LWT - Food Science and Technology 90 (2018) 138–144

Contents lists available at ScienceDirect

LWT - Food Science and Technology

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

Effects of controlled thawing media temperatures on quality and safety of *pre-rigor* frozen Atlantic cod (*Gadus morhua*)

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ARTICLE INFO

Keywords:
Atlantic cod
Frozen storage
Thawing
Chemical quality
Microbial quality
Safety

ABSTRACT

Novel strategies for thawing of *pre-rigor* frozen Atlantic cod (*Gadus morhua*) in water with air circulation, applying different and controlled temperatures are presented. After thawing (day 0) and after six days of storage at 2.9 ± 0.6 °C (day 6), quality parameters (thawing- and drip loss, cooking yield, sensory evaluation, and textural properties), chemical (pH, water content, total volatile basic nitrogen (TVB-N)) and microbiological analyses (total viable counts (TVC-IA), H_2S-producing bacteria (H_2S-IA), coliforms, thermo-tolerant coliforms and presumptive *E. coli*, and *Listeria monocytogenes*) were performed. The results obtained were compared statistically. Both thawing strategies, thawing at 10 °C and −0.5 °C or at constant 10 °C, preserved good quality fish. The hygienic conditions during the thawing processes were satisfactory and there were no indications of impaired food safety during any of the thawing strategies. No pathogens were detected in any of the cod samples, nor in the thawing media. The results showed that water thawing at −0.5 to 10 °C is suitable for frozen cod, without compromising quality and safety, and that no significant difference were seen between the selected thawing temperature regimes.

1. Introduction

Because of their biological composition, fish are amongst the most highly perishable food products, and even at normal refrigeration storage conditions, the shelf life is limited by oxidation, and enzymatic reactions, as well as microbiological spoilage (Adams & Moss, 1995, pp. 119–125; Sampels, 2015). The main specific spoilage bacteria (SSB) reported in cold water marine fish are *Pseudomonas* spp., *Shewanella putrefaciens*, and *Photobacterium phosphoreum* (Gram & Huss, 1996; Ólafsdóttir, Lauzon, Martinsdóttir, Oehlenschläuger, & Kristbergsson, 2006). *P. phosphoreum* is CO_2-tolerant and is a spoilage organism of fish stored under modified atmosphere, whereas *Pseudomonas* spp. and *Shewanella putrefaciens* produce hydrogen sulphide (H_2S) and are the predominant SSBs of fresh marine fish from temperate waters stored at aerobic conditions (Gram & Dalgaard, 2002).

The catching of whitefish in Northern waters is typically seasonal, as can be seen during the short and intensive period where migrating spawning cod ("skrei") are caught in Northern Norway during the winter and spring each year (Standal & Bouwer Utne, 2007). A substantial part of the caught whitefish is received, and further processed by the land-based industry relying on raw materials from the fishing fleet. As the land-based industry is aiming to level out the seasonal character of their activity, strategies to extend the period of supply of high quality and safe raw materials are highly needed. This challenge can be met by applying fish frozen at sea, under the premise that the characteristics of the raw material are not negatively altered during freezing, storage, and thawing.

Freezing is a common method of preservation, important for shelf life extension and conservation of quality. Hence, freezing on board immediately after capture (*pre-rigor*), before autolysis and bacteria-driven degradations come into play, would be an optimal situation (MacCallum, Jaffray, Churchill, & Idler, 1968). However, the quality of the product is closely related to the freezing and thawing conditions, as they influence chemical reactions and muscle degradation (Baygar, Alparslan, & Çaklı, 2013; Ersoy, Aksan, & Ozeren, 2008; Genc, Esteves, Anibal, & Diler, 2015; Li & Sun, 2002).

There are many potential methods for thawing fish, the water thawing methods being most commonly applied by the industry

Abbreviations: H/G, Headed and gutted

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https://doi.org/10.1016/j.lwt.2017.12.030
Received 1 October 2017; Received in revised form 6 December 2017; Accepted 11 December 2017
Available online 12 December 2017

(Archer, Edmonds, & George, 2008; Backi, Leth, & Gravdahl, 2016; Haugland, 2002). Commercially, media temperatures applied for thawing are usually 12–25 °C (Archer et al., 2008). However, mostly the fish is thawed in uncontrolled manner using batch thawing in running water, without temperature control (Haugland, 2002). Methods applicable at an industrial scale were recently reviewed by Backi (2017).

In a recent study by Roiha, Jónsson, Backi, Lunestad, and Karlsdóttir (2018), it has been concluded that water thawing with air circulation provided efficient thawing and that the quality of the fish was good, with a shelf life of up to 14 days post-filleting. As a follow-up of the trial by Roiha et al. (2018), the aim for the present thawing trial was to investigate the effects of different controlled temperatures of thawing media during water thawing on the quality and safety of cod fillets. Thawed fresh fillets were further evaluated during chilled storage for up to six days.

