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Combined Blast and Contact cooling - Effects on physiochemical characteristics of fresh haddock (*Melanogrammus aeglefinus*) fillets

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Titill / Title	**Combined Blast and Contact cooling --** Effects on physiochemical characteristics of fresh haddock (*Melanogrammus aeglefinus*) fillets		
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Ágrip á íslensku:	Skaginn hf. hefur einkaleyfi á nýrri vinnslutækni við vinnslu ferskra og frystra flaka sem byggist á svonefndri roðkælingu fyrir roðflettingu. Tilgangur þessa rannsóknarverkefnis var að bera saman flakavinnslu með roðkælingu og hefðbundna flakavinnslu. Í verkefninu eru borin saman annars vegar fersk flök og roðkæld flök með tillit til nýtingar, gæða og geymsluþols. Tvær tilraunir voru framkvæmdar, annars vegar tilraun I þar sem vatnsheldni, gæði, suðunýting og útlit voru skoðuð, og hins vegar tilraun II þar sem þessir sömu þættir voru skoðaðir auk þess sem skoðuð var áhrif roðkælingar á aukið geymsluþol ferskrar og frosinnar ýsu. Tilraunirnar voru framkvæmdar hjá Festi ehf. í Hafnarfirði. Meginniðurstöður þessara rannsókna sýndu að flakavinnsla með roðkælingu hefur fleiri kosti en hin hefðbundna flakavinnsla. Roðkælingin gefur hærri nýtingu og verðmætari afurðir með lengra geymsluþol. Aukið geymsluþol fersks fisks gefur aukinn möguleika á útflutningi sem er mjög mikilvægt fyrir fiskiðnaðinn.		
Lykilorð á íslensku:	*Roðkæling, fiskflök, nýting, gæði, geymsluþol*		
Summary in English:	The aim of the project was to compare a new processing technique, CBC, with traditional processing of haddock fillets. In the latter the fillets go through the process without additional refrigeration. In the new processing technique, CBC, the fillets, after filleting and pre-trimming, go through pre-cooler/fluid-ice followed by CBC super-chilling. Two trials were performed, a preliminary experiment (I) and a main experiment (II). In the preliminary experiment (I), water holding capacity, quality and cooking yield were examined. In the main experiment (II) these same factors were examined, in addition to the super-chilling effect on extended shelf-life of fresh and frozen haddock fillets. After the pre-cooler step, the fillets gained weight with yields of 101.6% to 102.7%. After the CBC super-chilling the fillets had final yields of 100.3% to 101.2%. After skinning, the fillets without refrigeration (traditional processing) lost most weight. The highest value of cooking yield was obtained in CBC super-chilled fillets with skin. Skinless traditional and CBC super-chilled fillets showed similar cooking yield (P>0.05). CBC super-chilling increased the total yield of the fillets. The difference between the traditional fillets and the super-chilled fillets was significant. The appearance of the CBC super-chilled fillets was much better and with less gaping than the traditional fillets. The traditional fillets had more ragged outlines, and the ratio of cut-offs after fine-trimming was therefore higher for the traditional fillets than the CBC super-chilled fillets. Appearance of the traditional fillets showed a little yellow tinge which increased during the storage time. The CBC super-chilled fillets had a whiter and more “fresh” appearance and were therefore more attractive. Examination of total bacterial count, and amount of TMA and TVN showed that the CBC super-chilling process can extend the shelf life of fresh haddock fillets.		
English keywords:	*CBC super-chilling, fish fillets, yield, quality, storage life*		

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ABSTRACT

The aim of the project was to compare a new processing technique, CBC, with traditional processing of haddock fillets. In the latter the fillets go through the process without additional refrigeration. In the new processing technique, CBC, the fillets, after filleting and pre-trimming, go through pre-cooler/fluid-ice followed by CBC super-chilling. Two trials were performed, a preliminary experiment (I) and a main experiment (II). In the preliminary experiment (I), water holding capacity, quality and cooking yield were examined. In the main experiment (II) these same factors were examined, in addition to the super-chilling effect on extended shelf-life of fresh and frozen haddock fillets.

After the pre-cooler step, the fillets gained weight with yields of 101.6% to 102.7%. After the CBC super-chilling the fillets had final yields of 100.3% to 101.2%. After skinning, the fillets without refrigeration (traditional processing) lost most weight.

The highest value of cooking yield was obtained in CBC super-chilled fillets with skin. Skinless traditional and CBC super-chilled fillets showed similar cooking yield ($P>0.05$). CBC super-chilling increased the total yield of the fillets. The difference between the traditional fillets and the super-chilled fillets was significant.

