

CHANGES IN THE QUALITY AND YIELD OF FISH FILLETS DUE TO TEMPERATURE FLUCTUATIONS DURING PROCESSING

Mu Gang
Dalian Ocean University,
Heishijiao Street 52, Dalian, 116023, China
mugang@dlou.edu.cn

Supervisors:

Kristin Anna Thorarinsdottir
Fish Industry Center, Marel
Austurhraun 9 Gardabaer IS-210 Iceland
Kristin.Thorarinsdottir@marel.com

Arnljotur Bjarki Bergsson, arnljoturb@matis.is
Asbjorn Jonsson, asbjorn@matis.is
Matis ltd. - Icelandic Food and Biotech R&D
Vinlandsleid 12, 113 Reykjavik, Iceland

ABSTRACT

The objective of this study was to map the ambient and fish fillets temperature in a fish processing plant. Furthermore, to investigate the effects of ambient temperature (10, 16, 22°C) and holding time (0, 0.5, 1.0, 1.5, 2.0, 2.5 hours) on temperature rises and drip loss in fresh redfish and saithe fillets. During subsequent chilled storage ($2\pm 2^\circ\text{C}$), drip and quality changes of saithe fillets that were kept at $16\pm 2^\circ\text{C}$ for 0, 1, 2 hours before packaging were studied. Results showed that the highest ambient and fillets temperature appeared in packaging areas of the processing plant. Longer holding time and higher ambient temperature during processing led to significant drip losses and temperature rises in the fillets. According to sensory evaluation, microbiological and pH analysis, longer holding time significantly reduced shelf life of the products. Two hours holding before packaging, caused 21.5% (3 days) shelf life loss of saithe fillets in comparison with the product packed immediately.

Keywords: saithe, redfish, temperature fluctuation, holding time, drip loss, quality, shelf life

This paper should be cited as:

Mu. G. 2014. *Changes in the quality and yield of fish fillets due to temperature fluctuations during processing*. United Nations University Fisheries Training Programme, Iceland [final project].
<http://www.unuftp.is/static/fellows/document/mugang13prf.pdf>

TABLE OF CONTENT

LIST OF FIGURES.....	4
LIST OF TABLES	6
1 INTRODUCTION	7
1.1 Objectives.....	7
2 LITERATURE REVIEW	8
2.1 Cold chain management for fish fillets.....	8
2.1.1 Effect of temperature on post-harvest fish quality.....	8
2.1.2 Effect of temperature during processing on fish fillets quality.....	9
2.1.3 Effect of temperature on fish fillets quality during storage and transport.....	10
2.2 Temperature mapping of fish in cold chain	11
3 MATERIALS AND METHODS.....	12
3.1 Experimental design	12
3.2 Raw material.....	12
3.3 Processing and sampling	14
3.4 Temperature determination and mapping	14
3.5 Drip loss determination.....	16
3.6 Cooking yield determination	16
3.7 Colour determination.....	16
3.8 Texture determination	16
3.9 Sensory evaluation	17
3.10 Microbiological analysis	18
3.11 pH determination	18
3.12 Statistical analysis.....	18
4 RESULTS	19
4.1 Ambient temperature profile in fish processing plant.....	19
4.2 Temperature changes in fish during processing	20
4.3 Temperature changes in fillets during holding time	21
4.4 Drip loss during holding at different temperatures	22
4.5 Temperature changes in fillets during chilled storage	23
4.6 Drip loss during storage.....	25
4.7 Cooking yield	26
4.8 Colour	26
4.9 Texture	27
4.10 Sensory evaluation	27
4.11 Microbiological analysis	31
4.12 Analysis of pH.....	31

5	DISCUSSION	32
5.1	Temperature change in environment and fish fillets during processing	32
5.2	Drip loss and cooking yield	33
5.3	Effect of holding time on saithe fillets shelf life	34
6	CONCLUSIONS AND RECOMMENDATIONS	35
	ACKNOWLEDGEMENTS	36
	LIST OF REFERENCES	37
	APPENDIX I.....	42
	Pictures of saithe fillets samples during chilled storage	42
	APPENDIX II	43
	Drip loss of fillets during held at different temperature.....	43
	APPENDIX III	44
	Quality change in saithe fillets during chilled storage	44
	APPENDIX IV.....	45
	The scores of quality attribute evaluated with QIM scheme for saithe fillets during chilled storage.....	45

LIST OF FIGURES

Figure 1: Experimental design diagram of project.....	13
Figure 2: Location of loggers (No.1-21) in the fish processing plant, for monitoring of ambient temperature in different areas.....	15
Figure 3: Fillets processing flow diagram measure and points for temperature of redfish (left) and saithe (right).....	15
Figure 4: Cooking yield, colour (yellow circles) and texture sampling points of saithe fillets.	16
Figure 5: Ambient temperature profiles for coolers (storage of raw material), sorting room (size grading and gutting) and outside of the plant.	20
Figure 6: Ambient temperature profiles for redfish processing areas (beheading, filleting, trimming and pre-chilling with liquid ice).	20
Figure 7: Ambient temperature profiles for saithe processing areas (beheading, filleting, and trimming).....	20
Figure 8: Ambient temperature profiles for packaging area of redfish and saithe products. ...	20
Figure 9: Temperature in redfish (n=3-5) before and during processing (Mean \pm SD).....	21
Figure 10: Temperature in saithe (n= 3-5) before and during processing (Mean \pm SD).....	21
Figure 11: Temperature changes of large saithe fillets during holding time at different ambient temperatures.	22
Figure 12: Temperature changes of fillets (large saithe, small saithe and redfish) during holding in package area (RH: relative humidity).	22
Figure 13: Drip loss of fish fillets (n = 6) at 22 \pm 2 $^{\circ}$ C, after various holding times (Mean \pm SD).	24
Figure 14: Drip loss of fish fillets (n = 6) at 16 \pm 2 $^{\circ}$ C, after various holding times (Mean \pm SD).	24
Figure 15: Drip loss of fish fillets (n = 6) at 10 \pm 2 $^{\circ}$ C, after various holding times (Mean \pm SD).	24
Figure 16: Drip loss of redfish fillets (n = 6) at 10 \pm 2 $^{\circ}$ C, 16 \pm 2 $^{\circ}$ C, 22 \pm 2 $^{\circ}$ C, after various holding times (Mean \pm SD).	24
Figure 17: Drip loss of small saithe fillets (n = 6) at 10 \pm 2 $^{\circ}$ C, 16 \pm 2 $^{\circ}$ C, 22 \pm 2 $^{\circ}$ C, after various holding times (Mean \pm SD).	24
Figure 18: Drip loss of large saithe fillets (n = 6) at 10 \pm 2 $^{\circ}$ C, 16 \pm 2 $^{\circ}$ C, 22 \pm 2 $^{\circ}$ C, after various holding times (Mean \pm SD).	24
Figure 19: Fillet and ambient temperature of batch 1 during chilled storage. The fillets were held at 16 \pm 2 $^{\circ}$ C for 2 hours before the packaging into EPS boxes with ice mats.....	25
Figure 20: Fillet and ambient temperature of batch 2 during chilled storage. The fillets were held at 16 \pm 2 $^{\circ}$ C for 0, 1 and 2 hours before the packaging into EPS boxes with ice mats.	25
Figure 21: Drip loss (%) of small saithe fillets (n = 6) during chilled storage (2 \pm 2 $^{\circ}$ C) (Mean \pm SD). Prior to storage, the fillets after filleting, skinning and weighing, were held at 16 \pm 2 $^{\circ}$ C for 0, 1 or 2 hours. Then, packaged into EPS boxes with ice mats.	25
Figure 22: Cooking yield (%) of small saithe fillets (n = 3) during chilled storage (2 \pm 2 $^{\circ}$ C) (Mean \pm SD). Prior to storage, the fillets after filleting, skinning and weighing, were held at 16 \pm 2 $^{\circ}$ C for 0, 1 or 2 hours. Then, packaged into EPS boxes with ice mats.....	26
Figure 23: Shear force of small saithe fillets (n = 3) during chilled storage (2 \pm 2 $^{\circ}$ C) (Mean \pm SD). Prior to storage, the fillets after filleting, skinning and weighing, were held at 16 \pm 2 $^{\circ}$ C for 0, 1 or 2 hours. Then, packaged into EPS boxes with ice mats.	27

- Figure 24: Freshness scores of saithe fillets (n=3) during chilled storage (2 ± 2 °C) (Mean \pm SD). Prior to storage, the fillets after filleting, skinning and weighing, were held at 16 ± 2 °C for 0, 1 or 2 hours. Then, packaged into EPS boxes with ice mats. 28
- Figure 25: QI scores of saithe fillets (n=3) during chilled storage (2 ± 2 °C) (Mean \pm SD). Prior to storage, the fillets after filleting, skinning and weighing, were held at 16 ± 2 °C for 0, 1 or 2 hours. Then, packaged into EPS boxes with ice mats..... 28
- Figure 26: Average scores of each quality attribute evaluated with QIM scheme for saithe fillets (n = 3) during chilled storage (2 ± 2 °C) (Mean \pm SD). Prior to storage, the fillets after filleting, skinning and weighing, were held at 16 ± 2 °C for 0, 1 or 2 hours. Then, packaged into EPS boxes with ice mats. 30
- Figure 27: Total viable bacteria counts in saithe fillets (n=3) during chilled storage (2 ± 2 °C) (Mean \pm SD). Prior to storage, the fillets after filleting, skinning and weighing, were held at 16 ± 2 °C for 0, 1 or 2 hours. Then, packaged into EPS boxes with ice mats..... 31
- Figure 28: H₂S-producing bacteria counts in saithe fillets (n=3) during chilled storage (2 ± 2 °C) (Mean \pm SD). Prior to storage, the fillets after filleting, skinning and weighing, were held at 16 ± 2 °C for 0,1 or 2 hours. Then, packaged into EPS boxes with ice mats. 31
- Figure 29: Changes in pH of saithe fillets (n=3) during chilled storage (2 ± 2 °C) (Mean \pm SD). Prior to storage, the fillets after filleting, skinning and weighing, were held at 16 ± 2 °C for 0, 1 or 2 hours. Then, packaged into EPS boxes with ice mats..... 32
- Figure 30: Surface appearance of saithe fillets during chilled storage (2 ± 2 °C). Prior to storage, the fillets after filleting, skinning and weighing, were held at 16 ± 2 °C for 0, 1 or 2 hours. Then, packaged into EPS boxes with ice mats 42

LIST OF TABLES

Table 1: A scheme for assessing freshness grade of raw saithe fillets.....	17
Table 2: Quality index method (QIM) scheme used for evaluating raw cod fillets without skin	18
Table 3: Colour change in saithe fillets (n=3) during chilled storage (2 ± 2 °C) (Mean \pm SD). Prior to storage, the fillets after filleting, skinning and weighing, were held at 16 ± 2 °C for 0, 1 or 2 hours. Then, packaged into EPS boxes with ice mats.....	27
Table 4: Drip loss (at plant) of fish fillets (n = 6) held at 22 ± 2 °C, 16 ± 2 °C, 10 ± 2 °C, after various holding times (Mean \pm SD).	43
Table 5: The parameters of saithe fillets (n = 3) during chilled storage (2 ± 2 °C) (Mean \pm SD). Prior to storage, the fillets after filleting, skinning and weighing, were held at 16 ± 2 °C for 0, 1 or 2 hours. Then, packaged into EPS boxes with ice mats.....	44
Table 6: The scores of quality attribute evaluated with QIM scheme for saithe fillets (n = 3) during chilled storage (2 ± 2 °C) (Mean \pm SD). Prior to storage, the fillets after filleting, skinning and weighing, were held at 16 ± 2 °C for 0, 1 or 2 hours. Then, packaged into EPS boxes with ice mats.	45

1 INTRODUCTION

Fish has been an important source of human food since ancient times, and contains many high quality proteins, vitamins, and omega-3 fatty acids, especially found in pelagic fish. The fatty acids are heart-friendly and can make improvements in brain development and reproduction (Board 2005). According to the FAO (2012), world per capita fish consumption almost doubled from an average of 9.9 kg in the 1960s to 18.4 kg in 2009. The consumption in China has also increased dramatically, reaching about 31.9 kg in 2009. With the growth of consumption, customers have developed higher standards for the quality of products. Therefore, stronger attention to procedures for maintaining freshness and quality of the fish is needed on behalf of processors. The quality of fresh seafood along the value chain depends on the characteristics and condition of the raw material, as well as on factors such as management of temperature, relative humidity of air, hygiene and handling of fish (Valtysdottir *et al.* 2010). When processing plants and systems are designed, designers have to consider these factors and how they can be optimised, with regard to product quality and shelf life.

In recent years, more and more processing plants of fish have been established in the whole world. Especially in China, advanced processing technology and equipment ensure the availability of fresher fish compared with artisanal fish handling. Generally, modern fish fillet processing can be divided into two categories: the initial processing of raw fish and fish products manufacturing. In Iceland, aspects of fish processing occur on fishing vessels, fish processing vessels, and at fish processing plants. Typically, demersal fish is bled, gutted and washed on board. Then the fish is iced and kept in chilled store at sea to preserve raw material quality. After landing, the fish is beheaded and machine filleted. In processing of fresh products, the fillets are trimmed, portioned, and packed with ice-mats in insulated boxes for export (Matis 2013).

The main threats to optimal shelf life and quality of fresh fish products during processing, storage and transport are high ambient temperatures and temperature fluctuations, which lead to temperature rises in the fish muscle, higher loads of specific spoilage bacteria and accelerated degradation of the muscle (Valtysdottir *et al.* 2010). Most of the experiments have been performed in the field of storage and transport (Margeirsson *et al.* 2012, Sigholt *et al.* 1997, Yao *et al.* 2011). Information on the temperature mapping during fresh fillets processing and the impact of temperature abuse during processing on fresh fillets quality, are scarce. It is known that certain problems can occur if fillets are processed exposed to high ambient temperature in processing room. This is a problem specifically when throughput is delayed due to breaks and processing machine failure. An experiment was performed in a processing plant in 2009, with the purpose of gaining a better understanding of how fast the fillets temperature rises during breaks, such as coffee or lunch breaks. The results showed that temperature of fillets can increase by 3-4°C in only 30 minutes at an ambient temperature around 20 °C (Valtysdottir *et al.* 2010). Temperature increases during processing are presumed to result in shorter shelf life and products with quality defects, which are less appealing to consumers.

1.1 Objectives

The aim of this project was to investigate the ambient and fish fillets temperature fluctuation during different processing stages in an Icelandic fish processing plant, including beheading, filleting, trimming and packaging. The objective was to evaluate influences of temperature rises in fresh saithe and redfish fillets on drip loss as well as on quality changes of saithe fillets during subsequent storage at 2±2°C. The result of this study was used as a reference to recommend

changes in Icelandic plant layout and provide suggestions to designers of Chinese fish processing plants.

2 LITERATURE REVIEW

2.1 Cold chain management for fish fillets

The 'cold chain' refers to the equipment, processes and information management used to protect chilled and frozen foods. The main causes of quality loss in cold chain of fish are bacterial growth, enzyme activity, physical damage, dehydration, chemical reactions and contamination (Valtysdottir *et al.* 2010). It is well known that both enzymatic and microbiological activity are greatly influenced by temperature (Huss 1995). Efficient temperature control plays a critical role in slowing down the rates the reproduction, growth, and metabolism of spoilage bacteria and the reaction rates of the bacterial enzymes, keeping the fresh of fish in cold chains. Three categories of temperature control can be applied: chilling, superchilling, and freezing. (Ronsivalli and Baker 1981). In terms of fresh fish fillets, the first two categories are usually used. Chilling is the process of cooling fish or fish products to a temperature approaching that of melting ice, 0 °C/32 °F (Shawyer and Pizzali 2003). It is in the wet range of temperatures (where no freezing of the fish is desired), during chilling the fish is kept lowers the rate of deterioration. Superchilling (also called partial freezing or deep chilling), the second category, is often used to describe a process where food products are stored between the initial freezing point of the products and 1–2°C below this (Duun and Rustad 2007). The initial freezing temperature of fish refers to the temperature at which phase change (crystallisation) of water inside the muscle. It depends on water and fat content of the tissue and therefore varies between fish species. The temperature for most of fish is between 0°C to -2°C, for instance, cod with 82 % water content, freezes at -0.9°C (Kolbe and Kremer 2007). Maintenance of superchilling temperature of fish can slow down microbial growth rates and the corresponding deterioration of fish products due to microbial activity. However, the sub-zero temperature zone may influence enzymatic reactions, as substrate concentration increases following partial freezing of the water phase, which may lead to an altered spoilage process (Lauzon *et al.* 2010). Keeping fish at appropriate temperature is essential to ensure quality of fresh fish in cold chain, from harvest to consumer, as will be discussed in next chapters.

2.1.1 Effect of temperature on post-harvest fish quality

When fish is caught or harvested, it should be cooled fast and stored at low temperature (0°C) to slow down deterioration due to enzymatic and microbiological activity (Margeirsson *et al.* 2010a). Chilling is important for maintaining freshness and quality of the raw material, extending shelf-life (Li *et al.* 2013, Zhu *et al.* 2007). Delays in cooling or even slight increases in temperature for a short time storage lead to a shorter product shelf life. Bacteria constituted a higher proportion of total viable counts (TVC) in the abused than in the well-handled fish (Odoli 2006). Ice is the most common media for pre-chilling fish after capture, liquid ice or liquid cooling (water or sea-water) is also used recently.