2. Materials and methods

2.1. Experimental design

Atlantic cod (*Gadus morhua*) were caught by a commercial trawling vessel in the Norwegian Sea, in February 2015. The cod were headed and gutted (H/G) and frozen *pre-rigor* in blocks at −40 °C using a vertical plate freezer on-board the vessel. To avoid thaw *rigor*, the fish blocks were stored at −28 °C for nine weeks before thawing to ensure that the fish had passed *rigor mortis* (Stroud, 1969, p. 12). Four blocks of cod were randomly divided into two groups (T10 and T10–0.5), with approximately 20 fish in each group. The average gutted weight of the cod was 3.0 ± 1.1 kg. Using two different temperature regimes, the two groups were thawed in 1000-L fish tubs with an air diffusion element at the bottom, generating circulation to secure a homogenous water temperature. Additional turbulence was induced as the thawing medium (potable water) was exchanged and re-used after being heated in a heat exchanger. The first group (T10) was thawed with air circulation and continuous water flow at constant-value controlled temperature of 10 °C (4 h). The second group (T10–0.5) was thawed at 10 °C for 2 h before the water temperature was lowered to −0.5 °C (for 26–27 h), also at constant-value controlled levels.

2.2. Temperature profiling

For temperature profiling of the cod during thawing, temperature data loggers (iButton DS1922F, Thermochron, Maxim Integrated, San Jose, USA) recording temperature at 1 h intervals, were placed in the muscle of three fish per group after making an incision with a scalpel just below the first dorsal fin before freezing on-board. The temperature of the thawing water was recorded at 5 min intervals according to the graphical outline in Fig. 1.

2.3. Sampling

After thawing, the H/G cod were manually filleted skin on and pre-weighed before packing into Styrofoam boxes, covered with flake-ice of potable quality, and with plastic film between the ice and the fish. Quality and safety evaluations of fillets were performed 2–3 h after thawing (day 0) and after six days of storage at 2.9 ± 0.6 °C (day 6).

Fillets from the right side of the fish were washed in cold tap water for 10–15 s, and the surface water was wiped off using tissue paper. The fillets were weighed, and T10 (n = 20) and T10–0.5 (n = 20) fillets were subjected to sensory evaluation and evaluation of muscle redness and blood spots. Fillets from the left side of the fish were analysed for physicochemical- and microbiological parameters. A schematic drawing of a fillet and how sampling was conducted for each parameter is given in Fig. 2. Analysis of physicochemical parameters included water content, total volatile basic nitrogen (TVB-N), muscle pH, texture, cooking yield, and drip loss during storage. Microbiological parameters included total viable counts (TVC-IA), H_2S-producing bacteria (H_2S-IA), coliforms, thermo-tolerant coliforms, and *Listeria monocytogenes*.

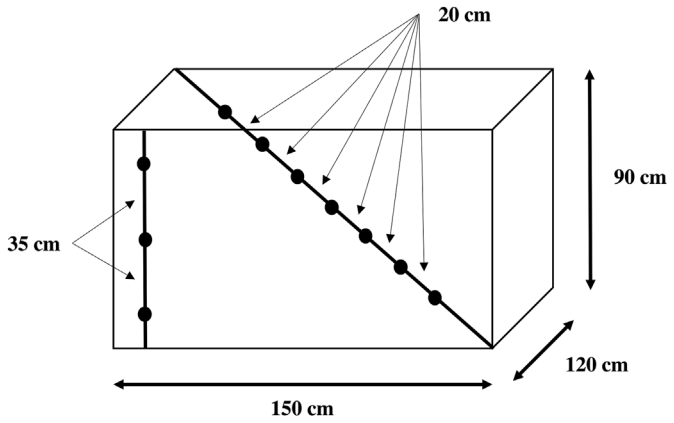

Fig. 1. Graphical outline of fish tubs, circles indicating location of temperature loggers in the water column.

2.4. Chemical analyses

Two sections of the fillet (Fig. 2) were used for measuring muscle pH and water content. The pH-measurements were performed according to the manual of the producer (Weilheim, WTW, pH3110, Germany). The muscle water content was determined by drying samples of approximately 2 g at 105 °C for 24 h (n = 6). The difference in weight before and after drying was taken as the total water content of the sample, and expressed as percentage (%).

For evaluation of cod freshness, total volatile basic nitrogen (TVB-N) was determined in duplicate by the Conway micro-diffusion method described by Conway and Byrne (1933), after extracting the fish muscle with 7.5% aqueous trichloroacetic acid solution (Malle & Tao, 1987). The results were expressed as mg TVB-N/100 g muscle.

2.5. Thawing and drip loss

Thawing loss of the thawed blocks was determined from the known weights of the fish blocks before and after thawing and expressed as:

$$\text{Thawing loss (\%)} = \frac{\text{weight of frozen fish block (g)} - \text{weight of thawed fish block (g)}}{\text{weight of frozen fish block (g)}} \times 100$$

The fillets were weighed at day 0 and at day 6 to evaluate drip loss during cold storage, according to following equation:

$$\text{Drip loss (\%)} = \frac{\text{weight of fillets before storage (g)} - \text{weight of fillets after storage (g)}}{\text{weight of fillets before storage (g)}} \times 100$$

2.6. Cooking yield

The cooking yield of the fillets was determined from 150 g of section 3 of each fillet (Fig. 2). The samples were cooked for 6 min in a pre-heated oven (Rational, SelfCookingCenter, Canada) at 95 °C and full steam (100%). After cooking, excess water was separated from the material and the cooked samples were allowed to cool to room temperature (20 °C) for 15 min before additional weighing. Percentage cooking yield was determined by the following equation: