bardal, Kjorsvik, and Nordtvedt (2013), Kaale, Eikevik, Bardal, and Kjorsvik (2013), Kaale, Eikevik, Rustad, et al. (2013), and Stevik et al. (2010) have performed superchilling by shell freezing food products and then letting the temperature equalise during storage at a temperature below the initial freezing point. The advantage of shell freezing is to facilitate temperature equalisation (enhance heat transfer) within the food and hence good mechanism of ice crystal formation. The ice formed in the food product acts as an internal ice reservoir during distributions or storage for short periods.

The main potential disadvantage of partially freezing foods is the risk of damage caused by ice crystal formation. The size and location of ice crystals formed during partial freezing (1–3 mm) from the surface is dependent on the superchilling rate. Furthermore, these crystals affect important quality parameters such as texture, water holding capacity and drip loss upon thawing (Mittal & Griffiths, 2005).

The question of the optimum method by which food should be shell frozen has been the subject of many studies. Recent studies Kaale and Eikevik (2013) and Kaale, Eikevik, Bardal, Kjorsvik, and Nordtvedt (2013), Kaale, Eikevik, Bardal, and Kjorsvik (2013), Kaale, Eikevik, Rustad, et al. (2013) indicated that shell/partial frozen food products using impingement freezer result in suitable properties of ice crystal with regard to size, distribution and shape provided that is done at a high rate of superchilling. Bahuaud et al. (2008), Chevalier, Sequeira-Munoz, Bail, Simpson, and Ghoul (2001), Dincer (1997), Fernandez, Otero, Martino, Molina-García, and Sanz (2008), Hagiwara, Wang, Suzuki, and Takai (2002), Kiani and Sun (2011), Martino and Zaritzky (1986), Martino, Otero, and Sanz (1998), and Petzold and Aguilera

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http://dx.doi.org/10.1016/j.lwt.2013.10.021

(2009) found that the size, distribution and shape of ice crystals have a major influence on the quality of food products.

1.2. Water holding capacity (WHC) and drip loss

A useful tool for describing the quality in muscle foods post-mortem is to measure the WHC of the muscle (Olsson, Ofstad, Lodemel, & Olsen, 2003). The WHC of food products is an important quality parameter as it affects both profitability and quality, because it affects the weight change during transport and storage, the drip loss during thawing, the weight loss and shrinkage during cooking, and the juiciness and tenderness of the meat (Duun & Rustad, 2007; den Hertog-Meischke, van Laack, & Smulders, 1997; Huff-Lonergan, 2002; Irie, Izumo, & Mohri, 1996; Shaviklo, Thorkelsson, & Arason, 2010). The WHC is closely related to textural properties, and a low WHC has often been described as an effect of post-mortem structural changes in the muscle. Such alterations could be shrinkage of the myofilament lattice, myosin denaturation and increased extracellular space (Duun, 2008). Myofibrils are long rod-like organelles found in skeletal and cardiac muscle that constitute approximately 80% of the volume of the muscle cell (Huff-Lonergan, 2002; Huff-Lonergan & Lonergan, 2005). Moreover, approximately 85% of the water in a muscle cell is held in the myofibrils (den Hertog-Meischke et al., 1997; Huff-Lonergan, 2002; Huff-Lonergan & Lonergan, 2005).

Drip loss, or the release of water during thawing, implies nutrient loss (Duun, 2008; Turan, Kaya, & Erkoyuncu, 2003). Drip loss is usually expressed as a percentage of the initial weight of the product (Huff-Lonergan & Lonergan, 2005). Most of the proteins found in drip are water-soluble, sarcoplasmic proteins. It is noted that, in general, muscle proteins in fish and shellfish are more susceptible to partial freeze denaturation compared with land animal proteins (Benjakul & Visessanguan, 2010).

Our previous studies Kaale, Eikevik, Bardal, Kjorsvik, and Nordtvedt (2013), Kaale, Eikevik, Bardal, and Kjorsvik (2013), Kaale, Eikevik, Rustad, et al. (2013) demonstrated that a high superchilling rate results in a high rate of heat removal, which leads to the formation of a large number of small nuclei and thus a large number of small ice crystals that grow both within and outside cells. Consequently, the cells maintain their integrity which in turn minimises drip loss; maintain water holding capacity and other quality parameters during thawing (Smith, 2011). However, this advantage was reduced during superchilled storage by the rapid growth in ice crystal size in the salmon fillets. Moreover, there were large differences between the ice crystal sizes at the surfaces and centres of the superchilled salmon fillets (Kaale, Eikevik, Bardal, & Kjorsvik, 2013). An increase in the size of ice crystals during superchilled storage may impart mechanical damage by physically rupturing cell walls, which may result in an increase in drip loss, a reduction of the WHC and changes in other quality parameters related to the damage of the cell structure.

Nevertheless, there are few studies showing the relationship between ice crystal development and quality of food during superchilled storage. Most of the studies on superchilling have focused on the physical, chemical and microbiological analysis (Ando et al., 2004, Bao, Arason, & Thórarinsdóttir, 2007; Duun & Rustad 2007, 2008; Gallart-Jornet, Rustad, Barat, Fito, & Escriche, 2007). Therefore, the objective of this study was to analyse the WHC at both the surfaces and centres of salmon fillets and drip loss. Taken together these results help to clarify the effect of ice crystal development during the superchilled storage.

2. Materials and superchilling process

Salmon (*Salmo salar*) fillets (0.9–1 kg), were delivered by Lerøy Midnor (Hitra, Norway). The samples were vacuum-packed and stored at 4 °C for 24 h before the superchilling process to ensure a constant temperature in all samples. Superchilling was performed 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 −30 °C and 227 W/m^2 K (at 2.5 kPa pressure differences of the fan in the impingement freezer) for 2.1 min to achieve an ice content of 20%. A previously developed model (Kaale, Eikevik, Kolsaker, & Stevik, 2013) was used to predict the degree of superchilling. The experiments for measuring the surface heat transfer coefficient (SHTC) were also performed in an Impingement Advantec Lab Freezer. A detailed experimental set up and the equations used to calculate the SHTC are explained elsewhere (Kaale, Eikevik, Kolsaker, et al., 2013). Once superchilled, the salmon samples were stored in a cold room at −1.7 ± 0.3 °C for 28 days. Three fillets were analysed at each sampling time.

2.1. Temperature trend during storage

The temperature, one of the critical parameters during superchilled storage, was strictly controlled during this study. The storage box (92 × 73 × 54.5 cm) was designed with an internal heating element to ensure adequate temperature regulation. Three Pt100 temperature sensors were inserted into the storage box. One sensor was used to measure the air temperature, and the other two were used to measure the temperatures at the surface and centre of the superchilled sample. The set-point temperature was −1.7 °C. The box was placed inside the storage room, which was at a temperature of approximately 5 °C (temperature outside the storage box).

2.2. Microscopic analysis

A fixation method similar to that proposed by Alizadeh, Chapleau, de Lamballerie, and Le-bail (2007) and Martino and Zaritzky (1988) was used to observe the spaces left by the ice crystals in the tissue. Detail information in the method used will not presented here because the micrographs presented in this study were taken from the previous study (Kaale, Eikevik, Bardal, & Kjorsvik, 2013). However, the superchilling process and storage were the same in both studies except, this study analysed WHC and drip loss while (Kaale, Eikevik, Bardal, & Kjorsvik, 2013) analysed ice crystal sizes of the salmon fillets.

2.3. Water holding capacity and drip loss

The liquid loss was determined for minced muscle by low speed centrifugation as described by the WHC method of Eide, Børresen, & Strøm (1982). A centrifugal force of 270 *g* was used instead of 1500 *g* (Hultmann & Rustad, 2002). The LL is expressed as the percentage of weight lost during the centrifugation of 2 *g* of minced sample for 5 min. The analyses were run in quadruplicate. The water content in the mince was determined by drying a 2 g minced sample at 105 °C for 24 h. These analyses were run in duplicate.

For the quantification of drip loss, the sample was removed from the vacuum bag after thawing at 4 °C for approximately 24 h and the remaining liquid in the bag was weighed. The calculation of the drip loss was based on the initial sample weight after thawing. Mean values were calculated from three triplicates.

2.4. Statistical analysis

The observations for the WHC at the two locations (surface and centre) and the drip loss with respect to the storage days were analysed by one- and two-way analyses of variance using Minitab 16 software. A general linear model, (post-hoc test) under Tukey's