Superchilling, ice fraction and quality

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ABSTRACT

The scope of the current experiments was to superchill a selection of fresh food by two superchilling methods followed by extensive storage studies and monitoring of quality during superchilled storage.

Several methods for superchilling have been implemented at fish processing sites, but to a very limited extent and not adjusted to automated production lines. The current study presents measurements of the efficiency and precision of two methods for superchilling (liquid CO_2 injection and air chilling) as well as their applicability for the expected development towards automated production lines in fresh food manufacturing. Secondly, as a precision index, the effect of the amount of ice caused by superchilling was investigated with respect to prolonged shelf-life and end product quality.

Superchilling by means of liquid CO_2 injection (LIC) and air chilling both gave an acceptable and reproducible ice fraction within a short period of chilling time (1-2 minutes). Analyses of drip loss, liquid loss and microbiological quality during storage showed that superchilling improved the shelf life of salmon and chicken fillets significantly - being an important contribution to food safety of fresh food. However, within the tested boundaries for ice fraction, the *level* of ice stored inside the fillets did not seem to considerably influence on the physical and microbiological quality of the products.

1. INTRODUCTION

Superchilling, described as early as in 1920 (Le Danois, 1920) is a method for conserving foods by holding the product at a temperature between -0.5 and -4^{o}C (Fennema *et al.*, 1973). For many food products, superchilling results in better quality compared to conventional chilling (Einarsson, 1988). The ability to supply sufficient amounts of fresh food to a growing population is currently a major worldwide challenge. In this context superchilling is considered a very adequate technology for ensuring a greater exploitation of fresh food, and further development and refinement of different superchilling methods as well as extension of the fresh food product range will be of great importance (Magnussen *et al.*, 2008).

It has been shown that the amount and distribution of ice in superchilled products prior to further processing greatly affects the process capacity and yield as well as the product quality, suggesting that an optimum ice content and distribution exists (Haugland *et al.*, 2005, Haugland, 2002).

At superchilling temperatures, the microbial activity is drastically reduced. The shelf-life of roast leg of pork could be more than doubled by superchilling, compared to traditional chilling and storage at 4°C (Haugland *et al.,* 2005). Superchilling can extend the shelf-life of fish with about 7 days compared with traditional ice storage (Duun and Rustad, 2007, Duun and Rustad, 2008, Sivertsvik et al., 2002). Duun and Rustad (2008) showed that ice chilled reference fillets from farmed salmon of premium grade, maintained good quality up to 17–21 days. The storage time of vacuum packed salmon fillets can be doubled by superchilled storage at -1.4°C and -3.6 °C compared to ice chilled storage.

Ice-forming and recrystallisation can cause microstructural changes to food tissue during freezing, resulting in cell dehydration, drip loss, loss of water holding capacity (liquid loss) and textural changes during thawing (Foegeding et al. 1996, Spangelo, 2004). However, the limited amount of water frozen during superchilling will lead to considerably less change in microstructure, denaturation and drip loss than for frozen foods (Einarson, 1988).

Several methods for superchilling og fresh foods have been tested and to some degree implemented in the food processing industry. Most attention has been devoted to shell freezing in blast air and cryogenic gases (CO_2 and N_2). However, direct contact freezers, brine and ice slurry systems may in some instances be equally efficient (Magnussen et al., 2008).

2. MATERIALS AND METHODS

2.1. Materials and superchilling process

Fillets of salmon (postrigor, 1-1.5 kg, stored at chilling temperatures for 2 days after slaughtering) and chicken (0.15-0.30 kg, stored at chilling temperatures (4ºC) for 2 days after slaughtering) were vacuum packed in polyetilene bags before superchilling. The products were superchilled to reach two different levels of ice content (10% and 20%). The superchilling was performed for all products in a liquid CO_2 injection cabinet (LIC) at -50ºC and in an air tunnel at -20ºC with an air velocity of 2 m/s. Immediately after superchilling, the ice fraction was measured calorimetrically. The superchilled samples were stored and monitored at conditions of -1.5ºC (low level of ice) and -1.7ºC (high level of ice). The quality of the stored, superchilled samples was measured by means of microbiological (colony forming units – CFU) and physical analyses (drip loss, liquid loss – LL).