The appearance of the CBC super-chilled fillets was much better and with less gaping than the traditional fillets. The traditional fillets had more ragged outlines, and the ratio of cut-offs after fine-trimming was therefore higher for the traditional fillets than the CBC super-chilled fillets. Appearance of the traditional fillets showed a little yellow tinge which increased during the storage time. The CBC super-chilled fillets had a whiter and more "fresh" appearance and were therefore more attractive.

Examination of total bacterial count, and amount of TMA and TVN showed that the CBC super-chilling process can extend the shelf life of fresh haddock fillets.

INTRODUCTION

This project builds on a new processing technique which Skaginn hf. has developed and holds a patent for. During the last few years, Skaginn has been developing and designing a new revolutionary method in the area of fish processing, a cooling process for roundfish which is called Combined Blast and Contact (CBC) cooling. The CBC technique consists of the combination of blast freezing and contact freezing, by using an aluminium crust freezing belt that crusts freeze the product instantly with maximum efficiency. The technique is based on surface freezing or surface chilling after filleting and trimming. The fillets lay skin-down on the Teflon coating aluminium belt, which has a temperature of approximately -8 °C. This rapid cooling process freezes the skin without freezing the flesh. Before the CBC cooling, the fish goes through pre-cooler/fluid-ice which contains approximately 2.5% salt, and because of the salt content the fillets can go through the CBC process without freezing the flesh. Fast freezing for a short time leads to the formation of small ice crystals in the flesh, while slower freezing leads to the formation of larger crystals that cause more damage to the cells. Fast freezing for a short period is therefore preferred (Belitz et. al., 2004). After the CBC cooling the skin is removed with special Skaginn skinner. The skinning has little effect on the fillets, since the fillets are stiff after the CBC cooling. The benefits of this technique are many, for example the firm fillets can withstand the necessary handling and preserve the quality all the way through the processing, leading to more valuable products. The drip loss also decreases in fillets in the super-chilled state, which gives improved yield and quality. By keeping the product at super-chilling temperatures throughout the process, from catch to consumer, an increased shelf life is gained.

Prior projects have shown that CBC super-chilling increased the water holding capacity of the fillets, quality and cooking yield. This project was performed in continuation of those projects. Two trials were performed, a preliminary experiment (I) and a main experiment (II). In the preliminary experiment (I) water-holding capacity, quality and cooking yield were examined. In the main experiment (II) these same factors were examined, in addition to the super-chilling effect on extended shelf-life of fresh and frozen haddock fillets.

The project was funded by the research funds AVS (R 057-05) and Tækniþróunarsjóður (051204007).

MATERIAL & METHODS

Raw material

The experiments were performed at Festi ehf., a fish processing plant. The raw material, fresh haddock (*Melanogrammus aeglefinus*), was caught by line by a commercial fishing boat. In the preliminary experiment the fish were caught in the end of July 2007. In the following main experiment, the fish were caught in the end of August 2007. The haddock was processed approximately 48 hours after being caught in both experiments. The fish was deheaded in a Baader 413 machine and filleted with a Baader 189 filleting machine (Baader, Lübeck, Germany). Each fillet was identified with a numbered plastic tag to trace the fillets through the process.

Preliminary experiment (I)

The experiment layout is shown in ***Figure 1***. After beheading and filleting, the fish was pre-trimmed with skin-on. Pre-trimming the fillets before cooling and skinning gives more accurate results than trimming the fillets afterwards. The material was divided into four groups, with 12 individuals in each group (n = 12 per group). The groups were processed in the following way:

- **Group A**: Skinless fillets without refrigeration (traditional process).
- **Group B**: Skinless fillets, pre-cooled in fluid-ice before skin removing.
- **Group C**: Fillets with skin, pre-cooled in fluid-ice and CBC super-chilled.
- **Group D**: Skinless fillets, pre-cooled in fluid-ice and CBC super-chilled before skin removing. After pre-trimming, the fillets went through the pre-cooler/fluid-ice for 10 min, followed by CBC super-chilling and finally the skin was removed.

The skin removing was performed with a Baader 51 (Baader, Lübeck, Germany) for all the groups (A, B, C and D).