Liquid ice has been shown to rapidly reduce the fish temperature compared to ice storage. Whole and gutted haddock cooled and stored by different ice media, the results showed that liquid ice cooled faster (<1 h to 0°C) than ice (4.5 h to 0°C) and reached a lower average temperature (-0.4 to -0.6°C compared to -0.1°C for ice). However, the spoilage process starts to develop rapidly in the fish stored in liquid ice, as evidenced by a more rapid growth of

spoilage bacteria and earlier production of total volatile bases nitrogen (TVB-N). This may be because of the salt uptake measured in the flesh of liquid iced fish after 8 days, creating a different environment favouring trimethylamine (TMA)-producing bacteria like *P. phosphoreum* and *S. putrefaciens* (H₂S-producing bacteria) as supported by bacterial data (Thorvaldsson *et al.* 2010).

The effect of different cooling methods on the storage quality of whole, bled gutted cod was investigated by Magnusson *et al.* (2010). Results indicated that due to insufficiently iced on board, the use of liquid ice instead of plate ice led to two to three day shorter shelf life. However, Magnusson *et al.* (2009a) applied liquid ice to store whole, gutted cod compared to ice storage. There was no marked difference in microbial and chemical measurements whether plate ice or liquid ice was used prior to filleting, but according to sensory analysis, the fish where liquid ice was used had one day extension in freshness and shelf life. The temperature of fillets stored in the plate ice was usually slightly higher than the liquid iced fillets.

A study on the effects of storage temperature on farmed salmon showed that a slight rise in storage temperature above 0°C had a clearly negative effect on quality that was detected after 8–10 days. This appeared as increased K-value, a lower external quality index and as a lower score in the sensory test, most noticeable on odour (Sigholt *et al.* 1997).

So considering the whole cold chain, the temperature of fish products should be controlled from the beginning, because of the quality of raw material greatly affects subsequent processing characteristics and the shelf life of products. Liquid/slurry ice and crushed ice should be used to cool fish. As mentioned above, even though liquid ice has faster cooling rate compare to plate ice, probably due to a larger contact area with fish, longer shelf life of fish stored in liquid ice for long term was hardly ever observed. Therefore, several days storage in liquid ice is not recommended. Margeirsson *et al.* (2010a) suggests that initially cool the raw material with slurry ice, re-ice with crushed plate ice after 24 hours, and then maintain the temperature after that with the crushed ice.

2.1.2 Effect of temperature during processing on fish fillets quality

The typical processing flow of fresh fillets is sorting, beheading, filleting, skinning, trimming and packaging. The temperature of processing environment is an important factor that affects the quality of fillets. According to regulations of the Administration of Occupational Safety and Health in Iceland (AOSH), the temperature in the processing hall should not be higher than 16°C as possible to minimise the thermal load on the products being processed. However, the temperature should not be lower than 10°C regarding manual work in cold rooms in food processing industry (Regulation no 384/2005) (Valtysdottir *et al.* 2010). The holding time of fresh fillets in the processing hall should be as short as possible. If products are exposed long time in high ambient temperature or temperature fluctuation, the fresh fish will experience high thermal load that may accelerate growth of spoilage bacteria and deterioration of quality. Such a scenario is very likely for example if the fillets are left without cooling during a lunch break or if the trimming is a bottleneck in the processing line. It should be noted that the increase of fish temperature depends heavily on the ambient temperature in the trimming/processing room. Research conducted by Matis has shown the fillets temperature increased by up to 6–7°C h⁻¹ when the fillets removed from the processing line after entering the trimming area and placed in a plastic box on a plastic table next to the processing line in the processing hall at 20°C (Margeirsson *et al.* 2010a). A study from Margeirsson *et al.* (2010b) reveal that even in liquid

cooling medium temperature increased rapidly to 3°C from 0°C during a 20 minutes processing break.

Precooling during processing is effective in lowering the temperature of fresh fish fillets before packaging. The fillets are then closer to storage temperature at packaging, resulting in prolonged shelf life (Margeirsson *et al.* 2010b). The aim of precooling is lowering of the temperature of fillets to zero or sub-zero (super chilling), which will limit temperature increase of the product, during transport and storage. According to the calculation by Margeirsson *et al.* (2010a), pre-cooling 5 kg of fillets down to -1°C before packaging in expanded polystyrene (EPS) boxes will maintain product temperature $\leq 0^\circ\text{C}$ for 10 hours, when stored at an ambient temperature of 15°C. However, if the fillets are packaged at 0°C, the temperature will reach almost 7°C after 10 hours. This example clearly demonstrates the advantage reached by superchilling if temperature increase can be expected after packaging, i.e. superchilling reduces the risk of thermal abuse during transport and storage (Matis 2014a).

Superchilling can also improve processing characteristics of the fillets. Therefore, it is in some instances used before skinning and trimming. Examples of methods used for superchilling are Combined Blast and Contact (CBC) cooling, liquid ice cooling or combination of both cooling techniques, an experiment with CBC-cooling revealed that temperature of cod fillet was lower ($-0.7\pm 0.2^\circ\text{C}$) than non-CBC chilled group ($1.5\pm 0.5^\circ\text{C}$) after packaging, the maintenance of product and shelf life was extended in the groups where CBC cooling was applied (Magnusson *et al.* 2009a). Another study for evaluating the effects of superchilling processing on storage life of both whole fish and fillets, results indicate that superchilling processing of whole cod can extend shelf life by two days. A quite long shelf life of cod fillets can be obtained (16-18 days) (Olafsdottir *et al.* 2012).

Furthermore, to protect fish fillets from undesirable fluctuations in temperature during storage and transport, ice/gel packs, dry ice and expanded polystyrene (EPS) box can be used when packaging fresh fillets. Some research has been done on those aspect. Results showed that microbial counts were lower and the formation of TVB-N and TMA slower during storage of cod loins where gel packs were used compared to no gel packs (Martinsdottir *et al.* 2010). Fish fillets packed with dry ice (carbon dioxide) had a longer shelf life than fillets cooled with water ice mat or fillets with no internal cooling material within the box (Olafsson 1999, Bao *et al.* 2007, Magnusson *et al.* 2009c, Margeirsson *et al.* 2010b). The insulating performance of EPS box for a whole 300 kg pallet can be twofold than of Corrugated plastic (CP) box, when surrounding air temperature is 10°C (Margeirsson *et al.* 2009).

2.1.3 Effect of temperature on fish fillets quality during storage and transport

Generally, some stages of the cold chain, such as transfer points or storage rooms, are found to be the weakest link in chilled perishable food management. Fish products, unless appropriately packaged, transported and stored, will spoil in relatively short time (Giannakouroua *et al.* 2005). Improper storage temperature or abuse will shorten the shelf life of perishable products, but usually ambient temperature during transport and storage can fluctuate, which increases the risk of accelerated degradation of the products. Olafsdottir *et al.* (2006) evaluated the influence of storage temperature on proliferation of specific spoilage organisms (SSO) and quality changes of haddock fillets, the fillets were stored in EPS boxes at 0, 7 and 15°C and under temperature fluctuation. Results showed that microbial metabolites were produced in higher levels and shelf life was shorter with increasing storage temperature. According to research on histamine production in tuna loins under different storage and abuse conditions, tuna loins stored at 0-2°C

with temperature abused at 30°C for 2 hours daily contained potentially toxic histamine concentrations (67-382mgkg⁻¹), whereas higher toxic histamine concentrations (544.5-4156.6 mgkg⁻¹) were found in the loins stored at 6-7°C (Economou *et al.* 2007), which expanding threat to consumer health.

It has been proven by many studies that superchilled storage exhibits good performance on extending shelf life. Farmed cod and salmon fillets stored superchilled temperature had longer shelf life with respect to reduced growth of sulphide producing bacteria compared to ice chilled. Lower drip loss were found at superchilled temperatures (Duun and Rustad 2007, Duun & Rustad 2008). Whole and gutted American plaice (*Hippoglossoides platessoides*) stored at -1.7 °C in air had an extended shelf life (14 days) compared to ice storage at 0.6°C (12 days) (Lauzon 2000). Similarly, cod loins stored in superchilled condition (-2°C) had 14 to 15 days' shelf life compare with 11 days stored at 0 °C. Moreover, superchilling storage combined with modified atmosphere packaging (MAP) for cod loins prolong the shelf life to 21 days (Lauzon *et al.* 2009). However, superchilling is in the narrow temperature range, if lowering beyond the initial freezing temperature of fish implies that some of the water freezes and the concentration of solutes in unfrozen solutions increase. This may lead to denaturation of the muscle proteins as well as structural damage of membranes, which can result in increased drip loss and textural change (Valtysdottir *et al.* 2010). A faster spoilage process was observed for cod when stored at -1.8°C in air than in ice at 0.6°C (Einarsson and Lauzon 1996).

Compared to storage, the risk of temperature fluctuation during of transport is higher, especially at transfer points. The transportation of fresh fish is usually by air and sea, the advantage of transport via air is that it is very fast, but the products may undergo a fluctuating temperature due to more frequently loading, unloading and holding at transfer points than typically occur in sea transport (Magnusson *et al.* 2010). It was confirmed that cooling the product below 0°C without freezing is important to ensure the highest quality of the fresh product and to make the product less sensitive to temperature fluctuations during transportation (Mai *et al.* 2012).

2.2 Temperature mapping of fish in cold chain

An optimal temperature monitoring is a prerequisite for cold chain management and thus for the production and supply of high quality and safe products as well as for the reduction of waste and economic losses (Raab *et al.* 2010). Temperature mapping is common method for monitoring temperature change in cold chain, which is the gathering of temperature data at several points within a defined space, over time. Usually, data loggers is use to map temperature of products and environment at regular intervals. By knowing temperature profiles within particular chain, weak points of temperature control can be identified and cause of fluctuation or temperature abuse can be analysed. Then corresponding measures to avoid or decrease risk of temperature rises in products can be taken.

Gudmundsson *et al.* (2013) used 15 temperature loggers to map ambient temperature and the processing time in a fish processing plant. The results showed that the ambient temperature was always below 10°C except in the pallet packaging and before packaging areas (15°C). According to the temperature mappings of the reefers used for shipping of fresh fish, the doors of the reefer were found to constitute a weak point regarding leakage, temperatures and temperature fluctuations were generally found to be the greatest at the reefer's door-end area (Eliasson *et al.* 2013). An investigation for transport of chilled cod loins was done by Martinsdottir *et al.* (2010), the results showed that the ambient temperature fluctuation much lower when transported by sea (-22°C to 18°C) than by air freight (-9°C to 1°C) from Iceland

to Germany. The product temperature of air freight fish was greater than 0°C for 35% of transportation time in contrast to 18% for sea freight. A similar study was done from Iceland to UK and France (Mai *et al.* 2012). A clear distinction of the ambient temperature between fresh cod loins transport by sea and air freights was observed. The product temperature in sea transportation was well below 0°C, whereas in the air trips, it was much higher and with large variation. Loading/unloading operation and holding in unchilled storage at airport caused the temperature rise of product. The temperature map of fresh haddock fillets transported by passenger flight, from Iceland to UK, showed that the fillets have underwent 29.5 h ambient temperature abuse, accounting for 46.6% of the total time from processor to retailer, the highest temperature reached 21°C (Magnusson *et al.* 2009b).

It is now clear that minimizing temperature fluctuation is as important as superchilling for keeping quality of fresh fish fillets. As temperature rises in the product, it stimulates chemical reactions (autolysis) that reduce product flavours, colour and texture, while accelerating bacterial growth (Otwell 1997). Insufficient temperature management may lead to a reduction in shelf life of products and causes economic losses and safety problems. Temperature mapping in cold chains have mainly focused on pre- and post- processing field, e.g. storage and transport (land transport, air or sea freight) (Matis 2014a). Processing is also a key link of cold chain of fresh fish, where the link of temperature fluctuation is high. Nevertheless, fish processing ambient temperature mapping and especially measurement of fillets temperature fluctuations during processing are scarce. In this project, a temperature mapping during fish fillets processing will be undertaken both of ambient and fillets temperature at different processing stages. The effect of temperature change of fish fillets during processing on product quality and drip loss will be investigated.

3 MATERIALS AND METHODS

3.1 Experimental design

This project was undertaken in two parts as shown in Figure 1. The first part (A) was to map ambient temperature profile and fluctuation in different fish processing areas and in fillets of two fish species: saithe and redfish. The second part (B) entailed evaluation of quality changes of fresh fillets as influenced by holding time before packaging. Two experiments (I and II) were conducted in part B. In experiment I, the drip loss and temperature of fish fillets during holding time (up to 2.5 hours) at different temperatures (10±2°C, 16±2°C, 22±2°C) were evaluated. Two different species, saithe and redfish fillets were used. The fillets varied size and weight as illustrated in Figure 1. In experiment II, only saithe fillets were used. After holding different times (0, 1, 2 hours), the fillets were packed and transported for evaluation of quality and shelf life changes during chilled storage (2±2°C). Drip loss, cooking yield, colour, texture, sensory, microbiological, and pH changes were followed for 13 days.

3.2 Raw material

The raw material used was saithe (*Pollachius virens*) and deep sea redfish (*Sebastes mentella*) caught by a trawler at 63.12°N, 24.34°W, on 8-9 February 2014. Only saithe was bled and gutted onboard and stored with slurry before processing, while the redfish were stored whole in crushed plate ice. The fish was processed on 13 February 2014 in an Icelandic fish processing plant. Additional saithe (batch 1) was caught using trawler at 63.13°N, 24.98°W, on 16 January 2014. Before processing (21 January 2014), the saithe was stored in slurry ice 5 days.

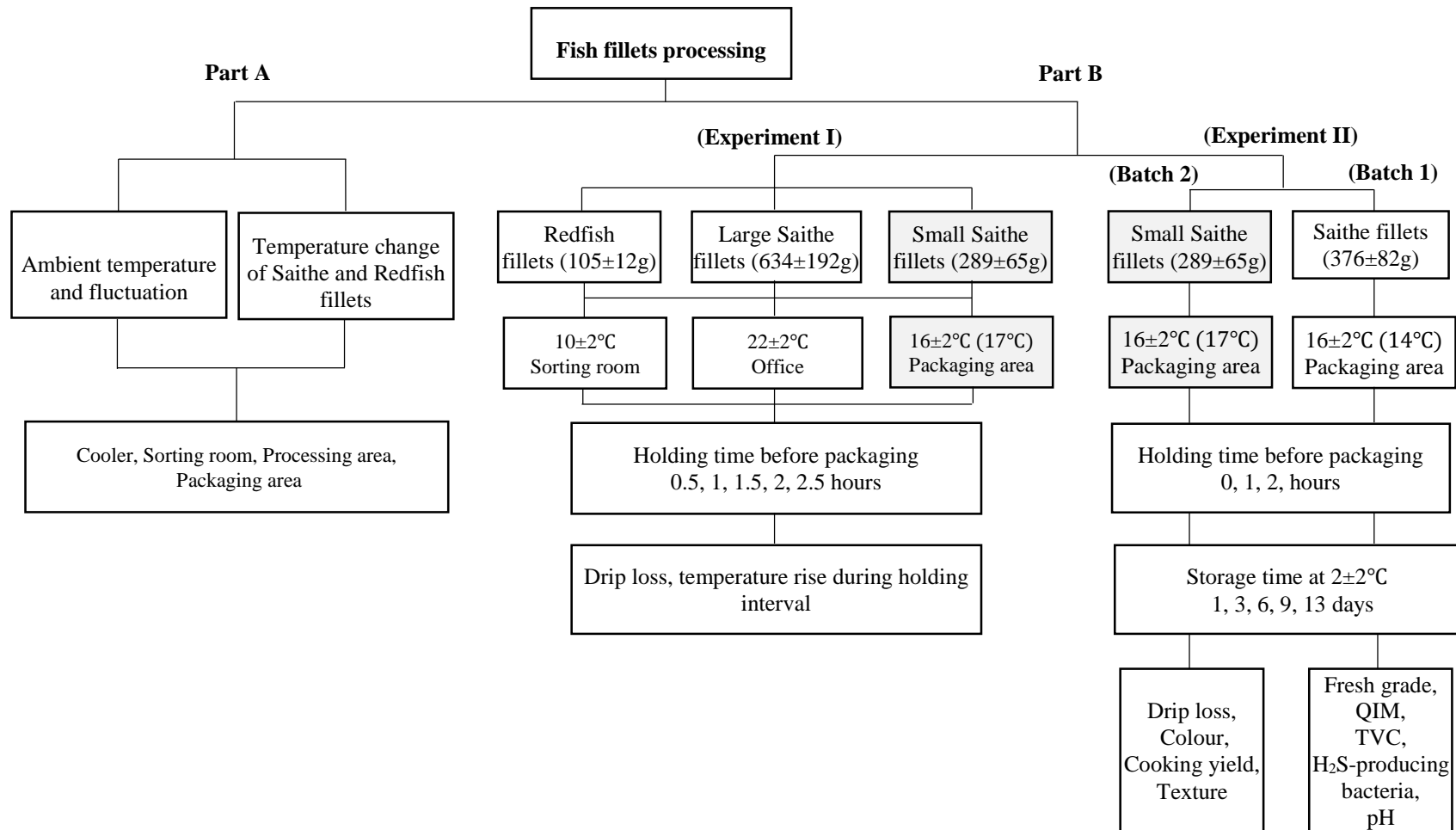


Figure 1: Experimental design diagram of project

3.3 Processing and sampling

Whole fillets without skin were collected from filleting and skinning machine in the fish processing plant, marked with numbered plastic tags. In the experiment I, the three type of fillets collected on 13 February 2014 were large saithe fillets (634 ± 192 g), small saithe fillets (289 ± 65 g) and redfish fillets (105 ± 12 g). After temperature and weigh determination, six fillets ($n=6$) of each trial group were placed in a plastic box and placed in different temperature areas (sorting room, $10\pm 2^\circ\text{C}$, packaging area, $16\pm 2^\circ\text{C}$, office, $22\pm 2^\circ\text{C}$) for holding time up to 2.5 hours. Temperature loggers were inserted inside saithe loins. The redfish fillets were thinner, therefore the loggers were put below the fillets in each box to monitor temperature changes during the holding time. Ambient temperature and relative humidity during experiment I was measured with HoBo U12 temperature and relative humidity loggers from Onset Computer Corporation (Bourne, MA, USA). Weight of each fillet was measured again for drip loss every 30 minutes.