2.2. Measurements of Ice Fraction by calorimetry

The ice fraction in the superchilled salmon and chicken fillets was measured using a calorimetric method (Haugland *et al.,* 2005). The calorimetric measurements were performed in steel thermoses (Finemech Inc., Cylindrical Dewar Container, Portola Valley, USA) filled with 1.5-2.5 liters of tempered water (~ 35ºC). Approximately 0.25-0.30 kg pieces of salmon fillets and chicken fillets of 0.15 kg was weighed directly after superchilling. Then one thermocouple (Agilent Technologies Inc., Agilent 34970A, Santa Clara, USA) was placed in the fillet piece/ fillet core and one

was placed near the fillet surface, before lowering the fillet into the thermos. The thermoses were tightly sealed, and the systems were left for temperature equalization under continuous logging for approximately 24 hours. Analysis was performed on three parallels for each ice-level. Based on temperature data from the equalization process, the initial ice fraction after superchilling was calculated by means of enthalpy balances.

2.3. Microbiological and physical changes during storage

Salmon and chicken fillets with target ice levels of 10 and 20% were stored for four and six weeks respectively at temperatures corresponding to the target ice levels to ensure the ice fraction in the product, and analyzed for CFU (colony forming units), drip loss and liquid loss at frequent intervals. The microbiological growth during storage was measured by method NMKL 96. Dilutions of the raw material sample was moulded in iron-agar plates and incubated at 20ºC for 72 hours. The number of colony forming units is counted on plates holding between 25 and 250 colonies.

For quantification of the drip loss, the sample was removed from the vacuum bag and the liquid left in the bag was weighed. Mean values were calculated from two replicates. Water content in the drip liquid was determined by drying sample of 2 g at 105 °C for 24 h in duplicate.

Liquid loss (LL) was determined on minced muscle by low-speed centrifugation as described by the water holding capacity method of Eide, Borresen, and Strom (1982). A centrifugal force of 210 g was used instead of 1500 g (Hultmann & Rustad, 2002). The LL is expressed as the percentage of weight of the mince lost during centrifugation of ∼ 2 g of sample for 5 min. The analyses were run in quadruplicate.

3. RESULTS AND DISCUSSION

3.1. Superchilling efficiency and ice-fraction

The achieved ice fraction after superchilling is presented in Table 1 below.

Table 1: Ice-fraction of superchilled salmon and chicken fillets (n=3)

Product	Superchilling method	Superchilling time (minutes)	Target ice fraction (%)	Achieved ice fraction (%)
Salmon fillets	LIC cabinet	5	20	29 ± 3
	Air tunnel	10	10	15 ± 3
		20	20	38 ± 4
Chicken fillets	LIC cabinet	4	10	23 ± 2
		6	20	29 ± 5
	Air tunnel	10	10	8 ± 3
		20	20	21 ± 10

Superchilling by means of LIC and air both gave an acceptable ice fraction within a short period of chilling time. The internal reproducibility of ice fraction in each batch was more precise for salmon than for chicken, related to a more even weight and geometrical distribution among the salmon fillets than for the chicken fillets. The results presented in Table 1 reveal the challenge of hitting the intended level of ice when a large number of pre-trials are not possible.

3.2. Physical and microbiological changes during storage

A low increase in drip loss could be seen for both salmon and chicken fillets during storage. For salmon fillets the drip loss increased from approximately 1.7 % to 4 % during four weeks storage, while the corresponding figures for chicken fillets raised from approximately 1 % to 6 % during six weeks storage, see Figure 1 and 2.

