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Sub-chilling of salmon

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Titill / Title	**Sub-chilling of salmon**		
Höfundar / Authors	Gunnar Thordarson, Magnea Karlsdottir, Roger Pedersen, Magnus Johannsson and Albert Hognason		
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Ágrip á íslensku:	Markmið verkefnisins var að auka gæði við framleiðslu á ferskum laxi, með því að bæta kælikeðju við framleiðslu og í flutningi. Með því að nota aðferðir ofurkælingar munu laxaframleiðendur geta lækkað framleiðslukostnað sinn vegna minni flutningskostnaðar og um leið bæta gæði framleiðslunnar. Laxinn var kældur niður í -1.5 °C sem jók líftíma og gæði vörunnar. Ásamt því að bæta framleiðslu við slátrun, slægingu og pökkun getur ofurkæling jafnframt skapað tækifæri fyrir áframvinnslu; flökun, reykingu, bitaskurð o.s.frv. til að bæta sína framleiðslu með aukinni nýtingu og verðmætum ásamt ánægðari viðskiptavinum. Meðal annars gefur ofurkæling möguleika á að flytja kælimiðilinn inn í fiskholdið í stað þess að nota ís við flutning. Í verkefninu var gerður samanburður á kælikeðju ofurkælds lax og hefðbundins. Sá fyrrnefndi var fluttur án íss en sá hefðbundni með ís, til áframvinnslu í Finnlandi og Noregi. Einnig var slíkur samanburður gerður á ofurkældum og hefðbundnum laxi sem fluttur var annarsvegar til Íslands í gegnum Osló og hinsvegar til Tokyo í gegnum Osló. Niðurstöður gefa tilefni til bjartsýni um notkun ofurkælingar í flutningakeðju á laxi, bæði til að lækka flutningskostnað og eins til að tryggja gæði afurða.		
Lykilorð á íslensku:	*Ferskur lax, kælikeðja, ofurkæling, kælimiðill*		
Summary in English:	The ultimate goals of the project was to increase quality of fresh salmon products, give a more secure cold chain of fresh product, and lower production and logistic costs. Having the fish in a sub-chilled state throughout the production, will give Grieg Seafood several quality advantage including firmer raw material and lower bacteria and enzyme activity in the fresh fish. Fish was packed in a sub-chilled state of -1.5 °C, hence extending shelf-life and quality. This will have several advantages for the primary producer, resulting in products with higher yield and more value, and in products of higher quality for their customer of secondary processing. Secondary processors will have better control of the product logistic and extended time for selling fresh product with longer shelf-life. Using the sub-chilling method, no ice will be needed during logistic, saving enormous transportation costs, especially in airfreight. Comparison between the cold-chain of sub-chilled and traditional produced salmon was executed in this project, with the former transported without additional ice. The salmon was trucked from Simanes to a secondary processors in Finland and Denmark with excellent result. The two groups were also flown to Iceland, via Oslo, and also to Tokyo via truck to Oslo. The result of this comparisons demonstrates that the sub-chilling method could be used to minimize transportation cost and secure the product quality during logistics.		
English keywords:	*Fresh salmon, cold chain, sub-chilling, chilling method*		

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1 INTRODUCTION

The ultimate goals of the project was to increase quality of fresh products, give more secure in the cold chain of fresh product, and lower production and logistic costs. Having the fish in a sub-chilled state throughout the production, will give producers several quality advantage including firmer raw material and lower bacteria and enzyme activity. Fish will be packed in a sub-chilled state of -1.5 °C, hence extending self-life and quality. This will have several advantages for the primary producer, resulting in products with higher yield and of better value, and in products of higher quality for their customer of secondary processing. Secondary processor will have better control of the product logistic and extended time for selling fresh product with longer self-life.

The project intended to address the problem of fluctuation and uncontrolled temperature in fresh salmon processing, from slaughtering to secondary producers and the market, by developing a new technology based on the sub-chilling concept ready for industrial implementation. The existing processing flow in Grieg Seafood (Simanes slaughtering production) was mapped, with emphasis on recording the temperature in the production cold chain. This recording or logging of the temperature revealed the weak spots in the Simanes production and opened the opportunity for improvements to deliver top quality product. The logistic cold chain was mapped by using temperature loggers recurrent to existing markets, secondary processors in Europe (trucking) and to customers in Asia and Iceland (airfreight). This data will be used to build up information on the logistic for Simanes production. Logistic in tubs instead of ESP boxes was measured. ESP boxes are expensive and environmental unfriendly compared to larger tubs. Usage of tubs to regular customers was investigated using sub-chill technique.

2 METHODOLOGY

2.1 Sub-chilling of salmon

In order to sub-chill the salmon directly after slaughtering (headed and gutted), 1,000 L tubs from Promens was used equipped with a centrifugal pump to recycle the chilled brine (Figure 1).

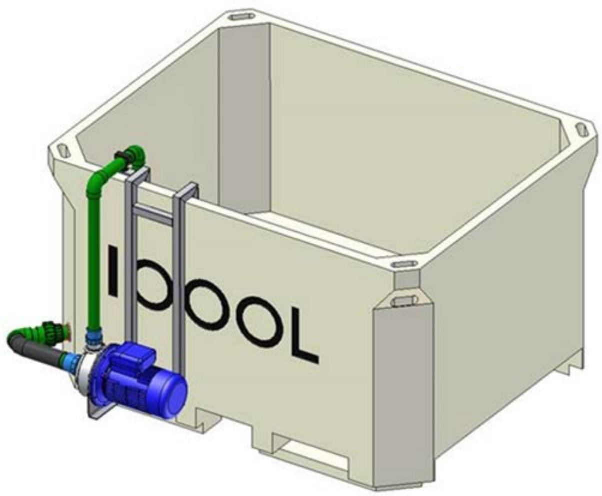

Figure 1 Schematic figure of the sub-chilling tub equipped with a centrifugal pump to recycle the chilled brine.

2.2 Temperature monitoring

Testo 176 Datenlogger thermometer from Testo, (Figure 2) was used to record the chilling process of the salmon. The thermometer has four sensors to measure temperature and time during the process. A bracket was built to hold the sensors at the right positions, under the fish skin, 15 mm deep and at the core of the fish.

Figure 2 Salmon with temperature sensors plugged.

IButton temperature loggers (DS1922L) from Maxim Integrated Products (Figure 3) were used for monitoring temperature in the trials. These loggers have an accuracy of ±0.5 °C, a resolution of 0.0625 °C and an operating range of -40 to 85 °C. The diameter is 17 mm and the thickness is 5 mm. All temperature loggers were factory calibrated and re-calibrated in thick mixture of fresh crushed ice and water. These temperature loggers were placed within the product, and on the outside of the boxes to monitor the ambient temperature.

Figure 3. A) IButton DS1922L temperature loggers used to monitor the temperature within the product and the ambient temperature. B) Tempsen ITAG-PDF single use temperature logger used to monitor the temperature of product and the ambient temperature.

Tempsen ITAG –PDF temperature data loggers were used to monitor the temperature of product and the ambient temperature (Figure 4). These loggers can collect data temperature for periods of 15 days and 25 days. The ITAG-PDF is ideal for temperature monitoring of long distance transportation. The measurement range is -30°C~70°C with the accuracy range ±0.3°C. The temperature resolution is 0.1 °C/°F and the data storage capacity is 3800 readings.

2.3 Quality evaluation

Quality tests on sub-chilled product and traditional product were carried out. Salmon from same production at Simanes was used as samples in the project. During processing a part of it was packed as traditional in normal EPS boxes or tubs, and iced on a traditional way. From the same sequence of production a part of it was sub-chilled and packed in EPS boxes (Airfreight type with no drip-holes) or tubs. This two groups were compared in several quality tests.

2.3.1 Determination of microorganism

Total viable psychrotrophic counts (TVC) were performed on iron agar (IA) as described by Gram *et al.* (1987). Counts of H_2S producing bacteria were evaluated on IA. Plates were spread-plated and incubated at 17 °C for 5 days. Counts of all colonies (both white and black) on IA gave the number of total count and counts of black colonies gave the number of H_2S producing bacteria.

2.3.2 Proximate analysis

Water content was determined by difference in weight of the homogenized muscle samples before and after drying for 4 h at 102 °C to 104 °C (ISO 1993). Results were calculated as g water/100 g muscle.

Total lipids (TL) were extracted from 25 g samples (80±1% water) with methanol/chloroform/0.88% $KCl_{(aq)}$ (at 1/1/0.5; v/v/v) according to the Bligh & Dyer (1959) method. The lipid content was determined gravimetrically and the results were expressed as grams lipid per 100 g wet muscle.

2.3.3 Free fatty acids

Free fatty acid content (FFA) was determined on the TL extract according to Lowry & Tinsley (1976), with modification from Bernardez *et al.* (2005). The FFA concentration was calculated as µmolar quantities of oleic acid based on standard curve spanning 2-22 µmol range. Results were expressed as grams FFA / 100 g of total lipids

2.3.4 Cooking yield

For evaluation of cooking yield, each fillet (n=3) was cut in approx. 50 g pieces. Cooking yield was determined by steam cooking the pieces at 95°C to 100°C for 8 min in a Convostar oven (Convotherm, Elektrogeräte GmbH, Eglfing, Germany). After the cooking period, the pieces were cooled down to room temperature (25 °C) for 15 min before weighing for cooking yield determination. The yield after cooking (%) was calculated as the weight of the cooked pieces in contrast with the weight before cooking.