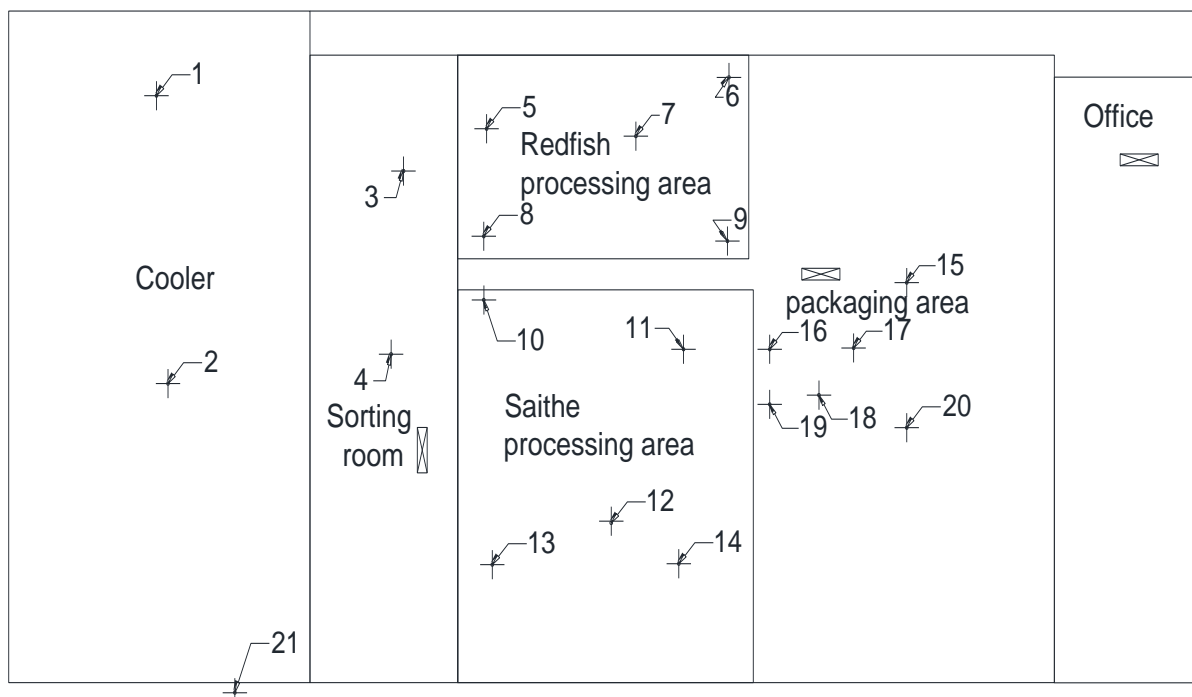
In experiment II, two batches of saithe fillets processed on different dates (21 January 2014 and 13 February 2014) were collected. The sample were split into three trail groups with holding time of 0, 1, 2 hours before packaging in plant, respectively. After holding time, the samples were weighed and packed, then put into expanded polystyrene box ($400\times 264.5\times 135$ mm). Every box contained 6 fillets with an ice mat (120 g) on top and an adsorbing pad at the bottom. The boxes were transported to the laboratory (Matís ohf in Reykjavik) within 30 min. The boxes were stored in a cold storage room at $2\pm 2^\circ\text{C}$ sampled on days 1, 3, 6, 9 and 13. Ambient and fillets temperature during storage was measured with temperature loggers (IButton DS1922L, USA). The procedure for each batch is described in following paragraphs.

Batch 1: Thirty saithe fillets (376 ± 82 g) of each trail group after holding in packaging area ($16\pm 2^\circ\text{C}$) were packaged to store for study shelf life with sensory evaluation, microbiological and pH analysis, Three fillets ($n=3$) of each group were taken out at each sampling day and used for sensory evaluation with freshness grading and quality index method (QIM). Another three fillets ($n=3$) of each group were used for total viable psychrotrophic counts (TVC) and H_2S -producing bacteria counts as well as pH analysis.

Batch 2: Eighteen saithe fillets (289 ± 65 g) of each group after holding in packaging area at $16\pm 2^\circ\text{C}$ were packaged and stored for evaluation of drip loss, cooking yield, colour and texture change during storage. At the same storage period as for batch 1, three fillets ($n=3$) of each group were used for evaluating changes in colour, cooking yield and texture. At each sampling day, drip loss of same fillets ($n=6$) in each group was measured until day 13.

3.4 Temperature determination and mapping

Twenty one loggers were hung from the ceiling of plant, 2-2.5m from floor (Figure 2). The mapping ambient temperature at different fish processing areas for about 72 hours, with 10 minutes sampling intervals, i.e. of the cooler (used for storage of raw material), sorting room (used for size grading and gutting of fish before fillets processing), processing and packaging area of both species, as well as outside of plant. The temperature loggers (IButton DS1922L, USA) had an accuracy of $\pm 0.0625^\circ\text{C}$ from -10°C to 65°C .



1: Inner cooler, 2: outer cooler, 3: redfish sorting, 4: saithe sorting, 5: redfish beheading, 6, 7: redfish filleting, 8: redfish trimming 9: redfish pre-chilling, 10: saithe beheading, 11, 12: saithe filleting, 13, 14: saithe trimming, 15: saithe loin packaging, 16,17,18,19: redfish packaging, 20: saithe loin packaging, 21: outside of plant

Figure 2: Location of loggers (No.1-21) in the fish processing plant, for monitoring of ambient temperature in different areas.

The temperatures of fish were determined at different processing stage, the measure point and processing flow of redfish and saithe is shown in Figure 3. The handheld thermometer (Testo 926, Germany) with an accuracy of $\pm 0.3^{\circ}\text{C}$ from -50 to $+400^{\circ}\text{C}$ were used to measure whole fish and fillets. Three whole redfish and saithe were sampled respectively from top of the tub, where the fish stored with crushed ice and slurry ice in the cooler. The thin sharpened probe of thermometer was inserted from the side of dorsal fin into fish flesh, with at least 75 to 100 mm depth (FAO 2001). When fillets ($n = 3-5$) were measured, the temperature-sensitive element at the end of the probe was inserted from side into the thickest part of fillets.

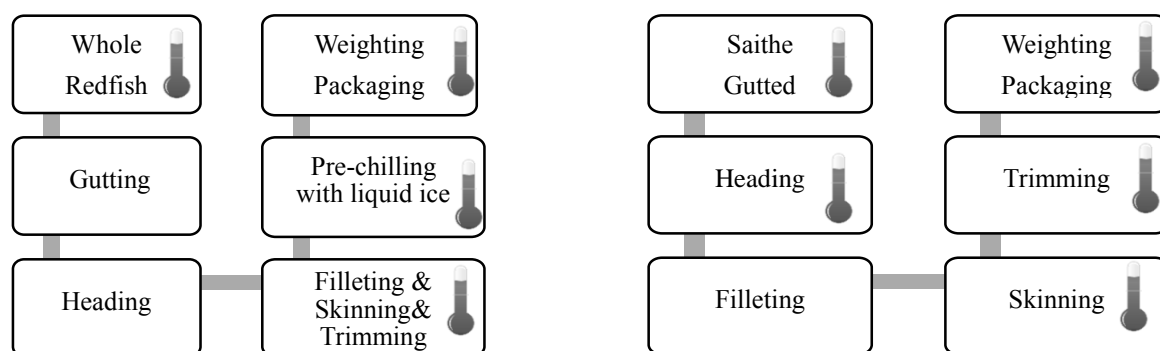


Figure 3: Fillets processing flow diagram measure and points for temperature of redfish (left) and saithe (right)

3.5 Drip loss determination

In experiment I (at plant), drip loss (%) was determined as the weight loss of fillets (large saithe, small saithe and redfish) over holding time at $10\pm 2^{\circ}\text{C}$, $16\pm 2^{\circ}\text{C}$ and $22\pm 2^{\circ}\text{C}$. The fillets ($n = 6$) of each trial group, were weighed directly after filleting and skinning. The fillets were again at 0.5 hour holding intervals until 2.5 hours. In the experiment II (during storage), drip loss (%) was determined as the weight loss during storage time (up to 13 days). The fillets ($n = 6$) were weighed before packaging (after the holding time) and after each storage period. The difference in weight (g) was divided by the initial weight of the product (g) and expressed as g /g% (Arnthorsdottir *et al.* 2008).

$$\text{Drip loss at plant (\%)} = \frac{\text{Initial weight (g)} - \text{Weight after holding (g)}}{\text{Initial weight (g)}} \times 100$$

$$\text{Drip loss during storage (\%)} = \frac{\text{Weight after holding (g)} - \text{Weight after storage (g)}}{\text{Weight after holding (g)}} \times 100$$

3.6 Cooking yield determination

Part of the loin (Figure 4) from each fillets ($n=3$) were cut into 40-50 g slices, and weighed before and after cooking. They were cooked 7 minutes on a grill pan in a pre-warmed oven (Convotherm Elektrogeräte GmbH, Eglfing, Germany) at $95\text{-}100^{\circ}\text{C}$ with air circulation and steam, then left for 15 minutes in room temperature ($\sim 22^{\circ}\text{C}$) to cool down. The surface moisture of loin was dabbed dry with a paper towel before weighing for cooking yield determination. The cooking yield was calculated as the weight after cooking divided by weight before cooking and expressed as g /g% (Arnthorsdottir *et al.* 2008).

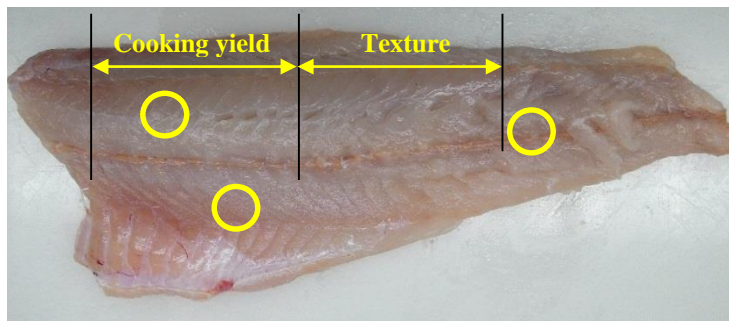


Figure 4: Cooking yield, colour (yellow circles) and texture sampling points of saithe fillets.

3.7 Colour determination

The colour of the fillets from was measured using a Minolta type CR-400 (Minolta camera Co., Ltd; Japan), portable tristimulus colorimeter. The instrument records the intensity by using the L, a, b value, where L correlate lightness (0-100), a, b correlate red (+)/green (-) and yellow (+)/blue (-). The colour changes of saithe fillets ($n=3$) were measured on three positions (in Figure 4, the circles show where colour measurements were performed) on each fillet (Purwaamidjaja 2010). The average of three locations were used for evaluate colour of each fillet. The average values for the fillets were used to calculate the mean values ($\pm\text{SD}$) for each group.

3.8 Texture determination

The texture of saithe fillets was assessed by the shear resistance, measured by using a TA.XT2 Texture Analyser (Stable Micro Systems, Surrey, England). Before determination, one sample from loin (Figure 4) of each fillet (n=3) was cut into one slice of size 70×30mm. A v-shaped Warner-Bratzler shear blade (type HDP/BS) was applied on sample. The maximum peak force in Newton required to shear through the sample was recorded as shear force (Bouton *et al.* 1975, Zhang 2004). The shear speed used was 0.5 mm/s and the distance travelled by the blade was 30 mm. The fillets were taken out 1 hour before testing, the shear force determined at room temperature (~22°C). The average of the slices was used for evaluate shear force of each fillet. The average values for the fillets were used to calculate the mean values (\pm SD) for each group.

3.9 Sensory evaluation

During storage, the saithe fillets (n=3) were evaluated with freshness grade and QIM for lean fish. Five to eight panellists from Matis participated in the sensory evaluation at each sampling day. The panellists were previously trained according to international standards (ISO 1993) (ISO 1994). The members of the panel were familiar with freshness grade and QIM scheme of lean fresh fillets. Before the evaluation, the samples were transferred from cooler and placed a clean table provided with white covering at room temperature for 30 minutes (Wang 2005). The samples were anonymously coded with the three-digit random numbers, and evaluated under fluorescent light.

A freshness grade scheme (Table 1) was used for assessing the freshness of the fillets, there are five freshness grades of raw fillets based on colour texture and odour (Matis 2014b). Five scores (excellent good, average, questionable and unsuitable) could be used for each description. Correspondingly, a score from 5 to 1, were given by panellists as the freshness grade of the fillets

Table 1: A scheme for assessing freshness grade of raw saithe fillets

Description	Grade
The colour is characteristic for the species. No unusual hue because of blood, insufficient washing or storage. The fish flesh is firm and not ruptured. Odour is fresh (marine).	EXCELLENT-5
The colour is characteristic except for small colour changes in fillet (just noticeable). The fish flesh is fairly firm and not ruptured. Odour is fresh and normal.	GOOD -4
Small colour changes. Reddish colour in the flesh (not a strong blood colour) and small bloodspots visible in some fillets. Fish flesh is soft when pressed and gaping is visible in some fillets and in minor parts of them. Fish odour is weak but no abnormal odour.	AVERAGE -3
Fillets and part of fillets have lost their characteristic colour. Grey, yellow and brown shades are visible in some fillets. Reddish hue and other colour changes caused by blood are visible. This raw material is definitely old. Flesh is soft and torn. No fresh odour but abnormal odour is apparent in some fillets (TMA or defrosted odour).	QUESTIONABLE -2
The appearance and texture is unsuitable for fish. Spoilage odour is obvious (strong TMA, sour and putrefaction).	UNSUITABLE -1

A modified QIM scheme from (Bonilla *et al.* 2007) developed for fresh cod fillets with skin was used to evaluate saithe without skin (Table 2). The method involved evaluation of the

texture, blood, odour, colour, brightness and gaping of raw fillets, using a score from 0 to 3 in a demerit points system. The panellists individually evaluated changes in the attributes accordance with the QIM scheme. The pooled mean value from panellists was used as an estimate of each attributes for each fish.

Table 2: Quality index method (QIM) scheme used for evaluating raw cod fillets without skin

Flesh Quality Index	Description	Score
Texture	Firm	0
	Rather soft	1
	Very soft	2
Blood	Bright red, not present	0
	Dull red	1
	Shadowy, brown	2
Odour	Fresh, neutral	0
	Seaweed, marine, grass	1
	Sour milk	2
	Acetic, ammonia	3
Colour	White, greyish	0
	Some yellowish, a little pinkish	1
	Yellow, over all pink	2
Bright	Transparent, bluish	0
	Opaque	1
	Milky	2
Gaping	No gaping, one longitudinal gaping at the neck part of the fillet	0
	Slight gaping less than 25% of the fillet	1
	Slight gaping, 25-75% of the fillet	2
	Deep gaping or slight gaping over 75% of the fillet	3
Total		(0-14)

3.10 Microbiological analysis

Total viable psychrotrophic counts (TVC) and H₂S-producing bacteria counts were carried out in triplicate on each sampling day. A sample was aseptically cut from a muscle of each fillet. Then the sample was minced in a commercial laboratory blender (Waring, USA) for 1 minutes, 20 g of samples were homogenized with 180 ml dilution buffer homogenized in a stomacher (Seward 400, England) for 1 minute. A series of decimal dilutions were made and transferred with pipettes onto the surface of Petri plate. Iron agar (IA) using in this experiment as described by (Gram *et al.* 1987), but with 1% NaCl and no overlay. Plates were incubated at 17 °C for 5 days. Bacteria forming black colonies on IA produce H₂S from sodium thiosulphate and/or cysteine. Black colonies and total colonies were counted, and the values multiplied with the corresponding dilution factor. The data was expressed as a logarithm of the number of colony-forming units of the samples (log CFU g⁻¹).

3.11 pH determination

The pH of each minced sample (5 g) used during bacterial enumeration was determined using pH meter (Radiometer PHM80 Portable pH meter, Denmark), by dipping the glass electrode for 1 minute in the homogenate of fish muscle and distilled water (5 ml). The values for three samples in each treatment were averaged for every storage day evaluated.

3.12 Statistical analysis

Data were subjected to analysis of variance (ANOVA) using Microsoft Office Excel 2013 (Microsoft Inc., Redmond, WA, U.S.A.) and XLSTAT 2014 (Addinsoft Inc., New York, NY, U.S.A.). The program calculates multiple comparisons using Tukey's multiple comparison test. The significance level was set at 95% ($p < 0.05$), if not stated elsewhere.

4 RESULTS

4.1 Ambient temperature profile in fish processing plant

Temperature mapping of the fish processing plant was performed on 16 January 2014, for 9 hours. The ambient temperature profiles of cooler (used for storage of raw material) and sorting room (used for size grading and gutting of fish before fillets processing) are shown in Figure 5.