The amount of ice stored inside a superchilled product is considered a major contributor to the shelf-life of the end product (Haugland *et al.*, 2005, Magnussen *et al.*, 2008). It was also expected that the higher ice fractions could increase the drip loss of the fillets due to destruction of cell membranes (Foegedinger, 1996). However analyses of drip loss and liquid loss showed no favour of the fillets containing less ice, on the contrary fillets with high ice fraction showed the best scores for physical quality during storage.

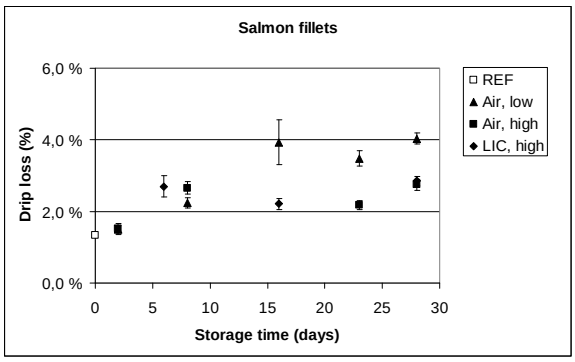

Figure 1: Drip loss for salmon during 30 storage days. *Air, low:* air tunnel giving low ice fraction. *Air, high:* air tunnel giving high ice fraction. *LIC, high:* liquid CO2 injection cabinet giving high ice fraction.

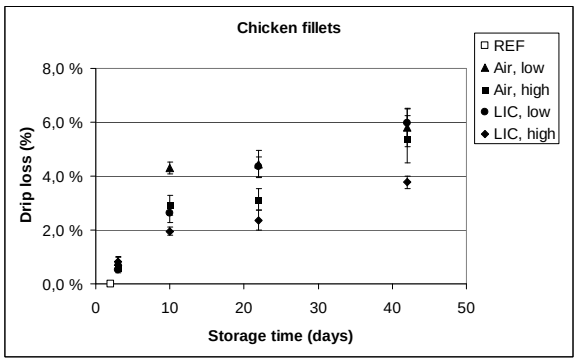

Figure 2: Drip loss for chicken during 50 storage days. *Air, low:* air tunnel giving low ice fraction. *Air, high:* air tunnel giving high ice fraction. *LIC, low:* liquid CO2 injection cabinet giving low ice fraction. *LIC, high:* liquid CO2 injection cabinet giving high ice fraction.

The liquid loss for salmon and chicken fillets during storage is presented in Figure 3 and 4.

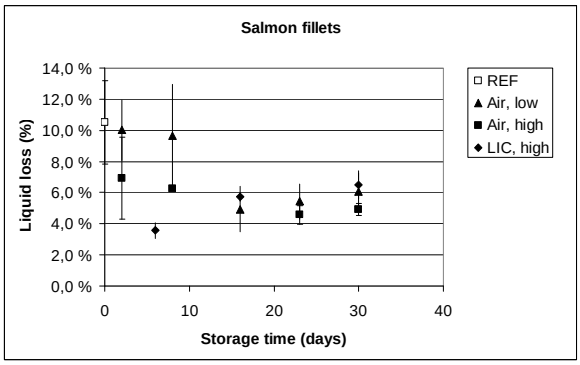

Figure 3: Liquid loss for salmon during 40 storage days. *Air, low:* air tunnel giving low ice fraction. *Air, high:* air tunnel giving high ice fraction. *LIC, high:* liquid CO2 injection cabinet giving high ice fraction.

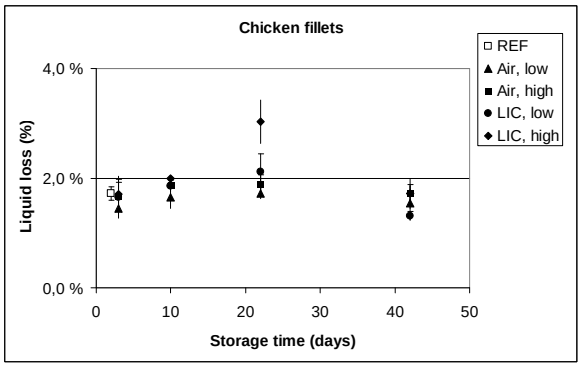

Figure 4: Liquid loss for chicken during 50 storage days. *Air, low:* air tunnel giving low ice fraction. *Air, high:* air tunnel giving high ice fraction. *LIC, low:* liquid CO2 injection cabinet giving low ice fraction. *LIC, high:* liquid CO2 injection cabinet giving high ice fraction.