Main experiment (II)

The main experiment was performed in a similar way as the preliminary experiment. The experiment layout is shown in figure 2. The material was divided into two groups, with 34 individuals (fillets) in each group (n = 34 per group). These groups were processed in the following way:

- **Group E**: Skinless fillets without refrigeration (traditional process). After the fish were deheaded and filleted, the skin was removed. The fillets were fine trimmed after skinning.
- **Group F**: Skinless fillets, pre-cooled in fluid-ice and CBC super-chilled before skin removing. After deheading and filleting, the fillets were pre-trimmed before the cooling process. The fillets went through the pre-cooler/fluid-ice for 10 min. followed by CBC super-chilling (-8°C for 8 min.), and finally the skin was removed. After skinning the fillets were fine trimmed.

The skin removing was performed with a Baader 51 (Baader, Lübeck, Germany) for group E (traditional) and with Skaginn S3 (Skaginn hf., Akranes, Iceland) for group F (CBC super-chilled).

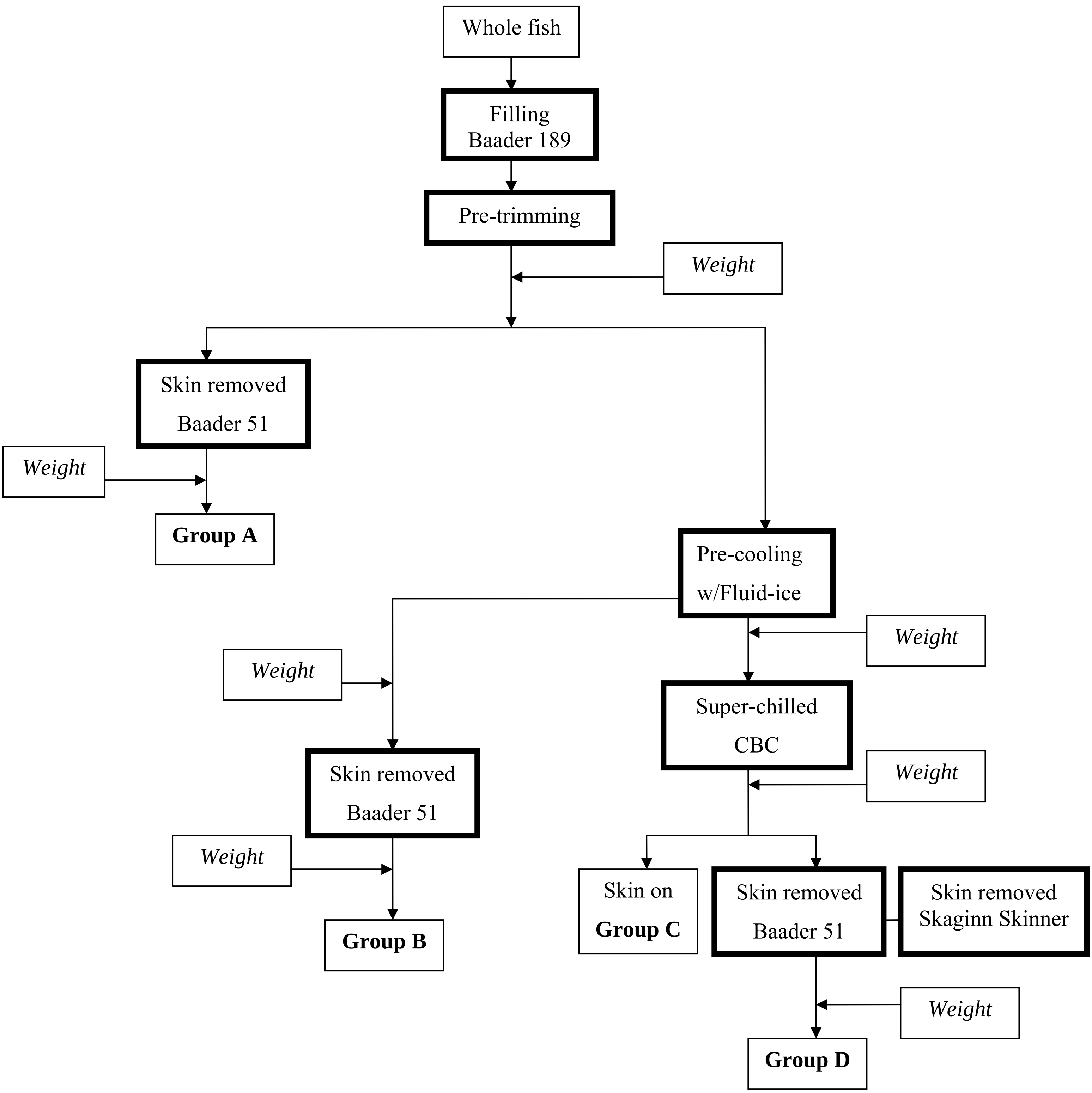

Figure 1 Preliminary (I) experiment layout.