The temperature of coolers was between 3°C and 5°C. Meanwhile, inhomogeneous temperature distribution also was observed in inner and outer of cooler. The raw fish can kept in this temperature 0-5 days before processing, according to the investigation. The range of temperature fluctuation was larger in the sorting room compared to cooler, or 7 to 11°C (Figure 5). The temperature also tended to increase more during the day in the sorting room.

The temperature in the processing areas fluctuated within the range of 13 to 18°C. It was 15-17°C in the redfish processing area (Figure 6). The highest temperature (17°C) occurred at the position near the beheading machine. Temperatures of other position of redfish filleting was similar for all loggers.

Compared with redfish processing area, the average temperature of saithe processing was lower (Figure 7). The ambient temperature of saithe processing areas fluctuated within the range of 13 to 17°C. Maximum and minimum temperature in this area appeared in position of trimming (loggers No 14 and 13). Lower temperature of No 13 were observed probably due to closed to sorting room, where the temperature was lower. The time of wide fluctuation was about 8:30 am, 10:15 and 13:20. The maximum amount of fluctuation was more than 2°C (No 13) in the trimming area for saithe.

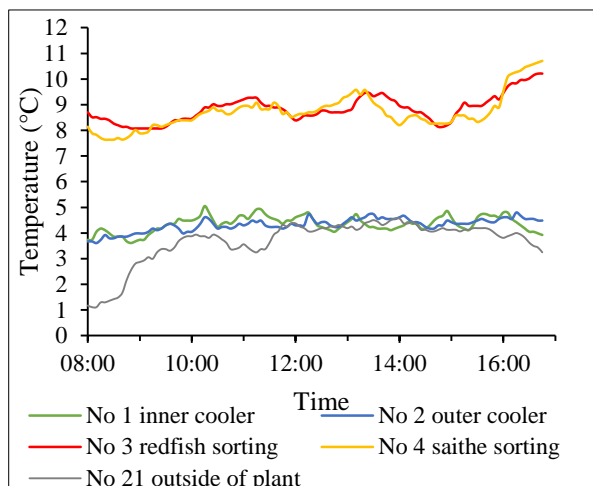


Figure 5: Ambient temperature profiles for coolers (storage of raw material), sorting room (size grading and gutting) and outside of the plant.

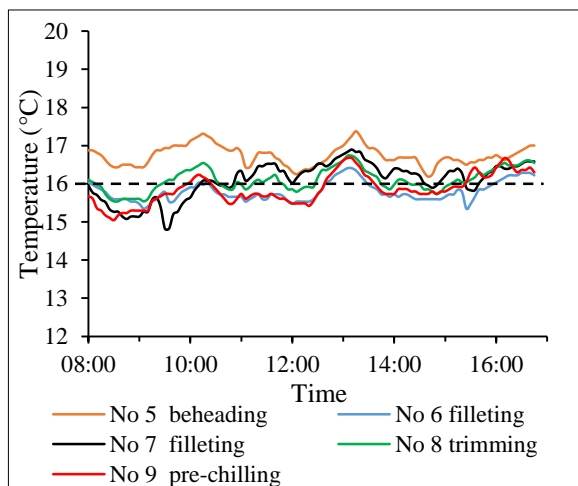


Figure 6: Ambient temperature profiles for redfish processing areas (beheading, filleting, trimming and pre-chilling with liquid ice).

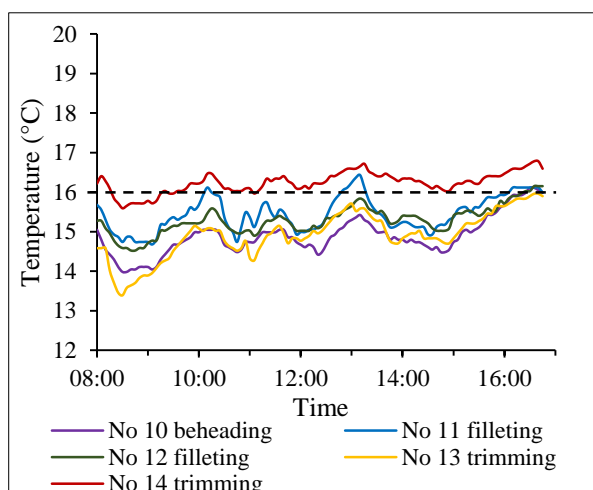


Figure 7: Ambient temperature profiles for saithe processing areas (beheading, filleting, and trimming).

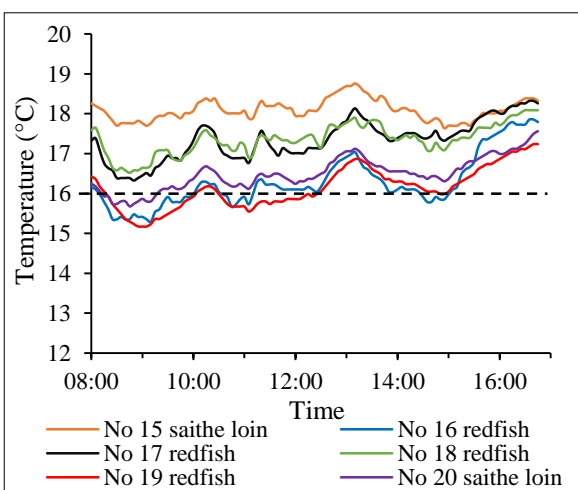


Figure 8: Ambient temperature profiles for packaging area of redfish and saithe products.

The highest temperature (18.7°C, No 15) was measured within the packaging area as shown in Figure 8. The average temperature of this area was about 17°C. Maximum temperature difference between the different measurements positions was more than 3°C. The fluctuation range of each position was around 2°C. The time of temperature peaks (approximately 10:15 and 13:15) was similar to what was observed in the processing area.

4.2 Temperature changes in fish during processing

Redfish and saithe temperature before and at different processing stages, are shown in Figure 9 and 10 respectively. The temperature of raw material (cold storage) was close to 0°C, for both species. Larger standard deviation was observed for saithe temperature than redfish. This was

due to differences in cooling medium (slurry for saithe and crush ice for redfish) between the species and position of fish in the tub.

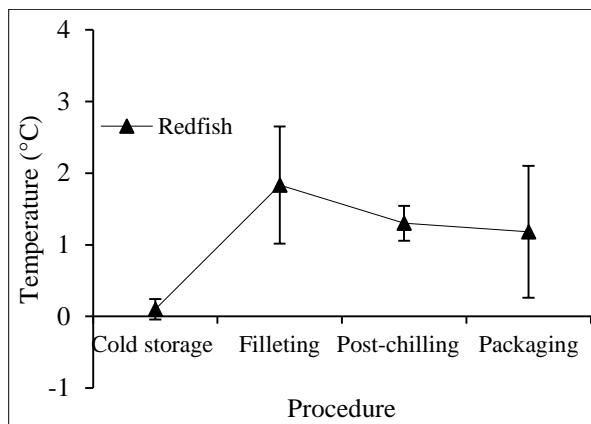


Figure 9: Temperature in redfish (n=3-5) before and during processing (Mean \pm SD).

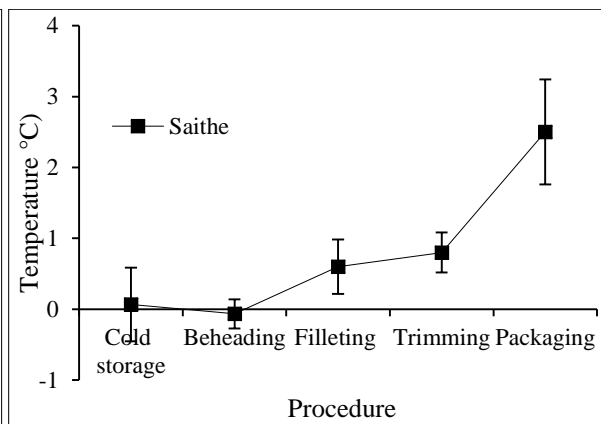


Figure 10: Temperature in saithe (n= 3-5) before and during processing (Mean \pm SD).

The temperature of saithe after beheading was similar to the temperature in raw material. During filleting and skinning of both fish, the temperature started to increase. It increased by 1°C for saithe and 2 °C for redfish. Higher temperature rises in redfish fillets was found probably due to smaller size of redfish fillets compared to saithe and led to heat transfer faster. The higher standard deviation in temperature of redfish fillets was presumably caused by inequality in fillet size.

After filleting, the redfish was chilled by liquid ice, resulting in lower temperature until packaging. However, the temperature of saithe fillets started to increase after trimming due to high environmental temperatures, and no pre-cooling was applied order to maintain low temperature like redfish, as mentioned above (Figure 3). The average temperature of saithe loins at packaging was up to 2.5°C. The temperature of some loins was even higher than 3°C, the maximum temperature measured was 3.8°C.

4.3 Temperature changes in fillets during holding time

The temperature changes during holding of large saithe fillets, which were placed on different temperature area are shown in Figure 11. The temperature rise was fast during the first 2 hours. Higher ambient temperature led to faster temperature increases of fillets. When the fillets were kept at 10 \pm 2°C, the temperature of fillets increased to ambient temperature from 2°C. The average increase was 3°C per/ hour ($^{\circ}\text{C h}^{-1}$). The rate of temperature changes reached 5 $^{\circ}\text{C h}^{-1}$ for fillets held at 16 \pm 2°C and 22 \pm 2°C. After 1.5 hours holding, the temperature of fillets held at 10 \pm 2°C, became relatively steady for the rest of the holding time. On the other hand, the temperature of fillets kept at higher ambient temperature (16 \pm 2°C, 22 \pm 2°C) kept increasing, up to final measurement.

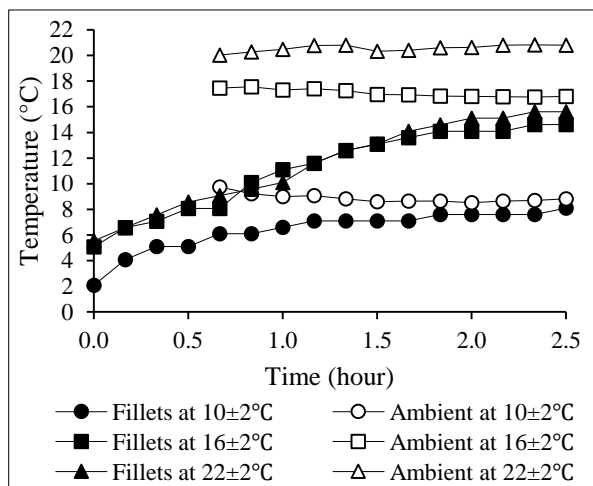


Figure 11: Temperature changes of large saithe fillets during holding time at different ambient temperatures.

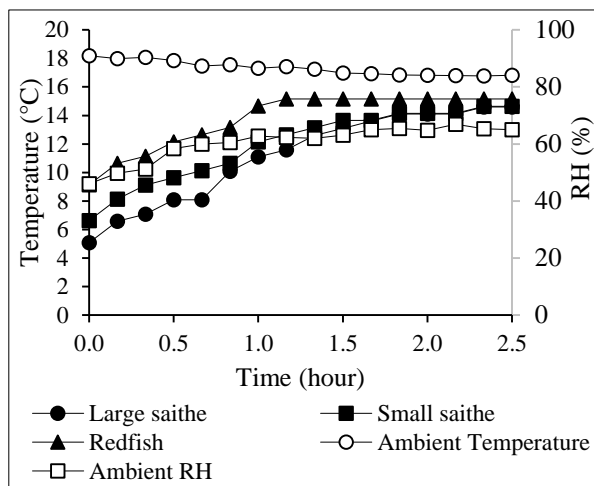


Figure 12: Temperature changes of fillets (large saithe, small saithe and redfish) during holding in package area (RH: relative humidity).

As shown in Figure 12, there was an equal increase in temperature (5.5-6°C) of three kinds of fillets, during first one hour holding at 16±2°C. However, it was observed that the redfish fillets had a higher reading (14.6°C) after the first hour, than large (11°C) and small (12°C) saithe fillets. For the remaining holding time, the temperature of fillets equilibrated with ambient temperature. This means that if fillets are exposed in packaging area for 1-1.5 hours without any heat protection, the temperature of fillets will close to ambient temperature.

4.4 Drip loss during holding at different temperatures

The drip loss increased more rapidly in redfish fillets compared to small and large saithe, during the 1 to 1.5 hour time frame. When comparing the different fillet types at each holding condition, a significant difference ($p < 0.01$) between fillets all groups held in at 22±2°C and 16±2°C, was observed (Figure 13 and 14, respectively). After 2.5 hours at 22±2°C, the drip loss of redfish, small and large saithe fillets reached 7.13%, 4.8% and 3.3%, respectively. The drip of redfish almost kept at an even speed from beginning, whereas both size groups of saithe fillets started to lose weight after 1 hour. Unlike the fillets kept in 22±2°C, the process of drip loss at 16±2°C had higher homogeneity for the three fillet types. Also, fillets began to lose weight more rapidly after longer holding time (1.5 hours vs. 1 hours at 22±2°C). The maximum drip of redfish and small saithe was 4.7% and 3.4% after 2.5 hours held in packaging area. Drip at low environmental temperatures (10±2°C) accelerated after 0.5 hours (Figure 14). Drip rate of redfish was faster than of saithe ($p < 0.05$).

The drip loss of fillets increased during the holding time, at all temperatures (Figure 13-15). The drip loss of same fillet groups was found to be significantly difference ($p < 0.01$) between three holding conditions (10±2°C, 16±2°C, 22±2°C). The strongest effects were observed in the redfish fillets. The average drip loss for redfish fillets, decreased with holding temperature in following order 22±2°C > 16±2°C > 10±2°C (Figure 16). For small saithe fillets the drip (Figure 17) was highest at 22±2°C ($p < 0.05$) but only slightly higher at 16±2°C compared to 10±2°C ($p > 0.05$). For large saithe fillets, the main difference was involved in how rapidly weight was lost during holding time. At lower temperatures (10±2°C), the drip peaked earlier (Figure 18). This may be due to lack of size uniformity of large saithe fillets held at different

temperatures. The results imply that higher surrounding temperature lead to more weight loss from fillets at same holding time. Furthermore, the drip loss of small size fillet increased always faster than large ones.

4.5 Temperature changes in fillets during chilled storage

The storage temperature of two batches of fillets and environment, is shown in Figure 19 and 20. After one day storage, the fillets temperature of 2 hours holding group (batch 1) had reduced to 2°C from 14°C (when packaged at the plant). After that the temperature in the fillets was relatively steady, about 2°C, until experiment finished. During the most of storage period, the ambient temperature of cold storage room (at Matis) fluctuated from 0-4°C.

The situation of batch 2 was similar to batch 1 (Figure20). The temperature of the 1 hour holding group decreased to 2°C from 12°C within 24 hours. The corresponding time for cooling the 0 hour holding group from 7°C to 2°C was 9 hours. Some temperature fluctuation of fillets during the storage period was observed, which resulted from weighing of the sample for evaluation of drip loss. However, the average temperature of two batch fillets during storage was maintained in around 2°C. The ambient temperature of the cooler was 2±2°C.

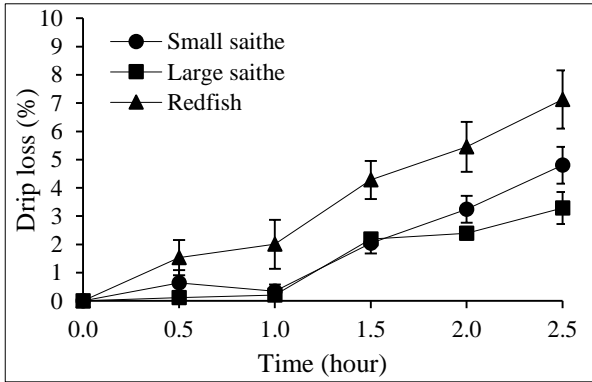


Figure 13: Drip loss of fish fillets (n = 6) at 22±2°C, after various holding times (Mean ± SD).

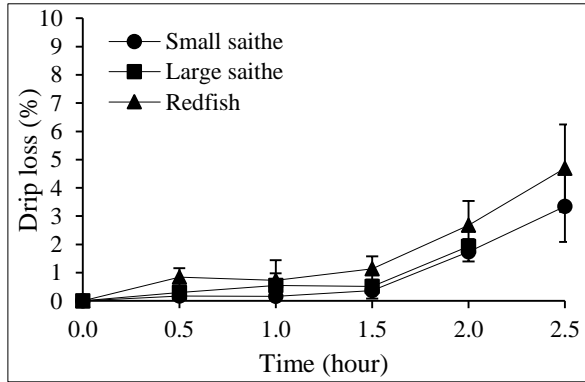


Figure 14: Drip loss of fish fillets (n = 6) at 16±2°C, after various holding times (Mean ± SD).

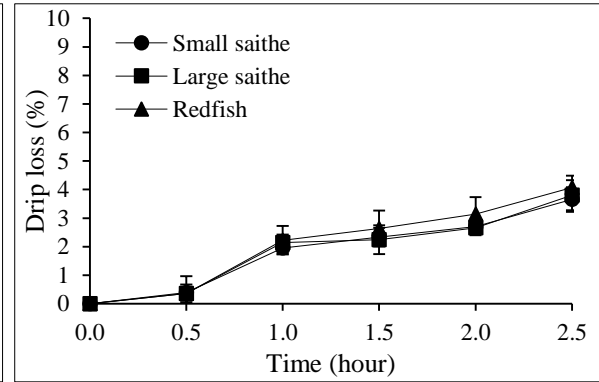


Figure 15: Drip loss of fish fillets (n = 6) at 10±2°C, after various holding times (Mean ± SD).