No trends for the liquid loss can be seen for either salmon or chicken fillets, but the levels are generally low, and for salmon the results are corresponding to former findings (Duun, 2008).

The microbiological quality of superchilled fillets of salmon and chicken was considerably prolonged compared to the stated shelf life of chilled fillets, see Figure 5 and 6.

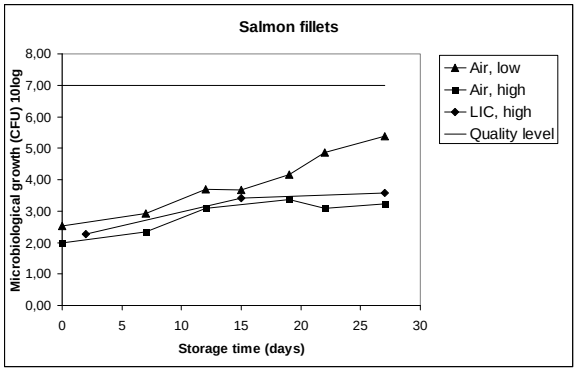

Figure 5: Microbiological growth in salmon during 30 storage days. *Air, low:* air tunnel giving low ice fraction. *Air, high:* air tunnel giving high ice fraction. *LIC, high:* liquid CO2 injection cabinet giving high ice fraction.

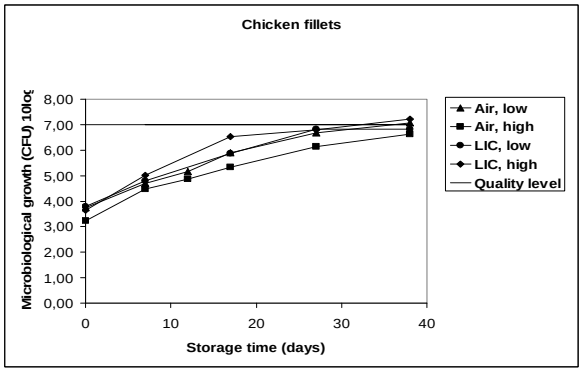

Figure 6: Microbiological growth in chicken during 40 storage days. *Air, low:* air tunnel giving low ice fraction. *Air, high:* air tunnel giving high ice fraction. *LIC, low:* liquid CO2 injection cabinet giving low ice fraction. *LIC, high:* liquid CO2 injection cabinet giving high ice fraction.

The quality limit of 10^7 CFU/g reflects a usual microbiological quality measure, above which food is regarded as unfit for human consumption (Gram and Dalgaard, 2002). The chicken fillets first reached the quality limit for microbiological growth at the end of the storage period (approximately 5 weeks storage), while the salmon fillets only reached a CFU level of 10^5 by the end of the storage period (4 weeks).

For salmon fillets the lower ice fraction seemed to give a shorter shelf life than the higher fraction, but a corresponding result could not be seen for chicken fillets.

Only a few preliminary quality studies of superchilled chicken fillets have been reported earlier (Nordtvedt, 2009). Consequently the results from the current study are very promising with respect to including this product in the portfolio of fresh food strongly benefiting from the superchilling technology.

4. CONCLUSION

Based on the performed experiments superchilling, giving the products a certain content of ice, improves the shelf life of salmon and chicken fillets significantly - being an important contribution to food safety of fresh food. The *level* of ice stored inside the fillets does not seem to considerably influence on the physical and microbiological quality of the products. Most likely the superchilling concept is somewhat robust, and gives the shelf life and quality related benefits within quite wide boundary limits for the ice fraction. In the current experiments the prolonged shelf life of salmon and chicken due to superchilling also showed that the end product physical quality was not influenced by the process.

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