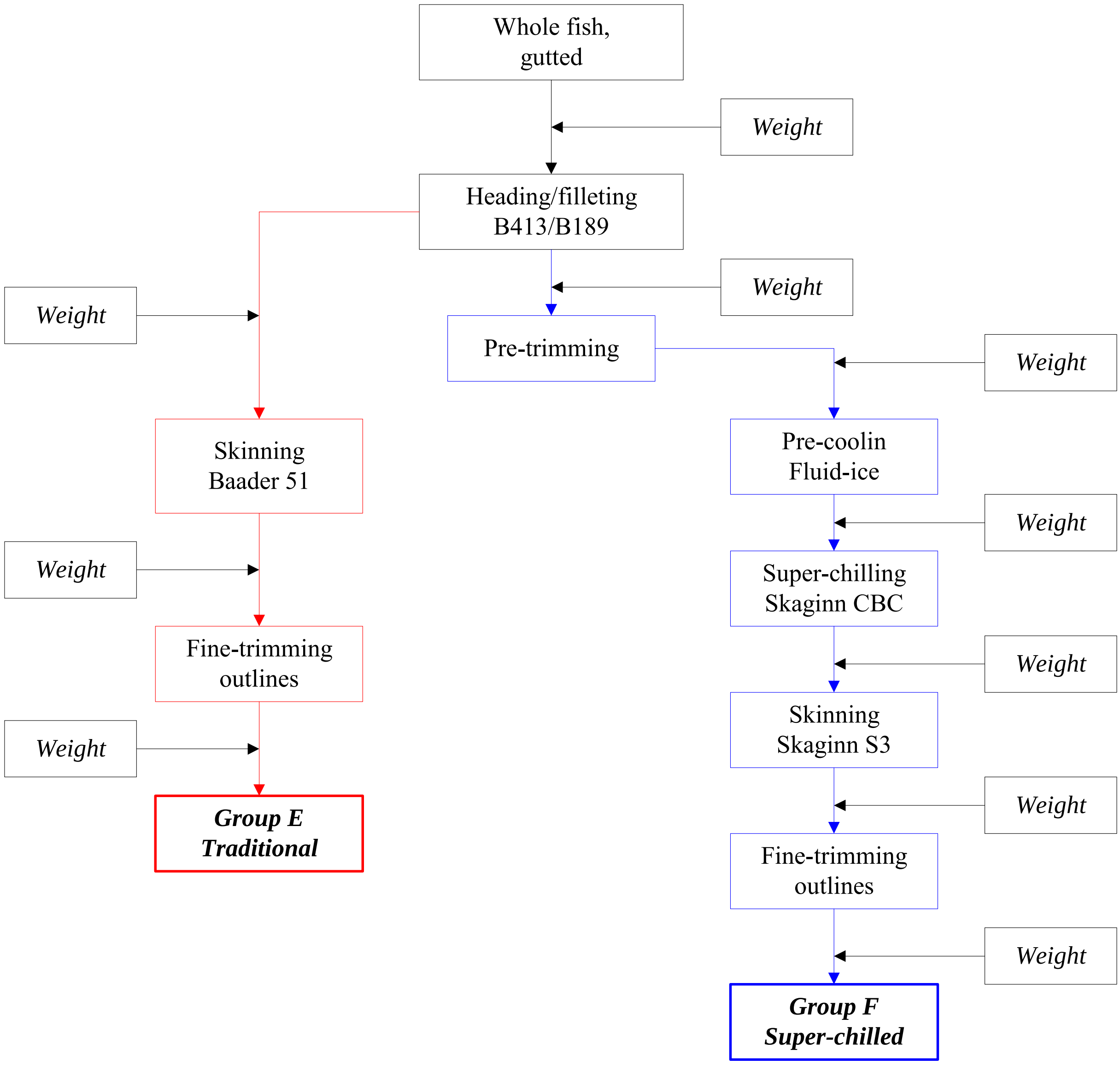

Figure 2 Main (II) experiment layout

Sampling

Samples were collected after each processing step, i.e. filleting, pre-cooling, CBC super-chilling and skin removing. In the main experiment, samples were also taken after trimming. The samples were weighed to find out the weight gain and loss of each process step and the total yield during the process. The final products were used for determination of chemical composition, water holding capacity (WHC) and cooking yield. In the main experiment, micro-organisms count was also determined. In the preliminary experiment, half of the samples were analysed on the same day the experiment took place and the other half after six days of storage at -1.0 °C. In the main experiment, samples were taken on four occasions from each group, i.e. in the following way:

1. The first part was analysed the day after the experiment took place (n = 8 per group)
2. The second part was analysed after six days storage at -1.5 °C (n = 8 per group).
3. The third part was analysed after 13 days storage at -1.5°C (n = 8 per group).
4. The fourth part (n = 5 per group) was frozen in a plate freezer and stored at -24°C. After 1 month's storage, the group (n = 5) was analysed.