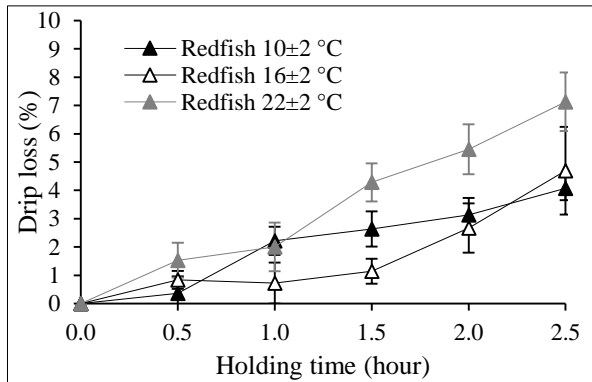


Figure 16: Drip loss of redfish fillets (n = 6) at 10±2°C, 16±2°C, 22±2°C, after various holding times (Mean ± SD).

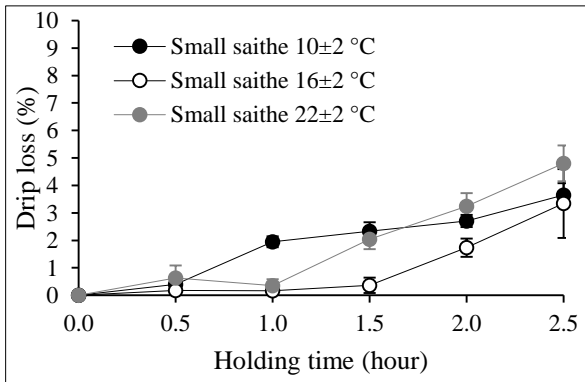


Figure 17: Drip loss of small saithe fillets (n = 6) at 10±2°C, 16±2°C, 22±2°C, after various holding times (Mean ± SD).

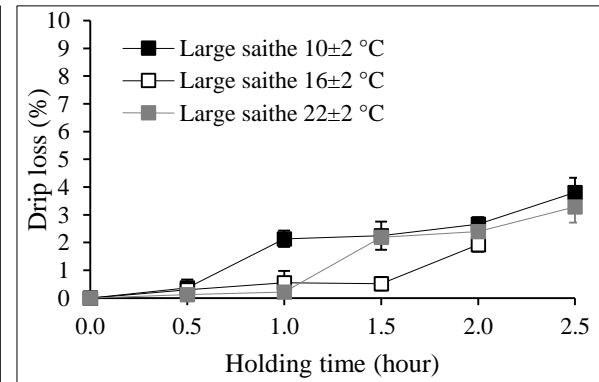


Figure 18: Drip loss of large saithe fillets (n = 6) at 10±2°C, 16±2°C, 22±2°C, after various holding times (Mean ± SD).

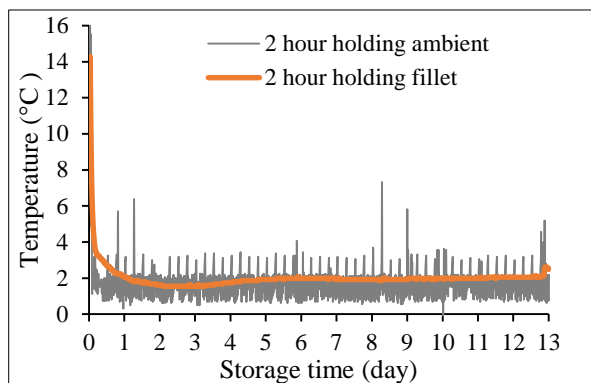


Figure 19: Fillet and ambient temperature of batch 1 during chilled storage. The fillets were held at $16\pm 2^{\circ}\text{C}$ for 2 hours before the packaging into EPS boxes with ice mats.

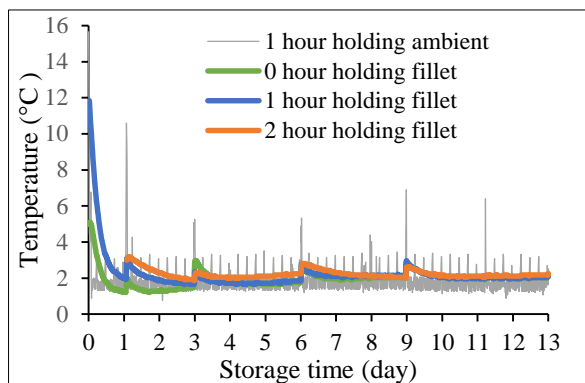


Figure 20: Fillet and ambient temperature of batch 2 during chilled storage. The fillets were held at $16\pm 2^{\circ}\text{C}$ for 0, 1 and 2 hours before the packaging into EPS boxes with ice mats.

4.6 Drip loss during storage

Drip loss of saithe fillets held for 0, 1, 2 hour at $16\pm 2^{\circ}\text{C}$ before packaging, was followed after subsequent storage at $2\pm 2^{\circ}\text{C}$ (Figure 21). The drip loss of fillets was significantly negatively correlated with holding time, but there was a positive correlation with storage time ($p < 0.01$), due to of the fish muscle during storage deterioration (Arnthorsdottir *et al* 2008). Maximum drip loss was found in the fillets were packed immediately after filleting, skinning and weighing (0 hour holding). The value was gradually increasing during storage period. After six days storage, the drip loss in the 0 hour holding group was significantly higher than in 2 hour holding group ($p < 0.01$). The drip in the 1 hour holding group less than in the 0 hour group but higher than 2 hour group on each sampling day. However, the lowest drip was observed in the 2 hour holding group, the value less than 2% throughout storage, maximum drip loss (1.94%) were found on day 13. On the other hand, the drip loss before packaging should not be ignored. The result of drip after 2 hours holding showed (Figure 14) that 1.74% weight had been lost, so the total drip loss was close to the 0 hour holding groups.

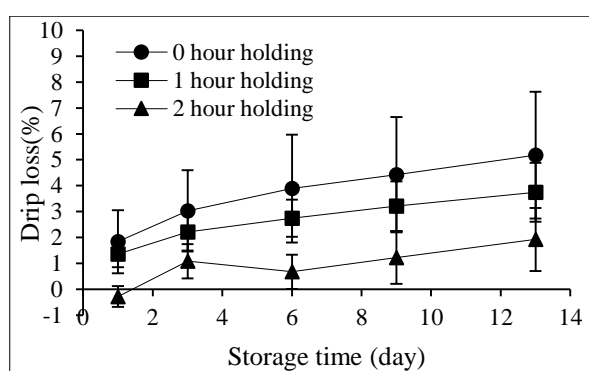


Figure 21: Drip loss (%) of small saithe fillets ($n = 6$) during chilled storage ($2\pm 2^{\circ}\text{C}$) (Mean \pm SD). Prior to storage, the fillets after filleting, skinning and weighing, were held at $16\pm 2^{\circ}\text{C}$ for 0, 1 or 2 hours. Then, packaged into EPS boxes with ice mats.

4.7 Cooking yield

The cooking yield of the 0 hours holding group was lower than for the 1 and 2 hour holding group after 3 day storage (Figure 22). However, there was no significant difference between the three groups during the storage period. Storage time had stronger effects ($p < 0.0001$) on cooking yield than holding time ($p = 0.076$). The cooking yield of all group increased significantly at day 9 ($p < 0.01$). The 1 and 2 holding group increased by 5.9% and 6.4% respectively, the value of the 0 hour holding group increased by 9.1%. Between 9 to 13 day storage, the yield of all groups changed only slightly ($p > 0.05$). During the first six days, the cooking yield decreased from 83.6% to 77.4% in the 0 hour holding group, which did not alter in other two groups.

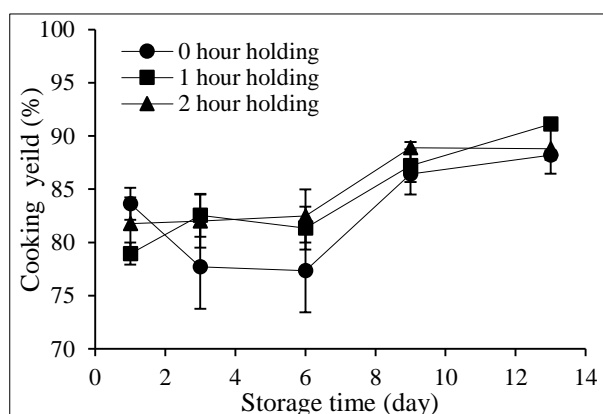


Figure 22: Cooking yield (%) of small saithe fillets ($n = 3$) during chilled storage ($2 \pm 2^\circ\text{C}$) (Mean \pm SD). Prior to storage, the fillets after filleting, skinning and weighing, were held at $16 \pm 2^\circ\text{C}$ for 0, 1 or 2 hours. Then, packaged into EPS boxes with ice mats.

4.8 Colour

The L- and b -value of all increased significantly ($p < 0.01$) with storage whereas a-values decreased (Table 3). It means that the fillets became lighter and yellow and green colours, increased with storage time. In general, no differences ($p > 0.05$) were detected in the colour attributes, between of fillets with different holding time. Although, the b -value tended to be higher for the fillets of 2 hours holding group compared with the other two groups except after 1 day of storage. This revealed that longer holding time at $16 \pm 2^\circ\text{C}$ before packaging, may accelerate development of yellowness during chilled storage.

Table 3: Colour change in saithe fillets (n=3) during chilled storage (2 ± 2 °C) (Mean \pm SD). Prior to storage, the fillets after filleting, skinning and weighing, were held at 16 ± 2 °C for 0, 1 or 2 hours. Then, packaged into EPS boxes with ice mats.

Storage time (day)	L			a			b		
	Holding time			Holding time			Holding time		
	0 hour	1 hour	2 hours	0 hour	1 hour	2 hours	0 hour	1 hour	2 hours
1	42.76 \pm 2.10 ^{abc}	41.55 \pm 2.30 ^{bc}	38.74 \pm 1.58 ^c	-2.11 \pm 0.51	-1.36 \pm 0.85	-1.52 \pm 0.61	-0.30 \pm 0.53 ^c	-0.22 \pm 0.04 ^c	-0.45 \pm 0.90 ^c
3	45.26 \pm 1.57 ^{ab}	42.72 \pm 1.57 ^{abc}	42.19 \pm 0.89 ^{abc}	-1.60 \pm 0.22	-1.72 \pm 0.37	-1.73 \pm 0.69	1.56 \pm 0.39 ^{bc}	0.79 \pm 0.90 ^{bc}	1.88 \pm 1.65 ^{abc}
6	45.84 \pm 2.77 ^{ab}	41.27 \pm 5.09 ^{bc}	46.32 \pm 1.32 ^{ab}	-2.43 \pm 0.34	-2.08 \pm 0.37	-2.61 \pm 0.41	1.88 \pm 1.65 ^{abc}	1.51 \pm 0.62 ^{bc}	1.94 \pm 1.80 ^{abc}
9	45.56 \pm 1.69 ^{ab}	46.13 \pm 1.10 ^{ab}	45.94 \pm 0.66 ^{ab}	-3.02 \pm 0.15	-2.44 \pm 0.23	-1.73 \pm 1.56	2.36 \pm 0.6 ^{abc}	2.83 \pm 0.15 ^{abc}	3.77 \pm 1.56 ^{ab}
14	48.00 \pm 0.80 ^a	47.32 \pm 1.36 ^{ab}	48.13 \pm 0.59 ^a	-2.72 \pm 1.07	-2.14 \pm 0.65	-2.53 \pm 0.31	3.28 \pm 0.83 ^{ab}	4.19 \pm 0.83 ^a	5.08 \pm 0.98 ^a

Note: ^{a-c} Different lower-case letters to indicate significant difference, at the 0.05 level. There was no significant differences between storage periods and holding time in a-value.

4.9 Texture

The average shear force was between 19 to 29 N for chilled saithe fillets during storage, (Figure 23). The values were similar to salmon using same part of fillet reported by Sigurgisladottir *et al.* (1999). The storage time and holding time had no significant effect ($p > 0.05$) on maximum shear force. Sorensen *et al.* (1997) also observed similar shear force in Atlantic salmon fillets during storage. Higher standard deviation was found in shear strength determination, the reason for this may be due to the different thickness of sample. Hyldig and Nielsen (2001) indicated that the testing-parameters used, e.g., thickness and temperature of the sample influenced the results of shear force.

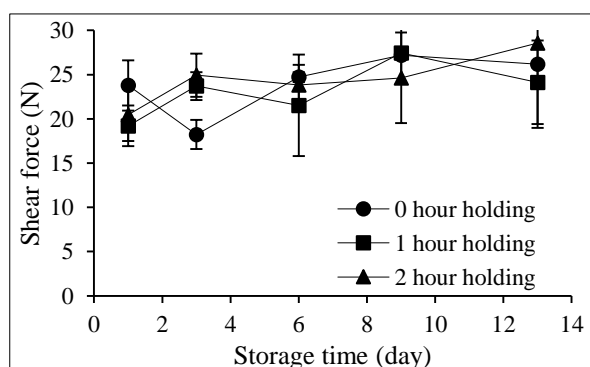


Figure 23: Shear force of small saithe fillets (n = 3) during chilled storage (2 ± 2 °C) (Mean \pm SD). Prior to storage, the fillets after filleting, skinning and weighing, were held at 16 ± 2 °C for 0, 1 or 2 hours. Then, packaged into EPS boxes with ice mats.

4.10 Sensory evaluation

The result of freshness evaluation is shown in Figure 24. The freshness grade for fillets held for 1 and 2 hours before packaging gradually decreased from the initial sampling day (1) whereas freshness decreased slowly in fillets packed immediately after processing and weighing (0

hours holding group). The freshness grade of fillets in 2 hours holding group was lowest throughout the storage period.

The fillets held for 1 hour had highest score (4.14) on day 1, but it was only significantly higher than the 2 hour holding group ($p < 0.05$). On day 3, the difference between three groups was not significant. The scores of all group had ($p > 0.05$) decreased from day 1. On day 6, the score there was highest significant difference ($p < 0.01$) between the groups was observed, the fillets held for 0 hours at the plant, obtained higher score, even slightly higher than at day 1 and 3. Presumably, this was due to more rapid decline in freshness of the other two groups, i.e. motivating the panellists to give the fillets from 0 hour holding group slightly higher scores, than before. The freshness score of fillets dropped to 1.7 on day 6, which means that the fillets became questionable, some fillets had lost their characteristic colour and abnormal odour was apparent. At the same day, the freshness grade for 1 hour holding group fillets had fallen to 3.

After 9 days of storage, the freshness scores of all group decreased to 2 and no difference was observed between the groups ($p > 0.05$) The results imply that the fillets of 0 and 1 hour holding also changed to questionable due to spoilage.

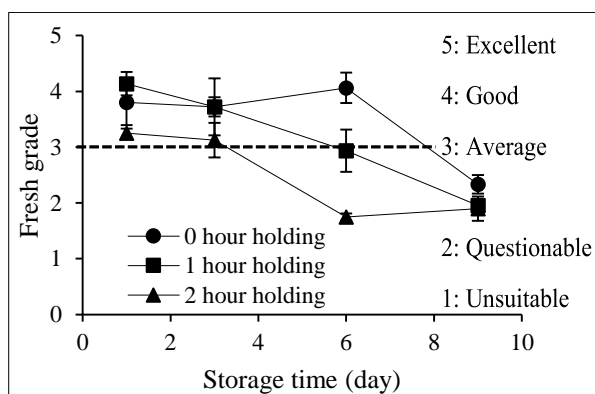


Figure 24: Freshness scores of saithe fillets ($n=3$) during chilled storage (2 ± 2 °C) (Mean \pm SD). Prior to storage, the fillets after filleting, skinning and weighing, were held at 16 ± 2 °C for 0, 1 or 2 hours. Then, packaged into EPS boxes with ice mats.

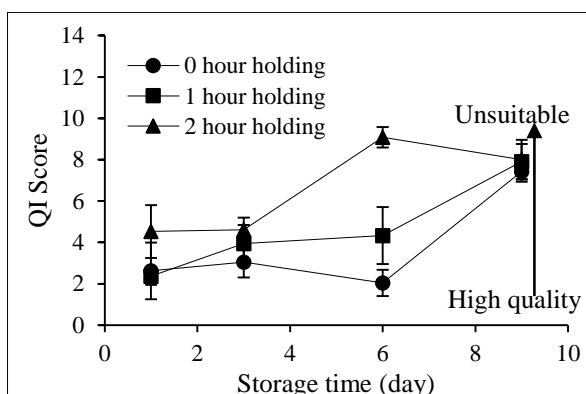


Figure 25: QI scores of saithe fillets ($n=3$) during chilled storage (2 ± 2 °C) (Mean \pm SD). Prior to storage, the fillets after filleting, skinning and weighing, were held at 16 ± 2 °C for 0, 1 or 2 hours. Then, packaged into EPS boxes with ice mats.

The total Quality Index (QI) scores increased with storage time (Figure 25), i.e. the quality decreased, although changes during the first three days were minor. The QI score of 0 hour holding group on day 6 was less than on day 1, which was in harmony with the freshness grades evaluation. There was no difference between three groups at same storage day. Except for day 6, when the fillets of 2 hours holding had significantly higher average score (9.1) than other two groups (4.3 and 2.0 for 1 and 0 holding group, respectively). At other sampling days, the 2 hour holding group obtained slightly higher score than other groups. Indicating that fresh saithe fillets held for 2 hours before packaging spoiled faster than those with less holding time.