2.3.5 Fillet quality test

The quality test measuring softness, elastics and gaping were built on instruction from Fishery and Aquaculture Industry research Fund (Appendix I) using following grade:

1. Inelasticity (0-2)
2. Softness during finger test (0-2)
3. Gaping in loin, belly and tail (0-5)

With zero the best quality.

3 RESEARCH PROJECTS

Two main researches were carried in this project. The first trial was conducted in January 2015 in cooperation with Grieg Seafood (primary processor), Hätälä (secondary processor) and Saihoku Fisheries Corp in Japan (secondary processor). The second trial was conducted in cooperation with Grieg Seafood and Hätälä in March 2015. Additionally, samples of salmon fillets were sent to Iceland for chemical and sensory analysis. The two trials and analysis in Iceland are described in following sub-chapters along with their main outcomes.

3.1 Research at Grieg Seafood in January 2015

The first research was carried out in January 2015. The sub-chilled salmon was chilled in -5 °C brine for over two hours or until the core temperature reached -1.5 °C. The sub-chilled salmon was then packet in EPS box without ice. The traditional product was however packed in EPS boxes with approximately 5 kg of ice on top (current practices). Three boxes of sub-chilled salmon products from Grieg Seafood, around 25 kg, were sent to Hätälä in Finland and to Saihoku Fisheries in Japan and three boxes of traditional product was taken from the same raw material to use as a control samples.

Figure 4 Testor logger sensors placed in a salmon

The temperature of the Grieg Seafood (Simanes) cold room was monitored (Figure 5). The results reviled a great temperature fluctuation within the cold room, but stable temperature is crucial during production of fresh fish. Moreover, the temperature of the sea was also monitored over one year and are the results displayed in Figure 6.

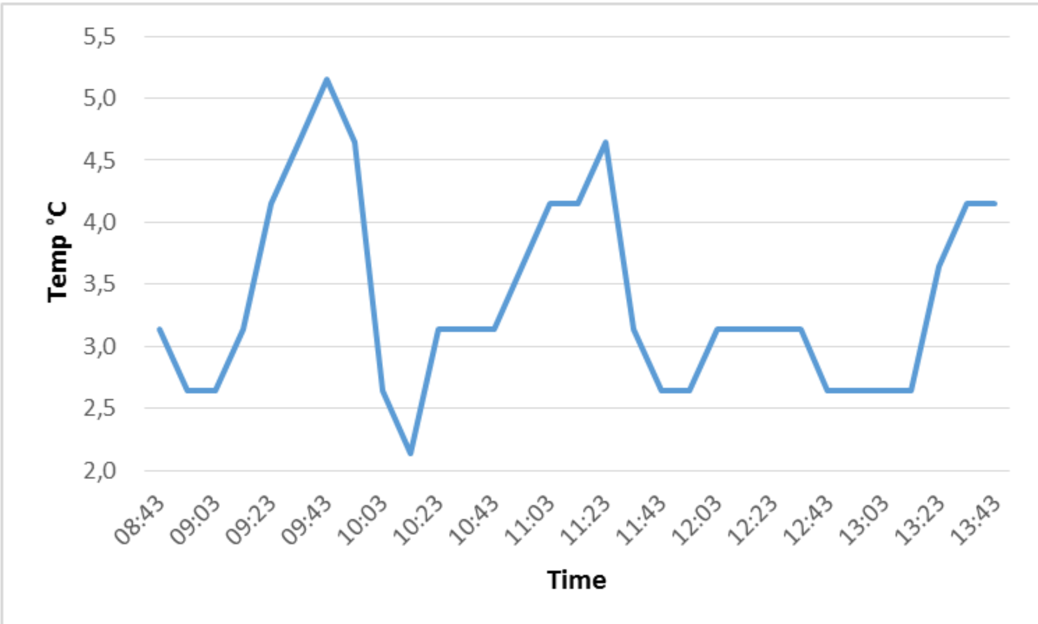

Figure 5 Temperature profile of Grieg Seafood Simanes factory cold room.

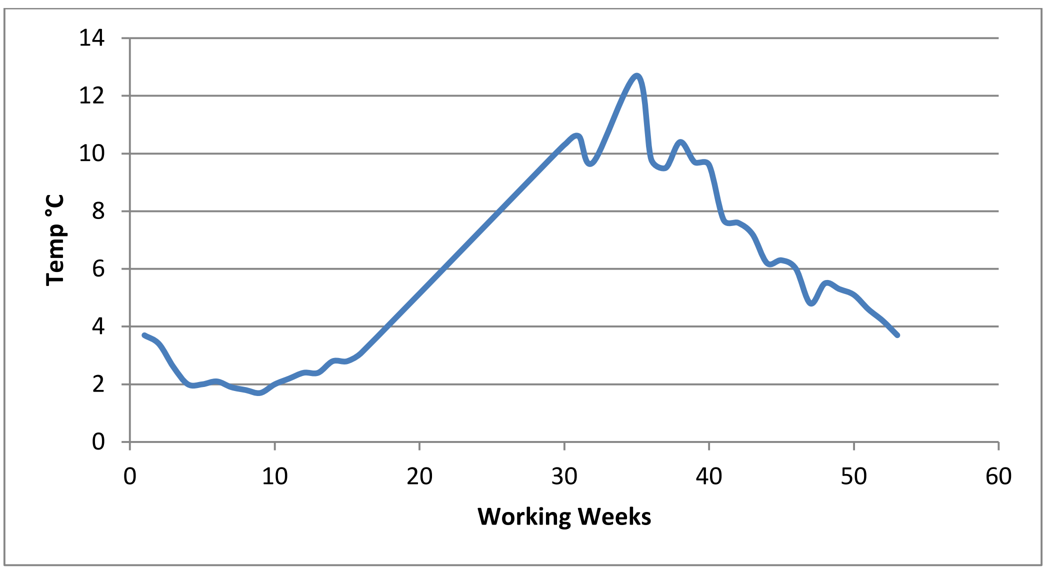

Figure 6 Sea temperature at Simanes around the year from 2014 to 2015.

During the first chilling process, two 460 L tubs were used and manual circulation of the brine. The process took around one hour to cool down the fish core temperature from +4 °C down to

0 °C, but another hour to cool it further down to -1 °C. Some difference was however observed between different location depths of the muscle (core of the fish vs. 15 mm from the surface; Figure 7). The time to cool down to -1 °C took over two hours, which was longer time than was expected. The reason is properly because of low ΔT lacking circulation in the brine during chilling. It was therefore decided to set up a chilling equipment for next trial, consisted of 1,000 L tubs with circulation pump to maximize the ΔT (Chapter 3.2). The process was identical for samples send to Olulu and to Tokyo.

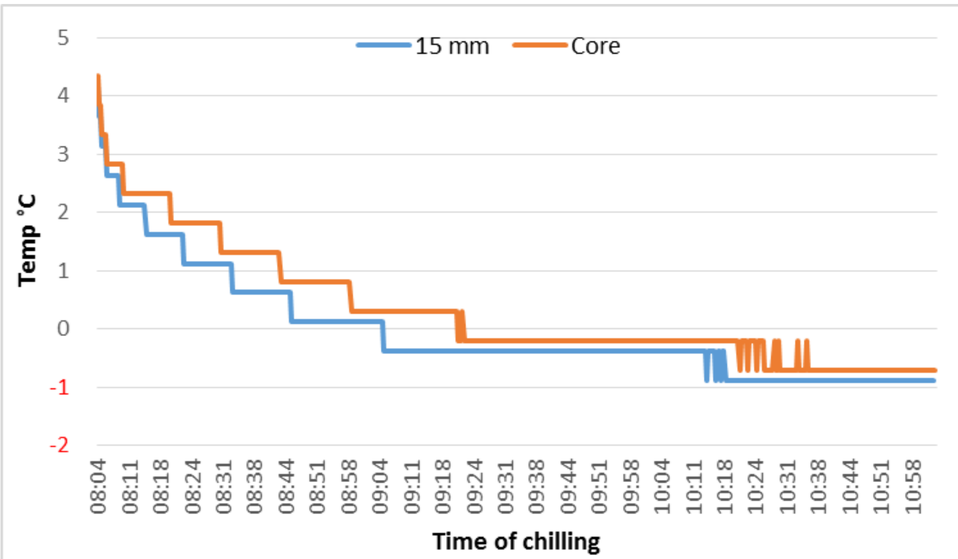

Figure 7 Temperature profile during sub-chilling of salmon logging of sub-chilling for Hätälä.

Temperature loggers were placed in each box, both within the salmon and outside the box to monitor the ambient temperature during transportation to Finland and Japan. The boxes were identified to be picked up at arrival in Olulu Finland and Tokyo Japan.

3.2 Research at Grieg Seafood and Hätälä in March 2015

In March 2015, a research was conducted at Grieg Seafood in cooperation with Hätälä in Finland (secondary processor). The aim of this research was to optimize the sub-chilling of newly slaughtered salmon at Grieg Seafood, monitor the transportation to Finland and evaluate the quality of the final product at arrival and during storage at Hätälä (Table 1) including texture, microbiological analysis and cooking yield. Salmon from current traditional process was at all time used as control for comparison.

Table 1 Research plan for sub-chilling trials of salmon at Grieg Seafood and Hätälä in March 2015.

Travelling days	15.mar	16.mar	17.mar	18.mar	19.mar	20.mar	21.mar	22.mar
Arraving in Alta								
Super-chillin								
Shipping out								
Sampling								
Travell to Hattala								
Research in Hattala								
Flying bach to Iceland								

At 17th of March, 4-6 kg salmon was sub-chilled in two 1,000 L tubs (Figure 1), to find out the optimal time, salinity and temperature for the process. During this process, temperature loggers were used to monitor the temperature changes. The aim was to get the core temperature of the fish as close to -1.5 °C as possible with minimum freezing of the fish surface. This temperature should secure that the ratio of frozen water within the fish muscle to be below 20%, but however guarantee sub-chilling of the salmon.

3.2.1 Product- and ambient temperature

Best results were found out by using -1 to 0 °C brine temperature for one hour, followed by two hours at -3 °C. Each tub was fillet up with 700 litre water using 35 kg of salt to give around 8% salinity. With good water circulation in the tubs, ice was poured in the brine until -1 to 0°C temperature was reached. In each tub, around 330 kg of 6 kg salmon were put into the brine, adding ice steadily to keep optimal brine temperature. More ice was poured in after one hour chilling or until -3 °C was reached and this temperature was maintained for the rest of the chilling process, for two more hours. The chilling process of sub-chilled salmon can be viewed in Figure 8. The starting temperature of the fish was +2 °C and reached approximately to 0 °C after one hour. For the next two hours, the core temperature of the fish reached almost -1 °C but that temperature was stabilized to -1.5 °C when the cooler temperature and the warmer core temperature synchronized.

The average temperature and time of the chilling process in both tubs, both in the brine and the core temperature of the product is demonstrated in Figure 8. The brine temperature starts at zero but is cooled rapidly down to -1 °C, and after one hour the temperature of the brine had dropped down below -3 °C.

In Figure 8, comparison between different muscle depths as well as of the brine is displayed. Regarding the fish muscle, temperature sensor were placed close to the core, medium (15mm) and under the skin. After two hours, the salmon was lifted out of the brine and stored in EPS boxes in a cold room.

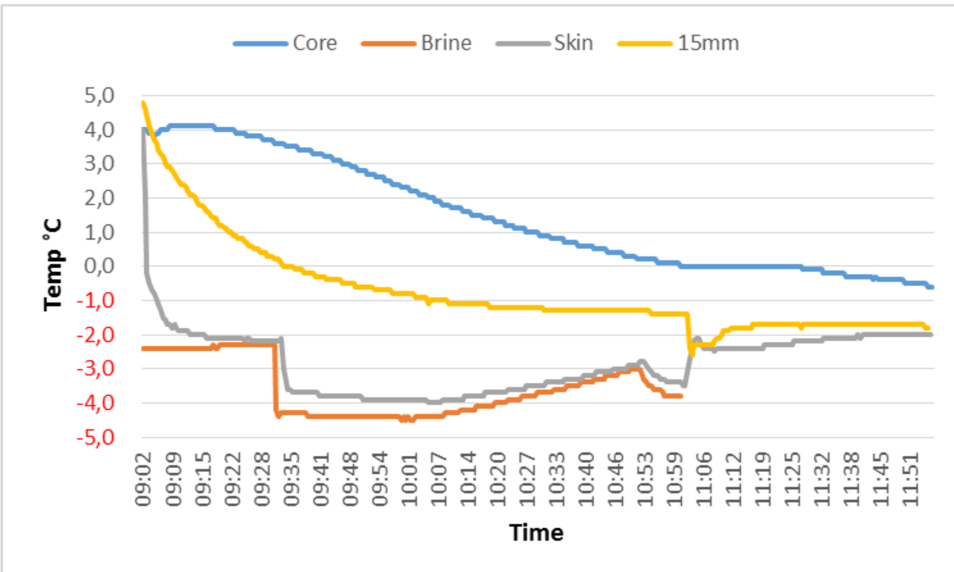

Figure 8 The sub-chilling process of salmon at Grieg Seafood (Hätälä product March17th). The temperature was monitored in the brine, in the core of the fish, at 15 mm depth into the muscle, right under the skin.

On the 17th of March, two samples of sub-chilled product and two of traditional product, were produced to be send to Hätälä factory in Olulu in Finland. The traditional product were packed in 460 L Promens tubs with 250 kg of salmon, according to Hätälä prescription; iced with 25 kg ice in the bottom and 25 kg on the top. Sub-chilled product were packed in 460 L Promens tub without any trace of ice (Figure 9). Samples of 4x18 kg of sub-chilled salmon were packed in 35 L EPS boxes with no ice and other 4x18 kg of traditional product packed with 5 kg of ice on top. In all tubs and boxes a temperature loggers were stored, as well as outside of tubs and EPS boxes to monitor any temperature fluctuation during transportation.

Figure 9 Sample send from Grieg Seafood in Norway to Hätälä in Finland

The core temperature profile of the sub-chilled product during the first four days after slaughtering at Grieg Seafood (Simanes) is shown in Figure 10. It took the fish around 30 hours to stabilize and reach the optimum temperature of -1.5 °C. The fish was quite stable at this prime temperature, both in the tub and in the EPS boxes.

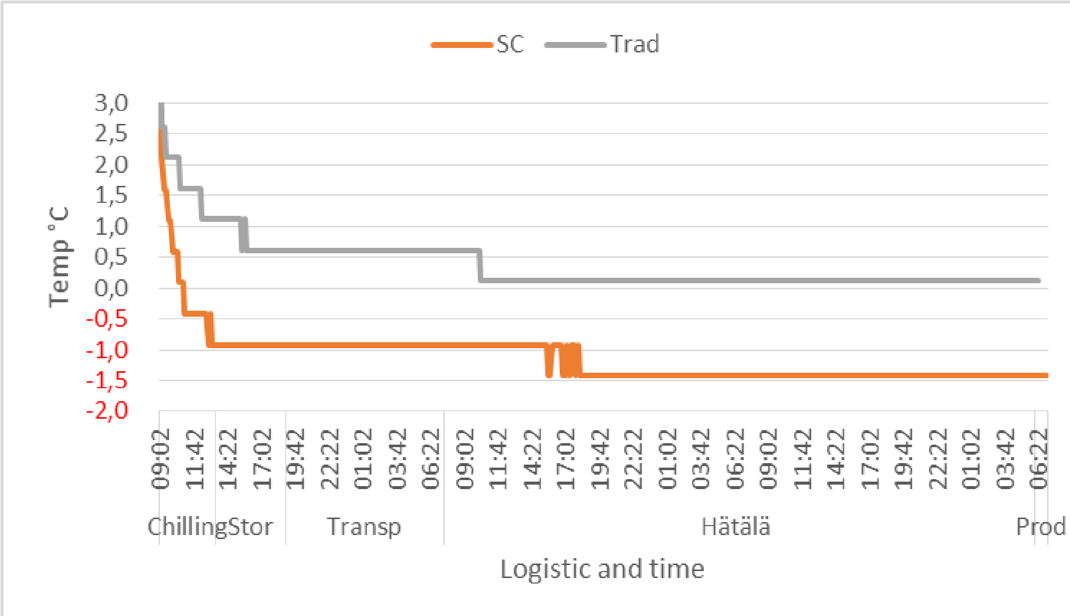

Figure 10 The temperature profile of four days for the fish core during the sub-chilling process and transportation from Grieg Seafood in Norway to Hätälä in Finland. (SC = sub-chilled salmon; Trad = traditional salmon).

In Figure 11, the ambient temperature is shown as well as within the sub-chilled and traditional product. It took almost 24 hours to cool down the traditional down to 0 °C, but the temperature was constant from that point forward. The salmon leaved Grieg Seafood cold room in the afternoon of March 17th with temp dropping to -2 °C by trucking to Olulu in Finland. After reaching the Hätälä cold room, the temperature fluctuated around 0.5 °C and up to +2 °C.

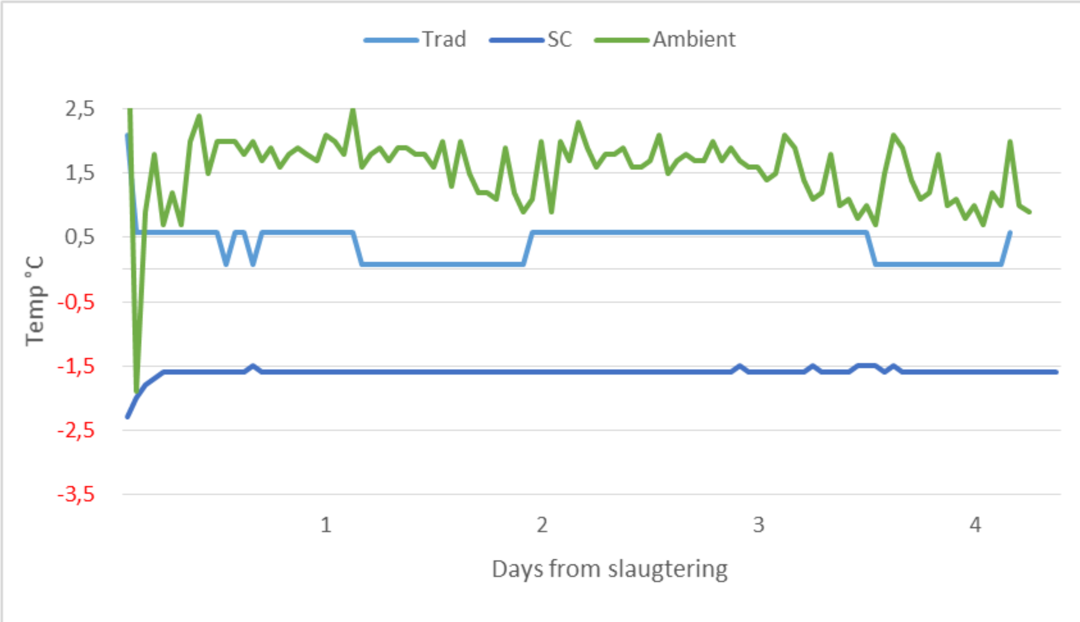

Figure 11 The temperature profile in Hätälä of sub chilled salmon (SC), traditional salmon (Trad) and the cold room (ambient). The temperature of the sub-chilled salmon is steady around -1.5 °C and the traditional salmon around 0 °C.