The scores for all quality attributes evaluated by the Quality Index Method are shown in Figure 26. The contribution of each attribute to total QI score was different. In terms of texture, the score tended to increase during storage, i.e. the fillets became less firm with time. Higher score were observed in the 2 hour holding group throughout the storage time, especially at day 6

($p < 0.05$). The score for blood of in the 2 hour holding group, increased continuously throughout the storage time, whereas it fluctuated for the 0 and 1 hour holding group.

The scores for brightness and colour remained similar during the first three days of storage and no difference between the three groups was observed. The average value was less than 1, which means the fillets were bluish and greyish. The results were in good agreement with the results of b- and L-value in colour determination. The b-value (Table 3) was negative in each group at day 1, i.e. the colour of fillets appeared blue rather than yellow. Lowest L-value were observed at day 1, indicating a darker colour of the fillets. Six days later for storage, the bright and colour scores of the 2 hours holding group reached 1.14 and 1.38, respectively. These values were significantly higher than for the 0 hour holding group ($p < 0.01$). This implies that the fillets of hour holding group became more opaque and yellow, which was also in harmony with L- and b-values. However, there was discrimination on fillets redness and greenish score, between the sensory panel and colorimeter (Table 3), this may be attribute to the fact that QIM scheme (Table 2) used in this trail was adopted from cod without greenish colour description, hence the observed greenish for colorimeter and pinkish for sensory colour attribute.

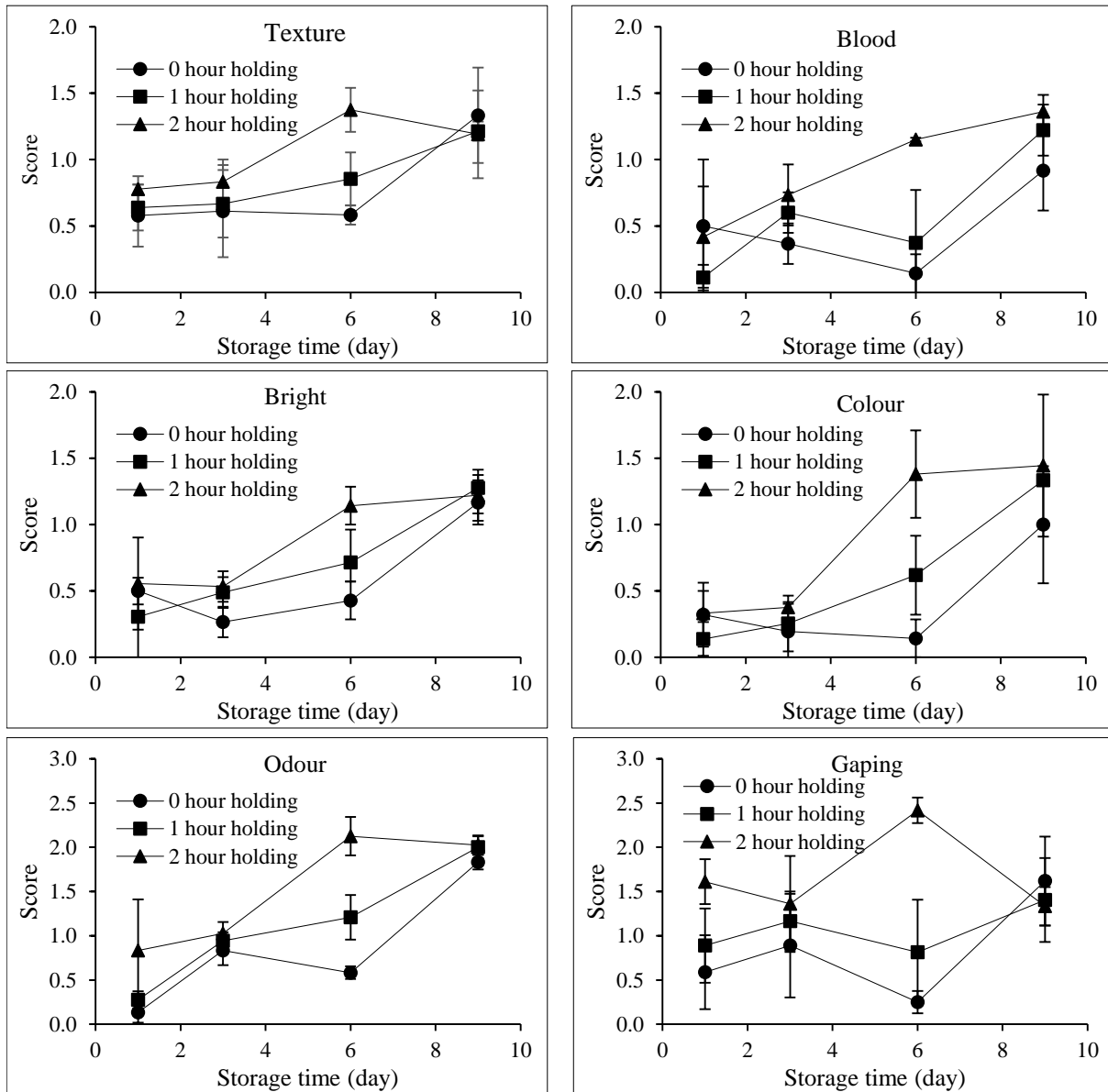


Figure 26: Average scores of each quality attribute evaluated with QIM scheme for saithe fillets ($n = 3$) during chilled storage (2 ± 2 °C) (Mean \pm SD). Prior to storage, the fillets after filleting, skinning and weighing, were held at 16 ± 2 °C for 0, 1 or 2 hours. Then, packaged into EPS boxes with ice mats.

The odour of each group increased with storage time. For the fillets of 2 hour holding, a seaweed or marine odour was detected from the first storage day. On day 6, the score of odour (2.13) for 2 hours holding group was significant higher than other two groups ($p < 0.01$). It became sourer, which may be one of the great contributions to total QI score. After 9 days storage, all scores reached approximately 2, i.e. fillets had sour odour.

The change of gaping was irregular throughout the storage time. However, the gaping score of fillets increased with holding time when comparing the groups at the same sampling day except for day 9. The score of the 2 hour holding group reached maximum (2.42) on day 6, the value was even higher than at day 9. This was a greater cause led to total QI score (Figure 25) of this group on day 9 were lower than day 6.

4.11 Microbiological analysis

The total viable psychrotrophic counts (TVC) increased with storage time (Figure 27). The growth of bacteria in the 0 hour group was delayed in comparison to the other groups. On the sampling day 1 and 3, a higher TVC (5.0 and 6.3 log colony-forming units CFU g⁻¹) was observed for fillets from 2 hour holding group compared to other two groups. Lowest TVC were found in 0 hour holding group on day 1, 3 and 6. There were no statistical difference ($p>0.05$) between three groups after 9 days storage. Similar trend for H₂S-producing bacteria counts was observed as for TVC (Figure 28). There were no statistical difference ($p>0.05$) between three groups on day 1, 9 and 13. On day 3, significantly higher levels ($p<0.01$) were found in the 2 hour holding group (4.6 log CFU g⁻¹) compared to the other two groups. The H₂S-producing bacteria counts for 1 hour holding group increased to 6.3 log CFU g⁻¹ on day 6, which was close to 2 hour holding group (6.7 log CFU g⁻¹). However, the counts of 0 hour holding group did not reached 6.4 log CFU g⁻¹ until 9 days of storage.

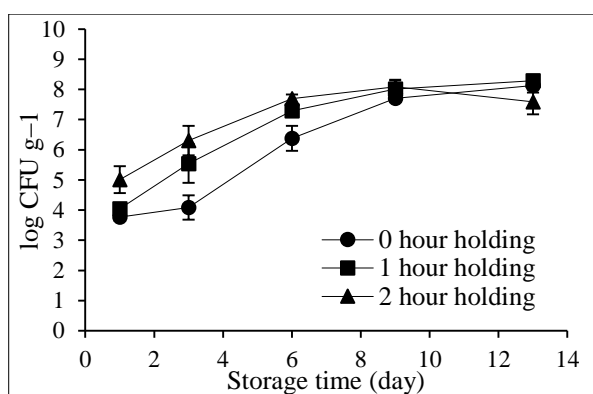


Figure 27: Total viable bacteria counts in saithe fillets (n=3) during chilled storage (2 ±2°C) (Mean ± SD). Prior to storage, the fillets after filleting, skinning and weighing, were held at 16±2°C for 0, 1 or 2 hours. Then, packaged into EPS boxes with ice mats.

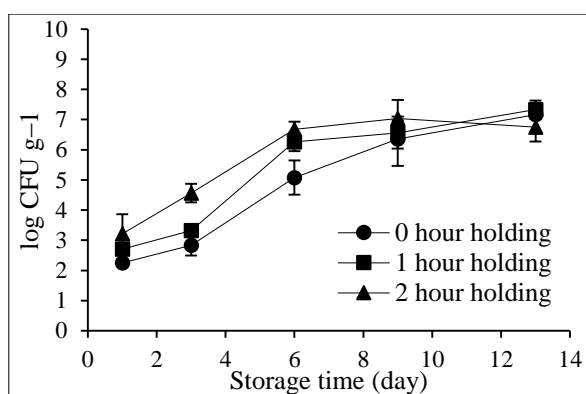


Figure 28: H₂S-producing bacteria counts in saithe fillets (n=3) during chilled storage (2 ±2°C) (Mean ± SD). Prior to storage, the fillets after filleting, skinning and weighing, were held at 16±2°C for 0,1 or 2 hours. Then, packaged into EPS boxes with ice mats.

4.12 Analysis of pH

The pH of the fillets increased with storage time (Figure 29). It was slightly higher (6.90) in the 2 hour holding group than in the other two groups on day 1, whereas lower pH (6.78) obtained on day 3, this is probably due to large individual variations, and there were insignificant difference between three groups for 3 days storage. On day 6, higher pH value ($p<0.05$) was observed in the 2 hour holding group (7.04) compared to the 0 hour holding group. The pH value (7.28) of the 1 hour holding group increased rapidly and exceeded on day 9, both of them significant higher ($p<0.05$) than the 0 hour holding group.

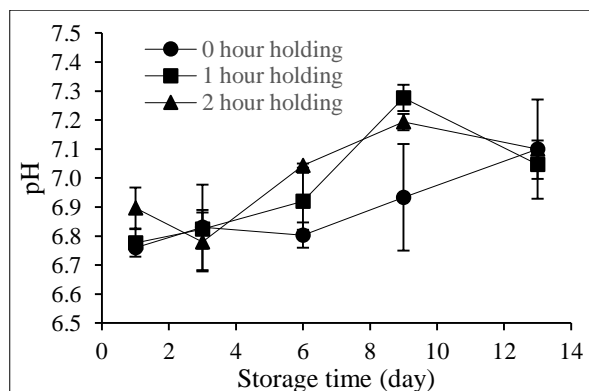


Figure 29: Changes in pH of saithe fillets (n=3) during chilled storage ($2 \pm 2^\circ\text{C}$) (Mean \pm SD). Prior to storage, the fillets after filleting, skinning and weighing, were held at $16 \pm 2^\circ\text{C}$ for 0, 1 or 2 hours. Then, packaged into EPS boxes with ice mats.

5 DISCUSSION

5.1 Temperature change in environment and fish fillets during processing

Fish is usually stored iced in tubs inside a chilled storage after it has been landed. The storage time before processing can vary from a couple of hours up to days (Lauzon *et al.* 2010). Commercial processing of fillets is usually started after the resolution of rigor mortis which often delays production for 2-4 days, because handling or filleting fish pre rigor or in-rigor can change the product properties and quality. The rigor time of fish after slaughtered depends on the fish species, temperature when pre-rigor storage in the factory and other factors (Elvevoll *et al.* 1996). In the present experiment, the fish was processed on 5th day after catch. According to temperature mapping of the fish processing plant, the ambient temperature fluctuated between $3\text{-}5^\circ\text{C}$, in the cooler where the raw materials were stored (Figure 5). This means that raw materials were held in this condition until processing. Maintenance of low environmental temperature of the raw material right from catch to processing has been proven to be critical in preserving fish quality. Ambient temperature fluctuated between 2 to 5°C in the cooler of the fish plant resulted in a shorter shelf life of whole cod (Magnusson *et al.* 2010). Therefore, temperature control in the receiving cooler before processing is very important and should be maintained close to 0°C , and minimum temperature fluctuation (Margeirsson *et al.* 2010a). In the present study, the temperature of fish stored in the cooler were found around $0 \pm 0.5^\circ\text{C}$. If the temperature of fish can be cooled down and maintained in superchilling temperature, it may slow down bacterial growth and extend shelf life (Lauzon *et al.* 2010). Whole and gutted plaice (*Hippoglossoides platessoides*) stored at -1.7°C in air had a longer shelf life (14 days) than ice storage at 0.6°C (12 days) (Lauzon 2000). Thus, to ensure fish receive optimum handling and obtain longer shelf life, maintenance of low temperature of raw material is necessary.

In the processing area of both species fish, the temperature in most of the locations was around 16°C , except in redfish beheading area (Figure 6) where the temperature was at 17°C . The results of this differs from the temperature (9.5°C) in mackerel beheading area, which was investigated in a fish processing plant of Faroe Islands (Gudmundsson *et al.* 2013). It should be pointed out that the ambient temperature in present investigation in processing area basically meets the regulations of the Administration of Occupational Safety and Health in Iceland (AOSH). According to the regulations, the temperature in the processing hall should not be higher than 16°C . However, the lower limits are 10°C with regard to employees, meaning that

the temperature could be properly reduced. Due to high ambient temperature where the fish was processed, the fish experienced high temperature load. This may result from heat conduction by processing machine, convection by natural circulation or fan circulation of the air and radiant heat transfer by indoor light sources. The high temperature load led to rapid increase of the temperature of fish fillets during holding. This means that the risk of temperature rises within the fillets during delays or breaks of processing, is high. It was noted that small fish can be heated more quickly than larger fish since thinner and mass less (Graham *et al.* 1993).

The temperature of the packaging area was higher than the higher limits of the AOSH regulation. In some instances, the packaging area recorded temperatures as high as 18.7°C. This might be attributed to the fact that there was a hot air conditioning outlet in the area. Under such conditions the temperature of fillets will increase in relatively short time (Figure 8). After 2 hours, the temperature of fillets was close to of environment (15°C) (Figure 11) and the rate of temperature rise was about 5°C h⁻¹, a little less than the result (6-7°C h⁻¹) reported by Margeirsson *et al.* (2010a). Similarly, for mackerel processing, relatively high ambient temperature (15°C) were found in pallet packing area and before plastic packaging, the mackerel core temperature based on simulation increased by about 0.9°C within 2 minutes stay in those areas (Gudmundsson *et al.* 2013).

In present study, the fillets temperature increased more rapidly at higher ambient temperature (22±2°C) and smaller size of fillets had faster temperature rises. However, Magnusson *et al.* (2009a) reported that the packaged fresh fish fillets were not severely affected by the temperature abused (11.7°C) for approximately two hours after packaging. This may be because the fillets were properly packed and CBC chilled before packaging, whereas in present study the fillets were exposed to the ambient temperature.

5.2 Drip loss and cooking yield

The results from drip loss of fillets during holding time revealed that the drip was positively correlated with holding time, holding temperature and negatively related to fillets size. All of the experimental factors tested had significant effects on drip loss. Effects decreased in following order was: holding time > type of fillets > ambient temperature. Longer holding time result in more drip loss as temperature increased gradually. This indicated that the free water within the muscle, was easily lost with environmental changes during processing (Ofstad and Hermansson 1997). It was noted that drip of redfish fillets was higher than for saithe fillets during the same time, this may be due to different composition of in the fish muscle. Differences in handling after catch, catching methods, post mortem age at processing are among factors that may influences variation in drip losses between species. Also, the water holding properties of different species may vary (Kingstown 2012, Stroud 2001, Burgaard 2010). The thaw drip of redfish has been found higher, than for cod (15±0.5°C) (Schubringa 2003). However, the greatest possibilities for this was smaller size of redfish fillets. Faster temperature rise of small fillets led to relatively loosely bound water lost more easily than in larger fillets. Correspondingly, more and faster drip was found in small size of saithe compared to large saithe.

During chilled storage, the increased drip with longer storage time was found each group, similar trend was observed in haddock and farmed Arctic charr fillets (Arnthorsdottir *et al.* 2008, Bao *et al.* 2007). This may be explained by partial degradation and breakdown of the muscle by bacteria and enzymes (Margeirsson *et al.* 2010b, Huss 1995). Less drip loss was seen in longer holding time (2 hours) during storage, the explanation may be that the fillets held in

ambient temperature for some time before packaging, part of the loosely bound water in fillets had already lost.

There was an inverse relationship between drip loss and cooking yield during storage period. The cooking yield in the 0 hour holding group was always lower than in the other groups except on day 1, whereas drip loss in the 0 hour holding group during storage was higher compared to the other groups. But there was no significant difference between the three groups during the storage period. The cooking yield declined in the 0 hour holding group during the six days storage period. Similar trends were observed in haddock fillets (Arnthorsdottir *et al.* 2008) and Arctic charr (Bao *et al.* 2007). This indicates that increased degradation of the muscle with storage time had negative effects on water holding properties of the muscle during heating (Bao *et al.* 2007). However, the cooking yield increased on day 9 in all groups. According to the sensory result, fillets in all groups deteriorated at this time. Presumably, much of loosely bound water was lost from muscle at that point resulting in less water (liquid) drainage during cooking.

5.3 Effect of holding time on saithe fillets shelf life

The result of freshness grade assessment in this study showed that freshness of the fillets without holding before packaging (0 hour) tended to questionable (Figure 24) after 9 day storage (14 days from catch). This is in agreement with the result of Karl and Meyer (2007), the shelf life of gutted saithe assessed with EU freshness classes are 14 days stored in 0°C. Longer holding time before packaging, decreased the shelf life. Similar freshness score were observed in 2 hour holding group on day 6 storage (11 days from catch) as for the 0 hour group at day 9. If the shelf life (14 days from catch) of 0 hour fillets without held were used as the reference, the product lost 21.5% shelf life due to 2 hours held before packing. It has been demonstrated that the losses in potential storage life are significant if fish is kept at higher temperatures ($16\pm 2^{\circ}\text{C}$) even for short periods (Graham *et al.* 1993). Any delay in chilling fish after catching is a sufficient reason to be concerned about (Doyle 1995).

According to Bonilla *et al.* (2007), who developed the QIM scheme for cod fillets with skin, the rejection score was 8 on day 8 (11-13 days from catch) for fillets stored on ice. This implies that if the score of fillets without skin is higher than 8, the fish will be rejected. A study done by (Wang 2005), indicated that the total QI score was around 8 demerit points for cod loins on day 13 of storage time at 1.5°C . Then fillets had reached the rejection point. In present experiment, the QI score of fillets in the 2 hours holding group was 9.1 after 6 days storage. Base on the rejection point mentioned above, the fillets had become inedible. However, the QI score of fillets in the 0 hour holding group less than 4 until 9 days of storage. The result of QIM was in good agreement with the results of freshness assessment.

Activity and amount of microorganism is one of the main factors that limit products' shelf life. According to ICMSF (1986), the proposed limit of acceptance for human consumption is 7 log CFU g^{-1} . Gram *et al.* (1987) reported that the total viable counts (TVC) had reached levels of 7-8 log CFU g^{-1} at rejection time of fish. The result in present experiment showed that the TVC in the 2 hours holding group (Figure 27) was 7.7 log CFU g^{-1} after 6 days' storage. Therefore, the fillets were unfit for human consumption according to the TVC level of rejection, and this was in agreement with the sensory results. However, the TVC of fillets in the 1 hours holding group had reached 7.3 log CFU g^{-1} at same time, but were not rejected by sensory panelists. This was probably due to less unacceptable characteristic, in comparison to the 2 hours holding group. Evidently, the fillets (6.4 log CFU g^{-1}) of without holding had not spoiled (6.4 log CFU g^{-1}) at this time.

A large number of bacteria (7-8 log CFU g⁻¹) is normally found on spoiling fish (Gram *et al.* 1987). Only part of this flora may be classified as active spoilers. Bacteria forming black colonies (H₂S-producing bacteria) are considered the main spoilage bacteria in fish. (Arnthorsdottir *et al.* 2008). The end of whole cod shelf life was determined when the counts of H₂S producing bacteria were around 7 log CFU g⁻¹ (Bonilla *et al.* 2007, Gram *et al.* 1987). Karl and Meyer (2007) reported that the number of H₂S-producing organisms in saithe varied from 6 to 7 log CFU g⁻¹ at the end of shelf life. Accordingly, the 0 hour holding group had longer shelf life (9 days storage) than the other groups. The result were in harmony with the result of TVC. Thus, longer holding time (delay) before packaging led to temperature rise in fillets, which triggered the development of H₂S-producing bacteria as well as the other bacterial groups, resulting in shorter shelf life.

The pH is commonly used to indicator of fish deterioration (Howgate 2009). The result of pH in saithe fillets showed increase of pH in each group with storage time, similar trend has frequently been reported by different researchers (Susanto *et al.* 2011, Abelti 2013, Magnusson *et al.* 2009b). This may be attributed to the accumulation of alkaline compounds such as ammonia and amines (e.g. trimethylamine) derived from microbial action during fish muscle spoilage (Capillas and Moral 2005). The pH of fillets in the 0 hour holding group was lower than other two group at same storage aging. The result was in agreement with the result from microbiological analysis. Slower the bacterial growth led to the lower pH of fish flesh (Okeyo *et al.* 2009). The fillets spoilage without held before packaging was delayed.

6 CONCLUSIONS AND RECOMMENDATIONS

This study empathises well the importance of proper maintenance of low environmental temperature of the raw material and fish product during processing. A clearly high temperature (18.7°C) and fluctuation was found in packaging area in the fish processing plant. Higher ambient temperature resulted in faster temperature rise in the fish fillets. The change occurred more rapidly for smaller size fillets. Holding time before packaging and environmental temperature had great effect on the drip loss of fresh fillets during processing. Within 2.5 hours holding at 16±2°C, the drip loss of saithe and redfish fillets was 3.4% and 4.7%, respectively.

Furthermore, according to sensory, microbiological and pH analysis, longer holding time significantly reduced shelf life. Two hours delay during processing led to 21.5% (3 days) shelf life loss of saithe fillets stored at 2±2°C in comparison with the product packed immediately (0 hours holding).

It is critical to maintain low and stable temperature in the cooler used for raw material storage and processing area, especially in packaging area. Processors need to make sure that heating sources are located far from those areas.

In addition, processors should:

- Minimise holding time during processing.
- Rotating lunch and coffee breaks can be used for fresh fillets processing line.
- Make sure there are no bottlenecks in the processing line.
- Reduce the risk of temperature rises of product.
- Control product temperature, i.e. have it close to storage temperature at packaging, i.e. use pre-cooling methods during processing / before packaging e.g. CBC-technique.
- Make sure that the product is transferred to cold storage room as soon as possible after packaging.

ACKNOWLEDGEMENTS

I am greatly indebted to my supervisors Kristin Anna Thorarinsdottir, Arnljotur Bjarki Bergsson and Asbjorn Jonsson for their elaborate guidance, valuable advice and help to me.

I am likewise deeply grateful to Tumi Tomasson, Thor Asgeirsson, Sigridur Kr. Ingvarsdottir and Mary Frances Davidson for giving me the opportunity to participate in the programme and their continued assistance, support and guidance during the six month period of the training programme. Also thanks to for their careful care to my life here.

Special thanks to Pall Steinhorsson. Adalheidur Olafsdottir and Magnus V. Gislason for their enthusiastic guidance and assistance. Thanks to Matis ltd. - Icelandic Food and Biotech R&D offering the sensory panel and facilities.

Last but not least I would like to thank all the UNU-FTP fellows, especially Quality Management of Fish Handling and Processing's fellows, for their help during my study and live in Iceland.

LIST OF REFERENCES

- Abelti, A. L. (2013). Microbiological and chemical changes of Nile Tilapia (*Oreochromis niloticus* L.) fillet during ice storage. *Journal of Food Science and Technology*, 5(10), 1260-1265.
- Arnthorsdottir, M. G., Arason, S., & Margeirsson, B. (2008). *Combined Blast and Contact cooling - Effects on physiochemical characteristics of fresh haddock (Melanogrammus aeglefinus) fillets*. Reykjavik: Matis.
- Bao, H. N., Arason, S., & Thorarinsdottir, K. A. (2007). Effects of dry ice and superchilling on quality and shelf life of Arctic Charr (*Salvelinus alpinus*) fillets. *International Journal of Food Engineering*, 3(3), 1-27.
- Board, I. S. (2005). *Nutritional Aspects of Fish*. Dublin: Bord Iascaigh Mhara.
- Bonilla, A. C., Sveinsdottir, K., & Martinsdottir, E. (2007). Development of Quality Index Method (QIM) scheme for fresh cod (*Gadus morhua*) filets and application in shelf life study. *Food Control*, 18, 352–358.
- Bouton, P., Harris, P., & Shorthose, W. R. (1975). Changes in shear parameters of meat associated with structural changes produced by aging, cooking and myofibrillar contraction. *Journal of Food Science*, 40(6), 1122-1126.
- Capillas, C.R., & Moral, A. (2005). Sensory and biochemical aspects of quality of whole bigeye tuna (*Thunnus obesus*) during bulk storage in controlled atmospheres. *Food Chemistry*, 89(3), 347–354.
- Burggaard, M. G. (2010). *Effect of frozen storage temperature on quality-related changes in fish muscle*. Copenhagen: Technical University of Denmark.
- Doyle, J. P. (1995). *Seafood Shelf Life as a Function of Temperature*. Alaska : Alaska Sea Grant College Program.
- Duun, A., & Rustad, T. (2007). Quality changes during superchilled storage of cod (*Gadus morhua*) fillets. *Food Chemistry*, 105, 1067–1075.
- Duun, A., & Rustad, T. (2008). Quality of superchilled vacuum packed Atlantic salmon (*Salmo salar*) fillets stored at 1.4 and 3.6 °C. *Food Chemistry*, 106, 122-131.
- Economou, V., Brett, M. M., Papadopoulou, C., Frillingos, S., & Nichols, T. (2007). Changes in histamine and microbiological analyses in fresh and frozen tuna muscle during temperature abuse. *Food Additives and Contaminants*, 24(8), 820-832.
- Einarsson, H., & Lauzon, L. (1996). *Final report to the European Commission for the project AIR 2 CT93-1251 "Predictive modelling of shelf life of fish and meat products" (1993-1996)*.
Eliasson, S., Margeirsson, B., & Arason, S. (2013). *Improved reefer container for fresh fish*. Reykjavik: Matis.

Elvevoll, E., Sorensen, N. K., Osterud, B., Ofstad, R., & Martinez, I. (1996). Processing of marine foods. *Meat Science*, 43, 265-275.

FAO. (2001). *Temperature measurement in the fish industry*. SIFAR: Torry Research Station. Retrieved from <http://www.fao.org/wairdocs/tan/X5992E/X5992e00.htm>

FAO. (2012). *The state of world fisheries and aquaculture*. Rome: Food and agriculture organization of the united nations.

Giannakouroua, M., Koutsoumanisb, K., Nychasc, G., & Taoukis, P. (2005). Field evaluation of the application of time temperature integrators for monitoring fish quality in the chill chain. *International Journal of Food Microbiology*, 102, 323– 336.

Graham, J., Johnston, W. A., & Nicholson, F. J. (1993). *Ice in fisheries*. Rome: FAO .

Gram, L., Trolle, G., & Huss, H. (1987). Detection of specific spoilage bacteria from fish stored at low (0 °C) and high (20 °C) temperatures. *Int J Food Microbiol*, 4(1), 65-72.

Gudmundsson, H. A., Margeirsson, B., & Arason, S. (2013). *Modeling of Temperature Changes, Energy Usage and Quality Changes During Automatic Box Freezing of Mackerel*. Reykjavik : Matis.

Howgate, P. (2009). Traditional Methods. In H. Rehbein, & J. Oehlenschlager, *Fishery Products: Quality, safety and authenticity* (pp. 19-41). Chichester, UK: John Wiley.

Huss, H. H. (1995). *Quality and quality changes in fresh fish*. Rome: FAO.

Hyldig, G., & Nielsen, D. (2001). A review of sensory and instrumental methods used to evaluate the texture of fish muscle. *Journal of texture studies*, 32(3), 1745-4603.

ICMSF. (1986). Sampling plans for fish and shellfish. In I. C. Foods, *Microorganisms in foods 2 sampling for microbiological analysis: principles and specific applications* (p. 188). Toronto, Canada: Blackwell Scientific Publications.

ISO. (1993). Sensory analysis - general guidance for the selection, training and monitoring of assessors. In *Part1:Selected assessors 8586-1* (pp. 1-10). Geneva: The International Organisation for Standardization.

ISO. (1994). Sensory analysis - general guidance for the selection, training and monitoring of assessors. In *Part 2: Experts:selected assessors. 8586-2* (pp. 1-11). Geneva: The International Organization for Standardization.

Karl, H., & Meyer, C. (2007). Effect of early gutting on shelf life of saithe (*Pollachius virens*), haddock (*Melanogrammus aeglefinus*) and plaice (*Pleuronectes platessa*) stored in ice. *Journal of Consumer Protection and Food Safety*, 2(2), 130–137.

Kingstown, A. M. (2012). *conservation of fresh golden redfish (sebastes marinus) fillets : influence of bleeding, modified atmosphere packaging using different gas mixtures and superchilling on quality deterioration*. Reykjavik: UNU-Fisheries Training Programme.

Lauzon, H. L. (2000). Shelf-life and Bacteriological Spoilage of American Plaice (*Hippoglossoides platessoides*). In F. Shahidi, *Seafood in Health and Nutrition, Transformation in Fisheries and Aquaculture: Global Perspectives* (pp. 327-354). St. John's: ScienceTech Pub.

Lauzon, H. L., Magnusson, H., Sveinsdottir, K., Maria, G., & Martinsdottir, E. (2009). Effect of brining, modified atmosphere packaging, and superchilling on the shelf life of Cod (*Gadus morhua*) loins. *Food Microbiology and Safety*, 74(6), 259-267.

Lauzon, H. L., Margeirsson, B., Sveinsdottir, K., Gudjonsdottir, M., Karlsdottir, M. G., & Martinsdottir, E. (2010). *Overview on fish quality research. Impact of fish handling, processing, storage and logistics on fish quality deterioration*. Reykjavik : Matis.

Li, X., Chi, H., Yang, X., Jiang, X., & Guo, Q. (2013). Effect of pre-chilling temperatures on quality changes of *Pseudosciaena crocea* during ice storage. *Modern Food Science and Technology*(5), 486-489.

Magnusson, H., Lauzon, H. L., Sveinsdottir, K., Margeirsson, B., Reynisson, E., Gudjonsdottir, A. R., . . . Martinsdottir, E. (2009b). *The effect of different cooling techniques and temperature fluctuations on the storage life of cod fillets (Gadus morhua)*. Reykjavik: Matis.

Magnusson, H., Lauzon, H. L., Sveinsdottir, K., Margeirsson, B., Reynisson, E., Runarsson, A. R., . . . Martinsdottir, E. (2009a). *The effect of different cooling techniques and temperature fluctuations on the storage life of cod fillet (Gadus morhua)*. Reykjavik: Matis.

Magnusson, H., Sveinsdottir, K., Thorvaldsson, L., Guojonsdottir, M., Lauzon, H. L., Reynisson, E., . . . Martinsdottir, E. (2010). *The effect of different cooling techniques on the quality changes and shelf life of whole cod (Gadus morhua)*. Reykjavik: Matis.

Magnusson, H., Thorvaldsson, L., thorvaldsson, L., Thorvaldsson, L., thorarinsdottir, K. A., Arason, S., & Martinsdottir, E. (2009c). *The effect of liquid cooling at processing and different cooling techniques during transport of cod (Gadus morhua) fillets*. Reykjavik: Matis.

Mai, N. T., Margrírsson, B., Margeirsson, S., Bogason, S. G., Sigurgísladottir, S., & Arason, S. (2012). Temperature mapping of fresh fish supply chains—air and sea transport. *Journal of Food Process Engineering*, 35(4), 622–656.

Margeirsson, B., Arason, S., & Palsson, H. (2009). *Thermal performance of corrugated plastic boxes and expanded polystyrene boxes*. Reykjavik: Matis.

Margeirsson, B., Lauzon, H. L., Palsson, H., Popov, V., Radovan Gospavic, M. T., Sigurgísladottir, S., & Arason, S. (2012). Temperature fluctuations and quality deterioration of chilled cod (*Gadus morhua*) fillets packaged in different boxes stored on pallets under dynamic temperature conditions. *International Journal of Refrigeration*, 35(1), 187-201.

Margeirsson, B., Lauzon, H. L., Thorvaldsson, L., Arnason, S. V., Arason, S., Valtysdottir, K. L., & Martinsdottir, E. (2010a). *Optimised Chilling Protocols for Fresh Fish*. Reykjavik: Matis.
Margeirsson, B., Magnusson, H., Sveinsdottir, K., Valtysdottir, K. L., Reynisson, E., & Arason, S. (2010b). *The effect of different precooling media during processing and cooling techniques during packaging of cod (Gadus morhua) fillets*. Reykjavik: Matis.

Martinsdottir, E., Lauzon, H. L., Margeirsson, B., Sveinsdottir, K., Thorvaldsson, L., Magnusson, H., . . . Eden, M. (2010). *The effect of cooling methods at processing and use of gel packs on storage life of cod (Gadus morhua) loins. Effect of transport via air and sea on temperature control and retail-packaging on cod deterioration*. Reykjavik: Matis.

Matis. (2013, 12 21). *Fresh fillet processing and markets*. Retrieved from Icelandic fisheries: <http://www.fisheries.is/products/processing-methods/fresh/>

Matis. (2014a, 2 8). *Cooling on board*. Retrieved from chilling fish from catch to consumer: <http://www.kaeligatt.is>

Matis. (2014b, 2 10). *Sensory evaluation of raw fillets*. Retrieved from Chill fish-from catch to consumer: http://www.kaeligatt.is/media/uppsetning/Enska_Flok.pdf

Odoli, C. O. (2006). *The effects of temperature abuse at the beginning of storage on the quality and shelf life of fresh water Arctic charr (Salvelinus alpinus)*. Reykjavik: UNU Fisheries Training Programme.

Ofstad, R., & Hermansson, A. M. (1997). Liquid loss and structural changes during heating. In J. B. Luten, T. Borreson, & T. Oehlenschlager, *Seafood from producer to consumer, integrated approach to qua* (pp. 191-201). Amsterdam: Elsevier Science Limited.

Okeyo, G., Lokuruka, M., & Matofari, J. (2009). Nutritional composition and shelf life of the lake Victoria Nile perch (*Lates nilotucs*) stored in ice. *African Journal of Food, Agriculture, Nutrition and Development*, 9(3), 901-919.