3.2.2 Research in Hätälä

Several quality evaluation tests were performed on the product when it arrived to Hätälä. The main purpose of these research was to compare quality of sub-chilled product with traditional product and measure the difference in product shelf-life and quality. Samples of sub-chilled and traditional salmon fillets were collected after 2, 6, 10, 16 and 21 day of storage for evaluation of temperature, rigor mortis status, bacteria (total count and spoilage bacteria), inelasticity, softness, gaping and cooking yield. The samples intended for microbiological analysis were sent to the OUKA Laboratory in Olulu.

3.2.2.1 Quality evaluation

The quality of the traditional salmon trucked in 460 L tubs were compared with sub-chilled salmon. The temperature in the sub-chilled product was -1.5 °C with no evident of freezing. The temperature of the traditional product was at 0 °C, but the flesh had heavy marks by ice cubes on the surface on fish located at the bottom of the tub. Figure 12 shows the different in appearance between the two experimental groups.

Figure 12 The different in appearance between sub-chilled fish transported with no ice and traditional fish transported with ice. The upper two fishes were from the traditional process, transported in tubs with ice. The lower two fishes were from the sub-chilled process, transported in tubs without ice.

On March 20th the fish from the tubs were processed through the processing line in Hätälä. Firstly headed in Baader 434 heading machine, and then filleted in Baader 581 filleting machine. The fillets were trimmed in Baader 899 trimming machine where belly flaps were removed followed by automatic the pin-bones removal. The sub-chilled fillets, which were still in rigor, went smoothly through the pin-bone remover with excellent result. On day three from slaughtering, the pin-bones were easily removed by the machine, clean with no flesh sticking to the bones. After the pin-bones removal, the fillets went then through Kaj Olesen cutting machine and at lastly through packing and weighing. The temperature of the fillets after this process was around 1-2 °C in the traditional fillets but -1.5 °C in the sub-chilled fillets. The traditional fillets were of a good quality but the sub-chilled exceeded in all fields of comparisons. The fillets were stiff and quite homogenous in quality, while some of the traditional fillets had soft texture and gaping (Figure 13).

Figure 13 Traditional fillet to left and sub-chilled fillet on the right; notice the pin-bones on the top of the fillets as well as difference in gaping of the muscles.

Figure 14 Evaluation of rigor mortis of the sub-chilled fillet, holes after removed pin-bones can be seen.

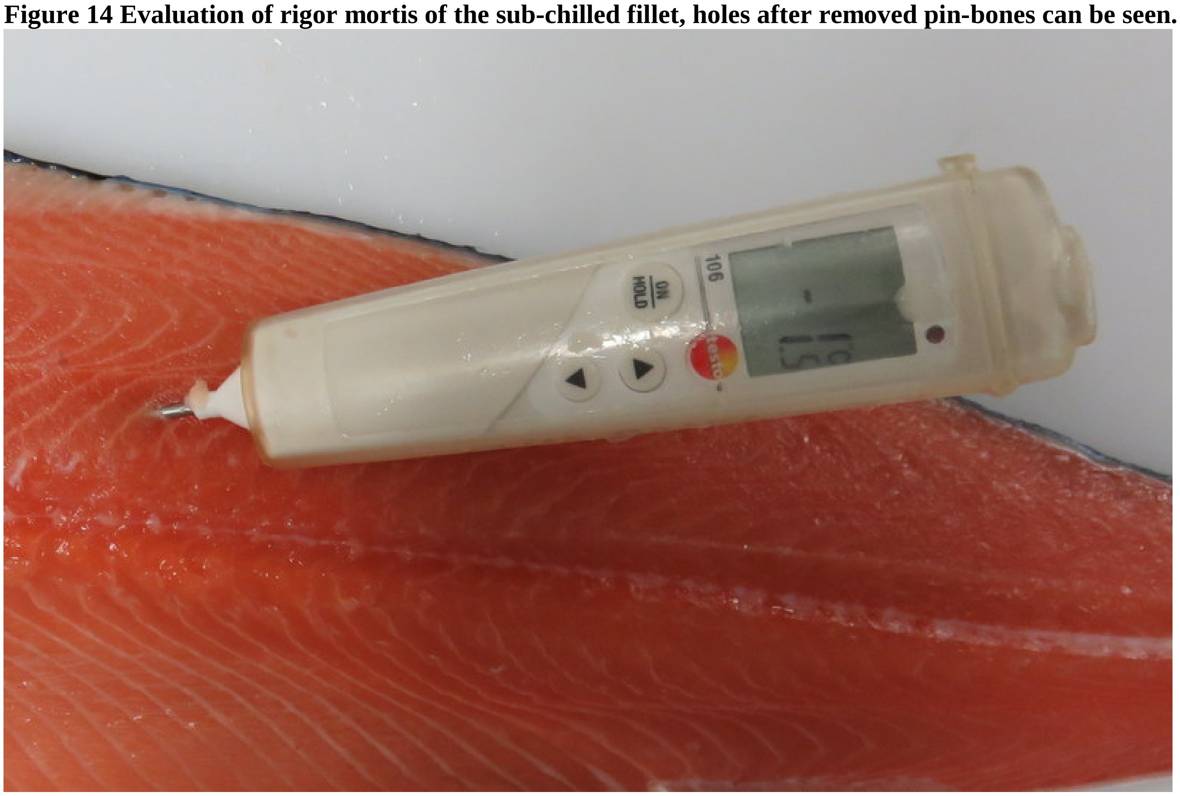

Figure 15 Sub-chilled fillets ready in packing for sub-chill market; the temperature was -1.5 °C

The processing yield of the two different experimental groups was evaluated on 10 fishes from each group (around 60 kg). The sub-chilled products showed slightly lower yield compared to the traditional product. The difference in yield can be explained by the difficulties in heading the sub-chilled product, but it was still in a heavy rigor and rather stiff when headed. When fillet yield with head was calculated the same yield turned out in both groups, with bone yield of 12.4% in sub-chill and 12.3% in traditional. Investigating the spinal bones there was no difference in flesh left on the skeleton. The filleting machine operator explained that the force on the filleting knives were at 5-6 bars, but maybe there is a need to extend that force when filleting sub-chilled salmon, because it is more firm and need to push the knives harder to the skeleton.

The quality difference between the sub-chilled and traditional fillets throughout the storage period can be viewed in Table 2, Figure 14 and Figure 15. The difference between the two experimental groups was substantial. The sub-chilled fillets were at all time of higher quality compared to the traditional fillets, even though the quality of the traditional fillets was considered good. The sub-chilled fillets were considered perfectly firm and extremely wholesome.

Table 2 Quality evaluation of sub-chilled and traditional fillets during cold storage.

Days from production	Sample	Temp °C		Quality			Rigor mortis status	Pin-bone removal	Ambient temp in cooler (°C)
		Loin	Tail	Softness	Inelasticity	Gaping			
2	Sub-chill	-1.5	-1.5	0	0	0	+	+	1.2
	Trad	0	0	1	1	2	+	+	1.2
6	Sub-chill	-1.5	-1.1	0	0	0	+	+	1.2
	Trad	0.5	0.5	3	3	3	-	+	1.2
10	Sub-chill	-1.5	-1.5	0	0	0	-	+	1.3
	Trad	1	1	1	1	3	-	+	1.3
16	Sub-chill	-1.5	-1.1	0	0	0	-	+	1.2
	Trad	0.5	0.5	3	3	3	-	+	1.2
21	Sub-chill	-0.5	1.6	0	0	0	-	+	1.3
	Trad	1.4	2	3	3	5	-	+	1.3

Microorganism is one of the main factor that limits products shelf life. The microbiological status of the fillets was also analysed throughout the storage period of 21 days. Both total bacteria count and H_2S producing bacteria (black colonies) were determined with Iron agar (Figure 16 and Figure 17, respectively). Bacteria forming black colonies on this agar produce H_2S and are considered the main damage bacteria in fish. One of the main damage bacteria in chilled fish, *Shewanella putrefaciens*, forms black colonies on this agar. No difference was observed between experimental groups (sub-chilled vs. traditional) the first 10 days of storage. After 16 days of storage, a significant difference between the groups was observed and gained with extended storage time. After 21 day of cold storage (final sampling day), the traditional fillets were well above log 7 in total bacteria count which is considered a limit for human consumption, while the sub-chilled fillets were at approximately log 6. Similar findings were observed with regard to the H_2S producing bacteria. At the end of the storage period, the sub-chilled fillets showed significantly lower amount of black colonies compared to the traditional fillets.

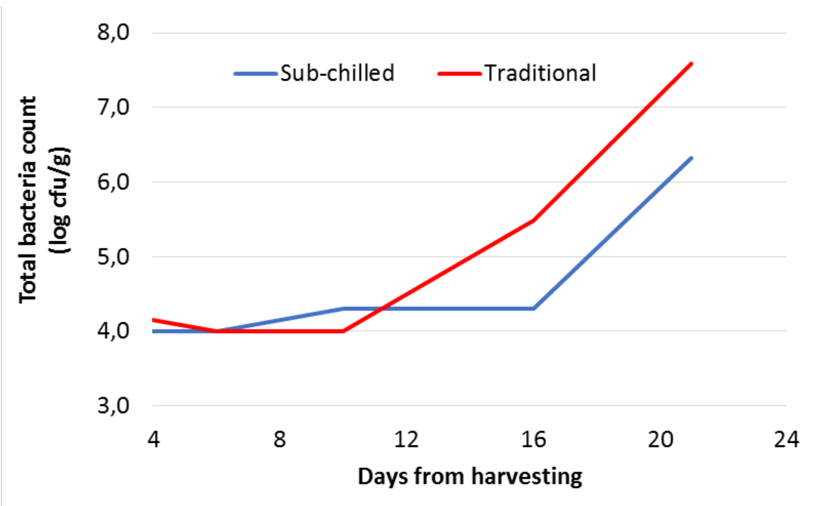

Figure 16 Total bacterial count (log cfu/g muscle) in sub-chilled and traditional salmon fillets during cold storage for up to 21 day.

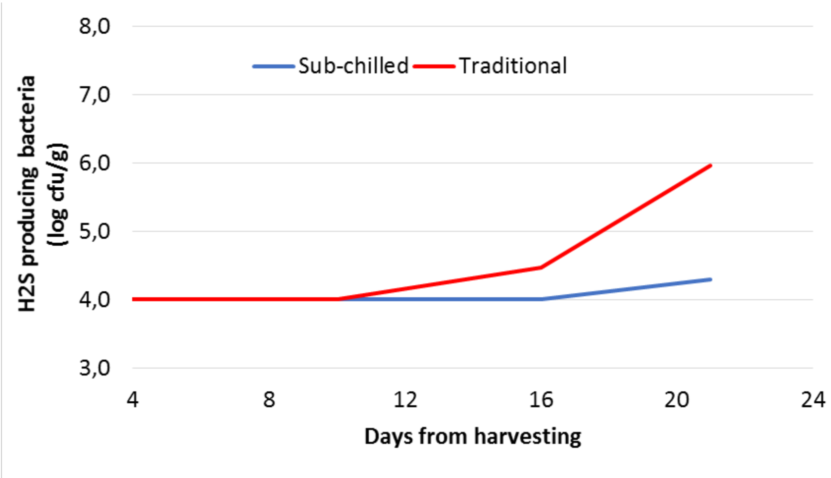

Figure 17 H_2S producing bacteria (black colonies; log cfu/g muscle) in sub-chilled and traditional salmon fillets during cold storage for up to 21 day.

One of the most important quality parameter is cooking yield. The cooking yield is measured to demonstrate if the salmon muscle can hold its natural juice through cooking, which can e.g. give indication if any muscle damage occurred by crystallization in sub-chilling process. During slow freezing, large crystals can damage muscle cells within causing the protein to leak natural water, and also causing more leaking when the product is cooked. Sub-chilled salmon was compared with traditional product and the result can be seen in Figure 18. No difference was observed between experimental groups (sub-chilled vs. traditional) the first 10 days of storage. After 16 days of storage, a significant difference between the groups was observed and gained with extended storage time.

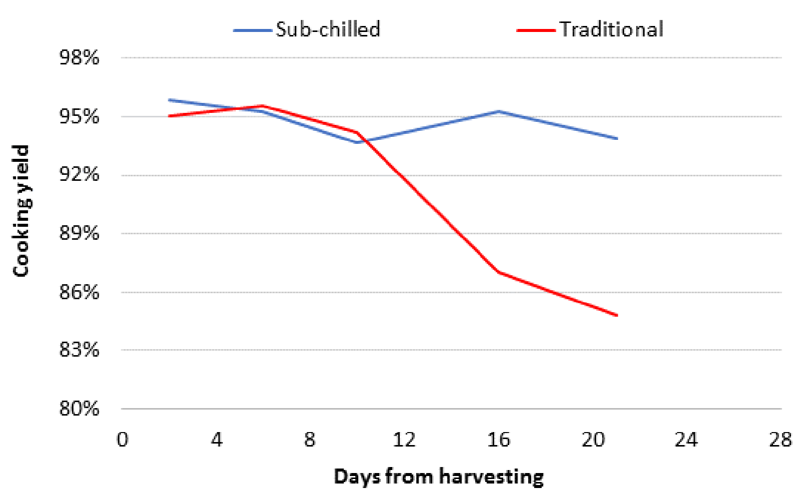

Figure 18 Cooking yield (%) of sub-chilled and traditional salmon fillets during cold storage for up to 21 day.

3.3 Samples sent to Iceland

Samples of salmon fillets were sent to Iceland for some chemical and sensory analysis. The purpose was to gain more understanding about the raw material, the effect of bleeding procedures and explore the effects of sub-chilling on consumers' experience.

In January 2015, samples of salmon fillets and bleeding water from Grieg Seafood were sent to Matis laboratory in Iceland. The salmon fillets were analysed with regard to proximate composition (water and fat content). The fillets were divided in different parts, loin, middle and tail, and each part analysed separately (Figure 19). The difference between different parts of the fillets was quite noticeable. Just over 55% of water was in the loin but around 58% in the middle and almost 70% in the tail. Corresponding values for fat content were 24%, 21% and 6% respectively. These information are very important and have to be considered when a sub-chilling process is designed, since the water- and fat content determine how low the temperature can be in the process.

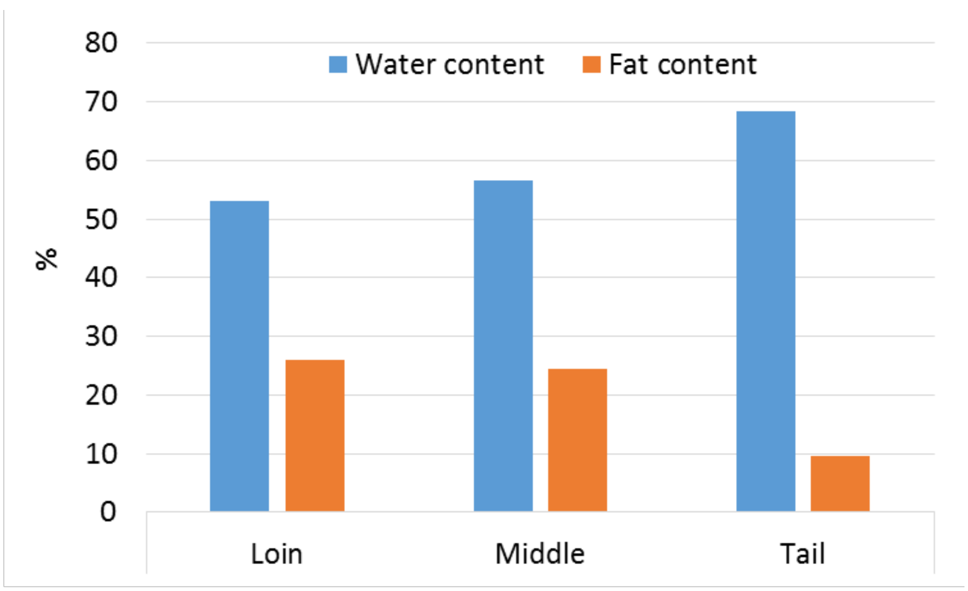

Figure 19 Fat- and water content in different parts of salmon fillets.

The samples of the bleeding water were collected in the morning of a production day and in the afternoon. During the production day, there is no circulation in bleeding water and it is therefore heavily contaminated at the end of the production day (Figure 20). At the end of the day the bleeding water and it is heavily contaminated of blood at the end of the production day. The water is pumped through filters in to tanks where it is treated with natriumhypochlorit and formic acid under control until it reach given measurements and then it is pumped to the sea. Bleeding fish in such water conditions as shown on Figure 20 can affect the quality and shelf life of the fish considerably.

Figure 20 Bleeding water in the production line at Simanes (Grieg Seafood) at the end of processing day

The collected samples of bleeding water were analyzed with regard to enzymatic activity or free fatty acids (FFA). Blood contains generally high amount of enzymes but enzymes can have several negative effects on the fish quality and storage stability. The difference between bleeding water collected in the morning and in the afternoon was significant, where the morning water had much lower FFA value compared to the afternoon water (Figure 21). These results demonstrate that using the same water (no circulation) throughout the production day can have considerable effect on the product quality.