Olafsdottir, A., Margeirsson, B., Sveinsdottir, K., Arason, S., Reynisson, E., & Martinsdottir, E. (2012). *Effect of superchilled processing of whole whitefish – pre rigor*. Reykjavik: Matis.

Olafsdottir, G., Lauzon, H., Martinsdottir, E., & Kristbergsson, K. (2006). Influence of storage temperature on microbial spoilage characteristics of haddock fillets (*Melanogrammus aeglefinus*) evaluated by multivariate quality prediction. *International Journal of Food Microbiology*, 111(2), 113-125.

Olafsson, K. P. (1999). *Effect of carbon dioxide snow (dry ice) of fresh cod fillets*. Reykjavik: Icelandic Fisheries Laboratories.

Otwell, S. (1997). *Time, Temperature, Travel -a quality balancing act*. Florida: Seafood International.

Purwaamidjaja, E. T. (2010). *Storage quality of fresh redfish (sebastesmarinus) fillets affected by different cooling methods*. Reykjavik: UNU Fisheries Training Programme.

Raab, V., Petersen, B., & Kreyenschmidt, J. (2010). Temperature monitoring in meat supply chains. *British Food Journal*, 113(10), 1268-1289.

Ronsivalli, L. J., & Baker II, D. W. (1981). Low temperature preservation of seafoods: a review. *Marine Fisheries Review*, 43(4), 1-13.

Schubringa, R., Meyer, C., Schluter, O., Boguslawski, S., & Knorr, D. (2003). Impact of high pressure assisted thawing on the quality of fillets from various fish species. *Innovative Food Science and Emerging Technologies*, 4(3), 257–267.

Shawyer, M., & Pizzali, A. F. (2003). *The use of ice on small fishing vessels*. Rome: FAO.

Sigholt, T., Erikson, U., Rustad, T., Jouhansen, S., Nordtved, T., & Seland, A. (1997). Handling stress and storage temperature affect meat quality of farmed-raised Atlantic Salmon (*Salmo Salar*). *Journal of food science*, 62(4), 898-905.

Sigurgisladottir, S., Hafsteinsso, H., Jonsson, A., Lie, O., R. Nortvedt, M. T., & Torrissen, O. (1999). Textural properties of raw salmon fillets as related to sampling method. *Journal of Food Science*, 64(1), 99-104.

Sorensen, N., R.Brataas, Nyvold, T., & K.Laurtzen. (1997). Influence of early processing (pre-rigor) on fish quality. In B. T. Luten JB, *Seafood from Producer to Consumer, Integrated Approach to Quality* (pp. 253-263). Amsterdam: Elsevier Science Limited.

Stroud, G. D. (2001). *Rigor in fish. The effect on quality*. Rome: FAO.

Susanto, E., Agustini, T. W., Ritanto, E. P., Dewi, E. N., & Swastawati, F. (2011). Changes in oxidation and reduction potential (Eh) and pH of tropical fish during storage. *Journal of Coastal Developmen*, 14(3), 223-234.

Thorvaldsson, L., Lauzon, H. L., Margeirsson, B., Martinsdottir, E., & Arason, S. (2010). *Comparison of cooling techniques -Their efficiency during cooling and storage of whole, gutted haddock, and their effect on microbial and chemical spoilage indicators*. Reykjavik: Matis.

Valtysdottir, K. L., Margeirsson, B., Margeirsson, B., Lauzon, H. L., & Martinsdottir, E. (2010). *Guidelines for precooling of fresh fish during processing and choice of packaging with respect to temperature control in cold chains*. Reykjavik: Matis.

Wang, T. (2005). *Combined application of modified atmosphere packaging (MAP) and superchilled storage to extend the shelf-life of fresh Cod (*Gadus Morhua*) Loins*. Reykjavik: UNU Fisheries Training Programme.

Yao, Y.-j., Zhang, J.-j., Gu, W.-g., Ji, R., & Hu, Y.-q. (2011). Effect of storage temperature on freshness of silver carp (*Hypophthalmichthys molitrix*). *Journal of Zhejiang University (Agric. & Life Sci.)*, 37(2), 212-2018.

Zhang, G.-c. (2004). *Study in heat pump dried shrimp and fish cake*. Reykjavik: UNU Fisheries Training Programme.

ZhuTianxiang, XuZhong, CaiShuqiu, GuoQuanyou, & YangXianshi. (2007). Microbiological quality of iced yellow croaker during the processing. *Sciencepaper Online*, 1-5.

APPENDIX I

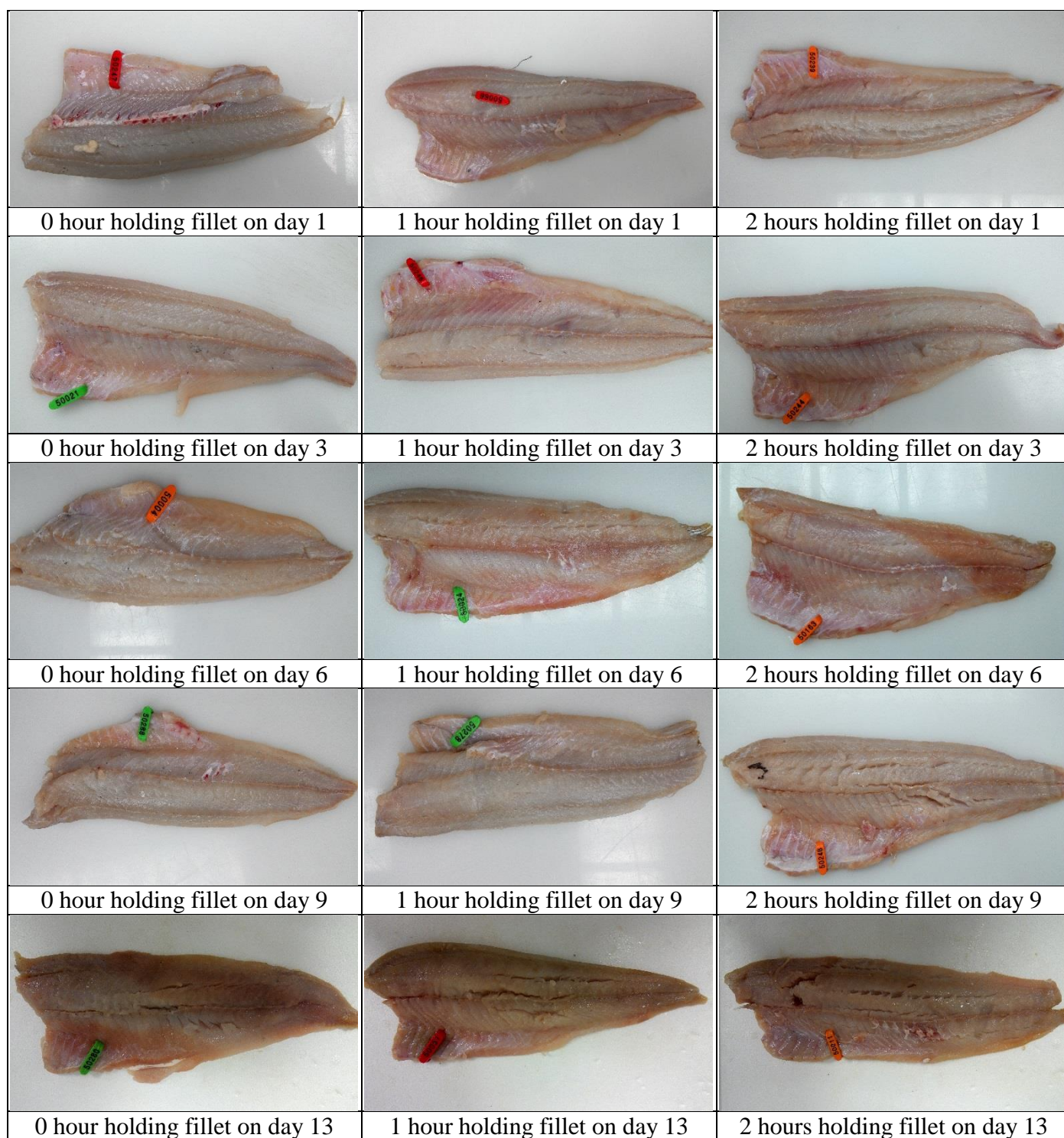
Pictures of saithe fillets samples during chilled storage

Figure 30: Surface appearance of saithe fillets during chilled storage ($2 \pm 2^{\circ}\text{C}$). Prior to storage, the fillets after filleting, skinning and weighing, were held at $16 \pm 2^{\circ}\text{C}$ for 0, 1 or 2 hours. Then, packaged into EPS boxes with ice mats

APPENDIX II*Drip loss of fillets during held at different temperature*

Table 4: Drip loss (at plant) of fish fillets (n = 6) held at 22±2°C, 16±2°C, 10±2°C, after various holding times (Mean ± SD).

Holding time (hour)	22±2°C			16±2°C			10±2°C		
	Large saithe	Small saithe	Redfish	Large saithe	Small saithe	Redfish	Large saithe	Small saithe	Redfish
0.0	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
0.5	0.12±0.20	0.64±0.45	1.53±0.62	0.30±0.17	0.17±0.21	0.84±0.32	0.36±0.30	0.40±0.17	0.36±0.61
1.0	0.21±0.16	0.35±0.23	2.00±0.86	0.55±0.44	0.17±0.19	0.72±0.72	2.14±0.29	1.95±0.19	2.22±0.50
1.5	2.19±0.18	2.04±0.36	4.28±0.67	0.51±0.24	0.36±0.28	1.14±0.44	2.24±0.51	2.33±0.33	2.64±0.62
2.0	2.40±0.22	3.24±0.47	5.45±0.88	1.93±0.26	1.74±0.33	2.67±0.87	2.66±0.26	2.71±0.22	3.14±0.60
2.5	3.29±0.57	4.80±0.65	7.13±1.03	0.00±0.00	3.34±1.25	4.70±1.55	3.80±0.53	3.65±0.43	4.07±0.42

APPENDIX III

Quality change in saithe fillets during chilled storage

Table 5: The parameters of saithe fillets (n = 3) during chilled storage (2 ± 2 °C) (Mean \pm SD). Prior to storage, the fillets after filleting, skinning and weighing, were held at 16 ± 2 °C for 0, 1 or 2 hours. Then, packaged into EPS boxes with ice mats.

Sampling day	Treatment	Drip loss (%)	Cooking yield (%)	Shear force (N)	Freshness grade	Quality Index	TVC (log CFU g ⁻¹)	H ₂ S producing bacteria (log CFU g ⁻¹)	pH
Day 1	0 hour holding	1.84 \pm 1.22	83.64 \pm 1.50	23.77 \pm 2.84	3.81 \pm 0.41	2.62 \pm 1.38	3.77 \pm 0.11	2.25 \pm 0.05	6.76 \pm 0.00
	1 hour holding	1.35 \pm 0.51	78.94 \pm 1.04	19.21 \pm 2.31	4.14 \pm 0.21	2.36 \pm 0.41	4.04 \pm 0.11	2.71 \pm 0.33	6.78 \pm 0.05
	2 hours holding	-0.28 \pm 0.40	81.77 \pm 2.48	20.48 \pm 2.98	3.25 \pm 0.08	4.53 \pm 1.28	5.01 \pm 0.45	3.21 \pm 0.65	6.90 \pm 0.07
Day 3	0 hour holding	3.02 \pm 1.57	77.69 \pm 3.91	18.23 \pm 1.65	3.72 \pm 0.51	3.06 \pm 0.75	4.08 \pm 0.40	2.83 \pm 0.33	6.83 \pm 0.15
	1 hour holding	2.21 \pm 0.72	82.55 \pm 2.01	23.70 \pm 1.58	3.72 \pm 0.17	3.94 \pm 0.90	5.54 \pm 0.64	3.32 \pm 0.15	6.82 \pm 0.07
	2 hours holding	1.08 \pm 0.66	82.01 \pm 2.50	24.93 \pm 2.45	3.13 \pm 0.31	4.61 \pm 0.59	6.30 \pm 0.49	4.56 \pm 0.31	6.78 \pm 0.10
Day 6	0 hour holding	3.89 \pm 2.08	77.35 \pm 3.91	24.72 \pm 0.57	4.06 \pm 0.27	2.04 \pm 0.63	6.38 \pm 0.42	5.08 \pm 0.57	6.80 \pm 0.04
	1 hour holding	2.75 \pm 0.72	81.35 \pm 2.01	21.52 \pm 5.73	2.94 \pm 0.38	4.33 \pm 1.38	7.29 \pm 0.02	6.26 \pm 0.31	6.92 \pm 0.10
	2 hours holding	0.67 \pm 0.66	82.48 \pm 2.50	23.82 \pm 2.29	1.75 \pm 0.06	9.08 \pm 0.50	7.69 \pm 0.14	6.68 \pm 0.25	7.04 \pm 0.01
Day 9	0 hour holding	4.42 \pm 2.22	86.42 \pm 1.93	27.20 \pm 0.53	2.33 \pm 0.16	7.43 \pm 0.50	7.70 \pm 0.13	6.36 \pm 0.32	6.93 \pm 0.18
	1 hour holding	3.21 \pm 0.96	87.21 \pm 1.53	27.45 \pm 3.40	1.95 \pm 0.04	7.90 \pm 0.85	8.02 \pm 0.28	6.56 \pm 1.09	7.28 \pm 0.05
	2 hours holding	1.22 \pm 1.01	88.91 \pm 0.53	24.63 \pm 5.12	1.90 \pm 0.22	8.00 \pm 0.96	8.08 \pm 0.24	7.04 \pm 0.07	7.19 \pm 0.03
Day 13	0 hour holding	5.17 \pm 2.45	88.19 \pm 0.45	26.18 \pm 7.19	ND	ND	8.13 \pm 0.24	7.16 \pm 0.09	7.10 \pm 0.03
	1 hour holding	3.74 \pm 1.14	91.13 \pm 0.46	24.12 \pm 4.73	ND	ND	8.28 \pm 0.18	7.33 \pm 0.30	7.05 \pm 0.05
	2 hours holding	1.92 \pm 1.22	88.82 \pm 2.37	28.56 \pm 3.16	ND	ND	7.59 \pm 0.41	6.75 \pm 0.48	7.10 \pm 0.17

APPENDIX IV

The scores of quality attribute evaluated with QIM scheme for saithe fillets during chilled storage

Table 6: The scores of quality attribute evaluated with QIM scheme for saithe fillets (n = 3) during chilled storage (2 ± 2 °C) (Mean \pm SD). Prior to storage, the fillets after filleting, skinning and weighing, were held at 16 ± 2 °C for 0, 1 or 2 hours. Then, packaged into EPS boxes with ice mats.

Sampling day	Treatment	Texture (0-2)	Blood (0-2)	Odour (0-3)	Colour (0-2)	Bright (0-2)	Gaping (0-3)	Total (0-14)
Day 1	0 hour holding	0.58 \pm 0.23	0.50 \pm 0.50	0.13 \pm 0.12	0.32 \pm 0.24	0.50 \pm 0.10	0.59 \pm 0.42	2.62 \pm 1.38
	1 hour holding	0.64 \pm 0.17	0.11 \pm 0.10	0.28 \pm 0.10	0.14 \pm 0.13	0.31 \pm 0.17	0.89 \pm 0.42	2.36 \pm 0.41
	2 hours holding	0.78 \pm 0.10	0.42 \pm 0.38	0.83 \pm 0.58	0.33 \pm 0.17	0.56 \pm 0.35	1.61 \pm 0.25	4.53 \pm 1.28
Day 3	0 hour holding	0.61 \pm 0.35	0.37 \pm 0.15	0.83 \pm 0.17	0.19 \pm 0.21	0.27 \pm 0.12	0.89 \pm 0.59	3.06 \pm 0.75
	1 hour holding	0.67 \pm 0.25	0.60 \pm 0.15	0.94 \pm 0.10	0.26 \pm 0.21	0.49 \pm 0.12	1.17 \pm 0.33	3.94 \pm 0.90
	2 hours holding	0.83 \pm 0.17	0.73 \pm 0.23	1.03 \pm 0.13	0.38 \pm 0.04	0.53 \pm 0.12	1.36 \pm 0.54	4.61 \pm 0.59
Day 6	0 hour holding	0.58 \pm 0.07	0.14 \pm 0.14	0.58 \pm 0.07	0.14 \pm 0.14	0.43 \pm 0.14	0.25 \pm 0.13	2.04 \pm 0.63
	1 hour holding	0.85 \pm 0.20	0.37 \pm 0.40	1.21 \pm 0.25	0.62 \pm 0.30	0.71 \pm 0.25	0.81 \pm 0.60	4.33 \pm 1.38
	2 hours holding	1.38 \pm 0.17	1.15 \pm 0.01	2.13 \pm 0.22	1.38 \pm 0.33	1.14 \pm 0.14	2.42 \pm 0.14	9.08 \pm 0.50
Day 9	0 hour holding	1.33 \pm 0.36	0.92 \pm 0.30	1.83 \pm 0.08	1.00 \pm 0.44	1.17 \pm 0.17	1.62 \pm 0.50	7.43 \pm 0.50
	1 hour holding	1.21 \pm 0.07	1.22 \pm 0.19	2.00 \pm 0.12	1.33 \pm 0.00	1.28 \pm 0.10	1.40 \pm 0.48	7.90 \pm 0.85
	2 hours holding	1.19 \pm 0.33	1.36 \pm 0.13	2.02 \pm 0.11	1.44 \pm 0.54	1.22 \pm 0.19	1.33 \pm 0.22	8.00 \pm 0.96