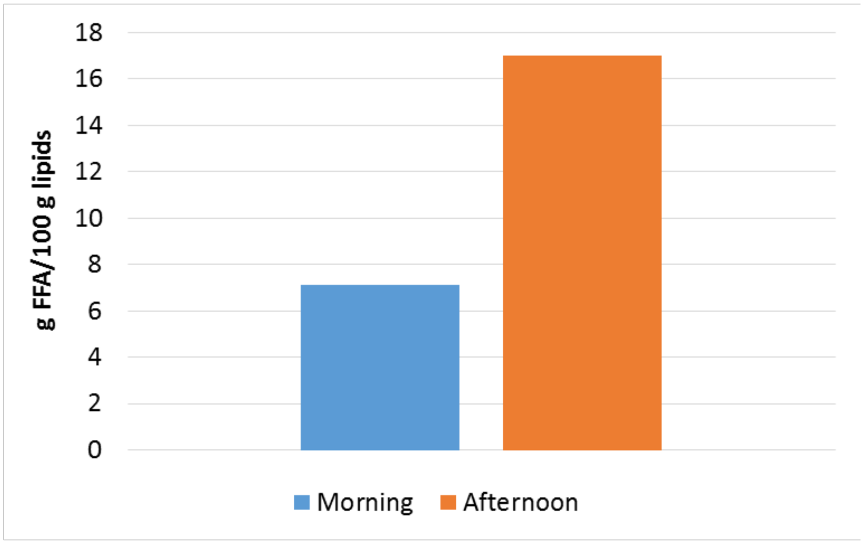

Figure 21 Free fatty acid content (g FFA/ 100g lipid) in bleeding water collected in the morning and in the afternoon of a production day.

On April 17th 2015, two EPS boxes, one sub-chilled and one traditional produced salmon, with around 20 kg each, were sent from Simanes factory (Grieg Seafood) to Matis in Iceland. The salmon was slaughtered the day before and sent by SAS via Oslo and with Icelandair to Keflavik. TempScan loggers were stored inside and outside of the boxes to monitor any temperature fluctuations. The boxes were then stored in Matis cold room at -1.5 °C for seven days, and then moved to +0.5 °C and stored there until the end of storage at day 21 (Figure 22).

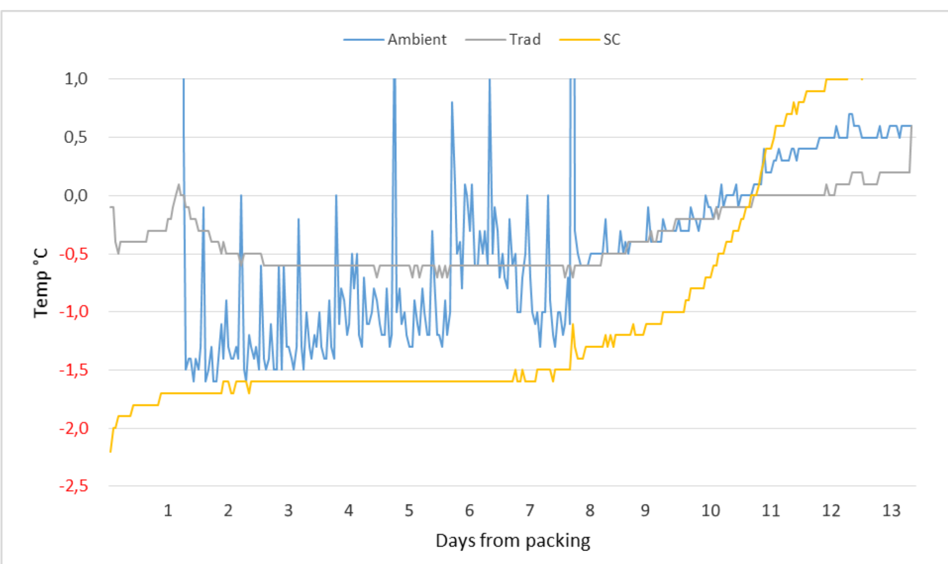

Figure 22 Temperature profile from the boxes during transportation from Norway to Iceland and Matis cold room. (SC = Sub-chilled salmon; Trad = Salmon from traditional processing).

Samples were collected from each experimental group were performed 8, 14 and 21 day post slaughtering. On each sampling day the salmon was filleted and broiled, and the right side fillet oven-cooked in Matis kitchen by a professional chef, for 10 min at 180 °C. The fish was then tasted by four experienced sensory panellists which then gave comments about the overall experience. The evaluation was blind test, meaning that the panellists didn't know which sample was what. All four judges favoured the sub-chilled product beyond the traditional at all sampling points. The sub-chilled salmon was defined to have better texture strength (less mushy), tasted better and retained better natural flavours. The traditional fish was a bit drier, but still at a very good quality, but had definitely lost more of its natural juice and flavour.

4 LOGISTICS TRIALS

Temperature profiles were monitored in the logistic chain of Grieg Seafood factory in Simanes; from production to logistic chain by transport to Japan, Iceland, Finland and southern Europe. In general, the time for trucking salmon from Simanes to Oslo was around 2-3 days. Then shipping to Denmark from Oslo took around one day and two days to France. Direct shipment from Simanes to Sweden, Denmark and France is around 2, 3 and 5 days respectively.

4.1 Production

The time and temperature during production was monitored and recorded in the Grieg Seafood Simanes factory during winter- and summer time in order to map the seasonal effects on temperature if any (Figure 23). The temperature at Simanes cold room fluctuated from 2 °C to 5 °C, with average temperature of 3.3 °C.

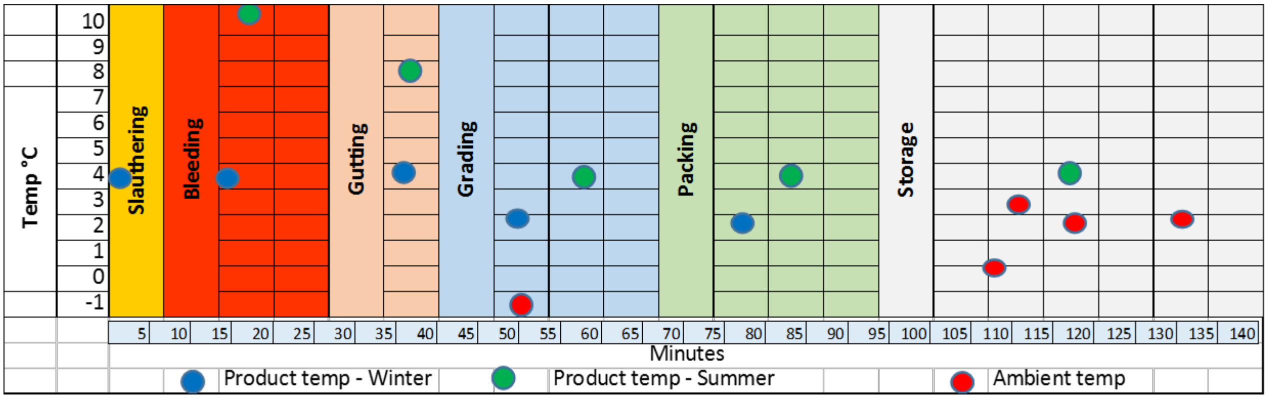

Figure 23 Time and temperature during production in the Grieg Seafood Simanes factory during winter and summer time. Additionally, the temperature in the cold room was monitored from 15th of January to February 6th 2015.

4.2 Logistic to Hätälä in Finland

Temperature fluctuation during trucking and storing of raw material sent to Hätälä, secondary processor in Finland from Simanes in Norway, was mapped during summer and winter. The ambient temperature fluctuation was from 2.5 °C down to 0.6 °C. The product temperature in sub-chilled salmon was from -0.9°C down to -1.1°C and the traditional product was just above 0°C. (Figure 24). Traditional product (surface of product) followed the ambient temperature, cooling down below zero during trucking. The sub-chilled product (surface of product) goes down below -3 °C but it evens out around -1.7 °C.

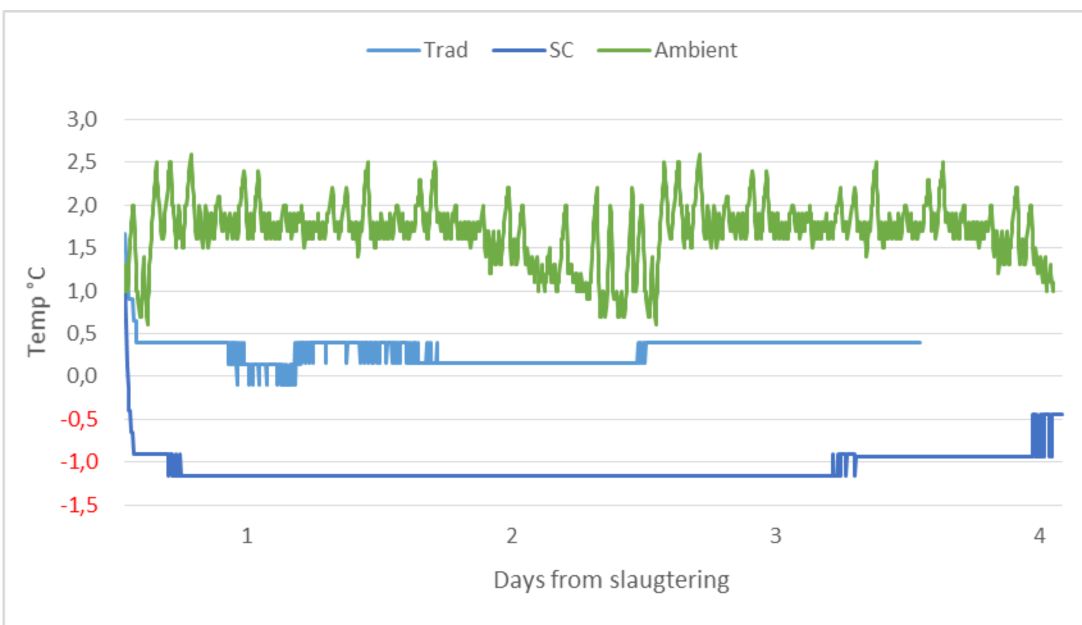

Figure 24 Ambient temperature profile during transportation from Simanes to Hätälä

4.3 Logistic to Japan

Two EPS boxes of sub-chilled and two of traditional salmon were sent to Tokyo by truck via Oslo and airfreight to the final destination. The ambient temperature went down to -4 °C during the trucking, but ranged from 2 °C to -1.5 °C in the airplane. After four days, the product arrived to Saihoku Fisheries Corporation in Tokyo. In Figure 25 the ambient temperature and surface temperature of sub-chilled and traditional product is showed. The low temperature of the sub-chilled salmon can be explained by difference between core and skin temperature after chilling, taking more than a day to stabilize to around -2°C.

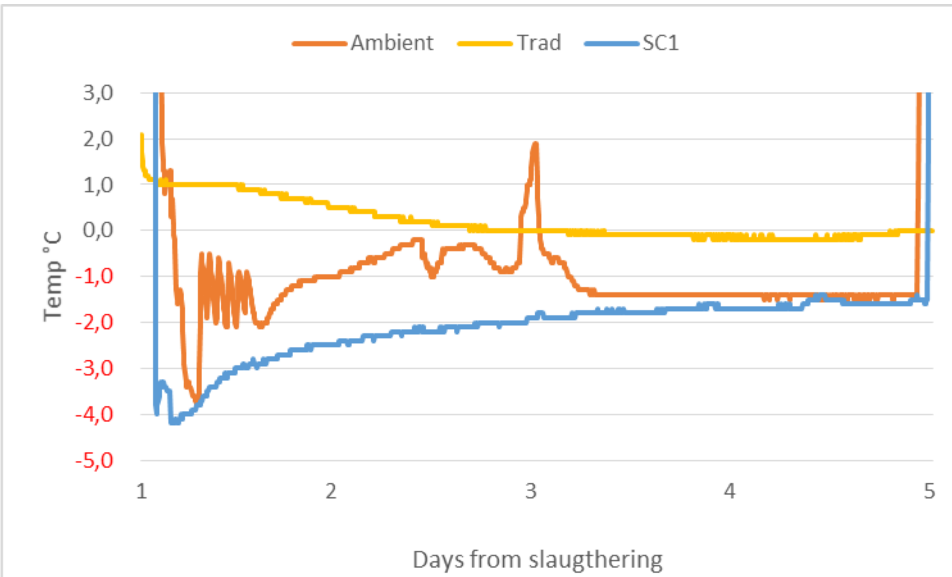

Figure 25 Temperature profiles of sub-chilled salmon (SC1), traditional salmon (Trad) and ambient conditions during transportation from Simanes in Norway to logging on SC and traditional product and the ambient temp during transport to Saihoku Fisheries Corporation in Tokyo.

4.4 Logistic to Norway Seafood in Denmark

Two 460 L Promens tubs, with sub-chilled products and traditional products were sent to Norway Seafood in Grenaa in Denmark in April 2015. The ambient temperature fluctuated from approximately 4 °C down to 1 °C during the transportation (Figure 26). The temperature of the sub-chilled product was however quite stable, or around -1.5 °C. Unfortunately, the temperature records of the traditional product are missing, but according to manual reading its temperature during transportation was close to 0 °C.

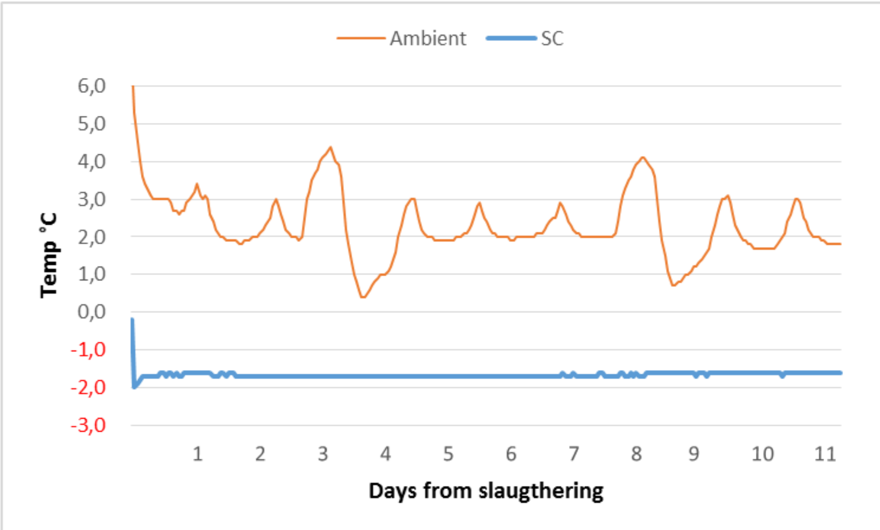

Figure 26 Temperature profiles of sub-chilled salmon (SC) and ambient conditions during transportation from Simanes in Norway to Norway Seafood in Denmark by truck.

In October 2015, temperature loggers were sent with a refrigerated truck load of salmon from Simanes to Norway Seafood in Grenaa in Denmark. The salmon was loaded on a truck at Thursday afternoon on day one, and arrived to Norway Seafood facility on day four (Figure 27).

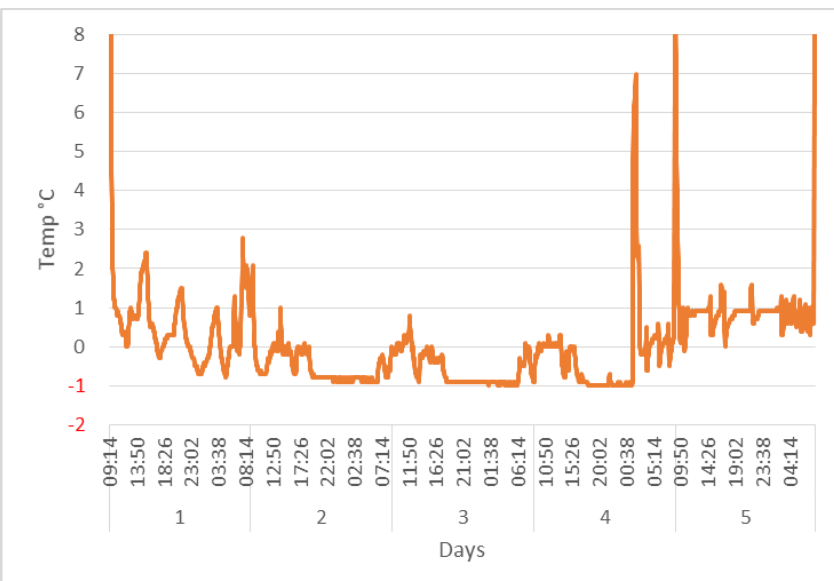

Figure 27 Ambient temperature within the refrigerated truck during salmon shipment from Simanes in Norway to Norway Seafood in Denmark.

4.5 Logistic to Italy

Temperature fluctuation during transportation of salmon from Simnaes in Norway to Italy 14th of March 2015 was monitored (Figure 28). As demonstrated on Figure 28, the temperature during trucking from Norway to Italy was rather stable the whole time. The temperature of the product was around 0 °C throughout the transportation.

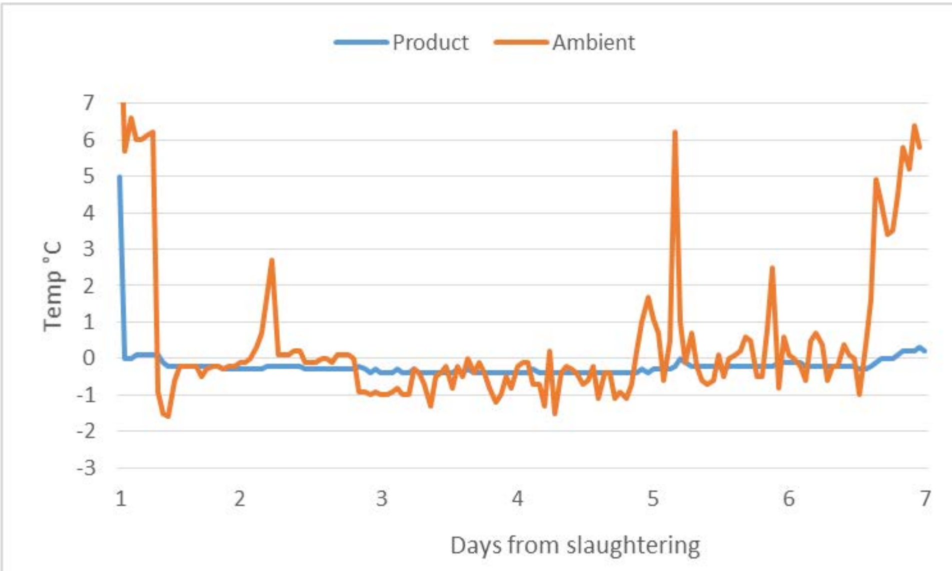

Figure 28 Temperature profile within the product as well of the ambient condition during transportation from Norway to Italy.

5 RESULTS SUMMARY AND DISCUSSION

5.1 Temperature measurements

The fluctuation of temperature in the Simanes cold room is of some concern, but fluctuation from 2 °C up to over 5 °C were recorded few times a day. Though it has to be kept in mind that products are only stored there for a short time, maximum one production day, and all products are stored in EPS boxes and iced. The addition of ice secures product temperature close to 0 °C and will easily last through one day at this condition. Never the less, a steady low temperature, close to 2 °C would be better to secure good quality.

The sea temperature fluctuated from under 2 °C up to 13 °C throughout the year, with the warmest time around week 35. No pre-chilling of salmon is conducted before the slaughtering and bleeding process, and with inadequate chilling in the processing line, the temperature of the product fluctuate greatly throughout the process. Up to 6 °C difference is in the bleeding process due to seasonal conditions (summer – winter), 4 °C in gutting and 2 °C during grading and packing. The chilling was generally inadequate in the process line giving to high temperature through the production, with temperature in product after packing in storage at up to 4 °C during summertime. It took over five hours for the product to cool down from +3 °C down to 0 °C.

Temperature is one of the most important factor on quality of a fish, general quality of the final product and its shelf life through the logistic to the consumer. The sub-chilled salmon was chilled from +3 °C, after grading, down to 0 °C within an hour, and down to -1 °C in just over two hours. This time could be reduced if the product temperature was close to 0 °C during the production. Tests were done to sub-chill salmon down before gutting with Baader machines, giving excellent result with 0 °C and satisfactory result at -0.5 °C. These results indicates that the product could be sub-chilled before gutting down to 0 °C.

5.2 Sub-chilling

Sub-chilled salmon, along with traditional product, was trucked to Hätälä in Finland, both in EPS boxes and 460 L tubs. The sub-chilled salmon was trucked without ice but tradition product with its normal 5 kg in a box. The temperature of the sub-chilled products stayed steady during logistic, storing and production, at temperature -1.5 °C. Packed products after heading, filleting, trimming and cutting were still at -1.5 °C. The quality of the sub-chilled salmon was considerable better compared with the traditional salmon; with less gaping, better inelasticity, more firm and significantly lower microbiological count after 21 day of storage. The two product groups were kept for three weeks for comparisons giving sub-chilled products a large advance in shelf life and lower bacteria count. Cooking yield was used to investigate if the sub-chilled salmon had been affected by ice crystallisation during the sub-chilling process. For the first 10 days of cold storage, no difference was observed between the groups. After 16 days of storage, a significant difference between the groups was observed and gained with extended storage time. These results indicates that the sub-chilling caused no damage to the muscle cells or the muscle protein. A large quality difference were observed between the two groups (sub-chilled salmon vs. traditional salmon) trucked in 460 L tubs. The traditional product were heavily damage by the ice, while the sub-chilled product, with no ice, kept its quality completely.

Samples sent to Japan in EPS boxes showed excellent result, with no fluctuations in temperature and good quality of product. Our Japanese partners were worried the fish was frozen but the temperature logging proved it is not so. When sub-chilled salmon is filleted the low temp of the flesh is crystallising moisture in the atmosphere making a thin layer of ice on the surface. This does not mean the fish is frozen, but the fish has a lower freezing point than clear water because of salinity and fat. It will be one of the most challenging continuance work of this project to convince the Japanese market of the quality of sub-chilled salmon.

5.3 Bleeding process

The current bleeding procedure of salmon at Grieg Seafood involves bleeding water with no circulation, which mean that the same bleeding water is used throughout the whole processing day. Samples of the bleeding water were taken in the beginning of processing day and in the afternoon and analysed with regard to amount of free fatty acids (FFA) or enzymatic activity. The results showed great difference between samples, where water sample taken in the afternoon had significantly higher FFA content compared to water collected in the morning. It is clear that this has to be studied further.

5.4 Logistic

Samples of sub-chilled salmon were sent to Norway Seafood in Grenaa, Denmark with excellent result. The temperature of the un-iced sub-chilled salmon was were steady around -1.5 °C through large fluctuations in ambient temperature. The product were kept for 11 days with no change in temperature.

Samples of traditional produced salmon were sent to Italy with loggers to monitor product temperature and ambient temperature. The plan was to log the logistic during winter and summer but problems were of recapture the loggers from Simanes customer in southern Europe.

5.5 Discussions

Eliminating ice from the logistic chain of fresh salmon can have great advantages. Grieg Seafood have been shipping up to 40 tons of ice to Asia per week to keep salmon for Japanese customers chilled. This project experience show that ice-less sub-chilled salmon kept stable low temperature through this logistic. This does not only save a large amount of money but has great positive environmental influence, with lower carbon footprints. By using tubs instead of EPS boxes will also save substantial lower cost as well as lowering carbon footprints. The project showed that trucking sub-chilled salmon in tubs without ice maintains its quality. However, trucking traditional salmon in tubs with ice caused considerable damage.

Overall, this project demonstrates that the salmon industry has the potential to use the sub-chilling process for their products and could therefore gain a grate competitive advantage on the world marked by lowering cost and being more environmental friendly.

6 ACKNOWLEDGEMENTS

This study was funded by *Norske Forskningsrådet* in Alta Norway. Employees of Hätälä OY in Oulu, Finland, and Norway Seafood A/S in Grenaa, Denmark, had an important contribution to this project.

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8 APPENDICES

I. FHF guide for evaluating fillet texture in Atlantic salmon

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GUIDE FOR EVALUATING FILLET TEXTURE IN ATLANTIC SALMON

Introduction

The purpose of this guide is to develop a standardised method to evaluate firmness in salmon that may be used to characterise texture. It is important to stress that the industry test is not designed for general assessment of the fillet texture during storage and transport (such as, for instance, the equivalent Quality Index Method). The industry test is rougher and is designed to detect significant texture-related quality defects resulting from the farming phase.

This guide is one of the results from the project *Industry test and training*, which was financed by the Fishery and Aquaculture Industry Research Fund (FHF).

Description of method

The industry test is designed to be as self explanatory as possible, so few additional comments are provided here. The industry test comprises three separate tests, which can be added up to provide a total score. The three tests shall be carried out in the following order (score stated in brackets):

1. Inelasticity (0 - 2)
2. Softness during finger test (0 - 2)
3. Gaping in loin, belly and tail (0 - 5)

Two of the three tests have a score from 0 to 2, whereby 0 is best and 2 worst, while the gaping score is from 0 to 5, whereby 0 is best and 5 worst. The evaluation is carried out jointly for the lion, belly and tail.

The method shall simulate filleting of salmon post-rigor. This may seem like a somewhat brutal way of handling the fillet, but it has been shown that the method reflects the differences that can be traced back to characteristics in the fish prior to filleting.

In order to provide an accurate evaluation, the fish must be post-rigor, so the test is carried out on fish that has been stored for three days or more.

This guide does not discuss where the line is drawn for commercial acceptance or for good quality. It is therefore up to the trade to agree upon the limits for acceptable quality.

Performing the industry test

Gutted salmon is chilled on ice for three days or more before the left fillet is cut out and trimmed to C –trim (pin-bone in) prior to evaluation.

Evaluate inelasticity by folding the fillet over on the table, releasing it and observing:

The elasticity in the fish muscle expresses whether the fish muscle can be folded over and then return to its original form. The longer the fish is stored; the fillet will lose elasticity and become more inelastic.

Score	Description
0	– Elastic: The fillet straightens out quickly
1	– Somewhat elastic: The fillet straightens out slowly
2	– Inelastic: The fillet remains folded over

Softness during finger test:

This method expresses softness in the fillet and shall be carried out on a point just under the dorsal fin, as shown in the photos. Press your finger at a 45°angle towards the fillet, with a pressure of approx. 1 kg – preferably with the fillet on balance to apply the correct pressure for two seconds.

Place your finger as such when testing softness.

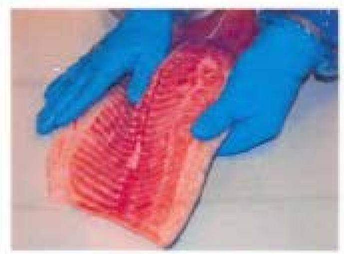
Score 0 – Firm fillet: The surface is restored a short time after the finger pressure ends.

Score 1 – Reduced firmness: The finger pressure leaves a lasting imprint that is not restored.

Score 2 – Soft fillet: The finger goes right through the fillet and causes a clear rupture between the segments.

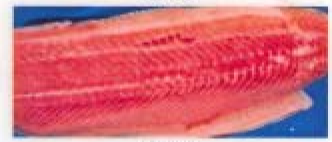
Gaping

Gaping is evaluated in three zones on the fillet: loin, belly and tail. To provoke gaping, the fillet shall be exerted by breaking it with a certain force. Start in the neck region and fold the loin sideways, as shown on the photo, and then continue along the fillet backwards until you reach the tail. Repeat in the same manner for the belly then evaluate the degree of gaping by comparing the fillet with the photos.

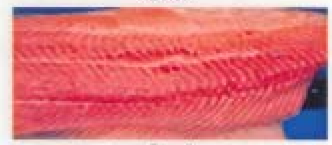


Score table for evaluation of gaping:

Score 0



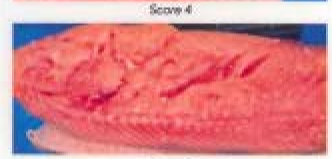
Score 1



Score 2

Score 3

Score 4



Score 5