Weight determination and yield after each processing step

In the main experiment, the whole gutted fish were weighed before and after deheading and filleting. In both experiments the fillets were weighed as raw material and after each processing step. Yield was determined by the changes observed in weight with respect to the weight of the raw fillets. Values less than 100% indicated that the fillets lost weight; while values over 100% indicate that the fillets had gained weight during processing.

Yield after cooking, drip and total yield

Evaluation of yield after cooking was determined by steam cooking the fillets at 95°C to 100°C for 8 min in a Convostar oven (Convotherm, Elektrogeräte GmbH, Eglfing, Germany). After the cooking period, the fillets were cooled down to room temperature for 15 min before weighing for cooking yield determination. The yield after cooking (%) was calculated as the weight of the cooked fillets in contrast with the weight of raw fillets (weight of fillets after the processing steps). It is important for the consumer to get what he buys, i.e. that the product does not shrink during cooking. The cooking yield is therefore important for the consumer.

In the preliminary experiment, drip (%) was determined as the weight loss during storage period of six days at -1.0°C. The fillets (n = 6) were weighed after the process and again after storage. In the main experiment, drip (%) was determined as the weight loss during storage period of six and 13 days at -1.5°C. The fillets (n = 8) were weighed after the process and again after storage. Thaw drip (%) was determined as the loss in weight during thawing after 44 hrs at 0 °C, by comparing the fillet weight before freezing and after thawing (n=5). Yield after differential storage time was also calculated as the weight of the stored fillets over the weight of raw fillets.

Evaluation of total yield was determined by multiplying the yield after each processing step and the cooking yield (equation 1). The first processing step started after filleting (untreated fillets with skin on were defined as raw material).

$$\text{Total yield (\%)} = \left(\frac{\text{Weight after storage}}{\text{Weight of raw fillets}} \times \frac{\text{Weight before cooking}}{\text{Weight after cooking}} \right) \times 100 \qquad (1)$$

Yield was measured by comparing fillets with skin to the cooked product. The yield after the processing steps, skinning etc., is the production capacity but yield after storage and cooking is sales and consumers capacity (***Figure 3***).

$$\underbrace{\frac{\text{Weight after skinning}}{\text{Weight with skin on}}}_{\textbf{Production capacity}} \times \underbrace{\frac{\text{Weight after 6 days}}{\text{Weight after skinning}} \times \frac{\text{Weight after cooking}}{\text{Weight after 6 days}}}_{\textbf{Sales and consumers capacity}} \times 100$$

Figure 3 Division of the total yield regard to production, sales and consumers capacity.

Determination of water and salt

Salt and water content was determined by the standard methods, AOAC no. 976.18 (2000) and ISO 6496 (1999), respectively.

Determination of water holding capacity

The water holding capacity (WHC) was determined by a centrifugation method (Eide and others 1982). The haddock (n = 3) were coarsely minced in a mixer (Braun Electronic, Type 4262, Kronberg, Germany) for approximately 15s at speed 5. Approximately 2 g of the minced haddock muscle was weighed accurately and immediately centrifuged at 210 x g for 5 min, with temperature maintained at 4°C. The weight loss after centrifugation was divided by the water content of the fillet and expressed as %WHC.

Determination of bacterial counts and freshness

Bacterial count was determined on the haddock fillets (main experiment) after each storage period. Three fillets (n = 3) from each group were analysed. A sample was taken from a muscle of each fillet and analysed for psychotropic bacteria (colony forming units) and H_2S-producing bacteria on Iron agar with overlay (IA). The plates were incubated at 15°C for five days. Bacteria forming black colonies on this agar produce H_2S from sodium thiosulphate and / or cysteine. One of the main spoilage bacteria in chilled fish, *Shewanella putrefaciens*, forms black colonies on this agar. This bacteria forms trimethylamine (TMA) from trimethylamine oxide (TMA-O), but TMA has often been used as a parameter on fish freshness.

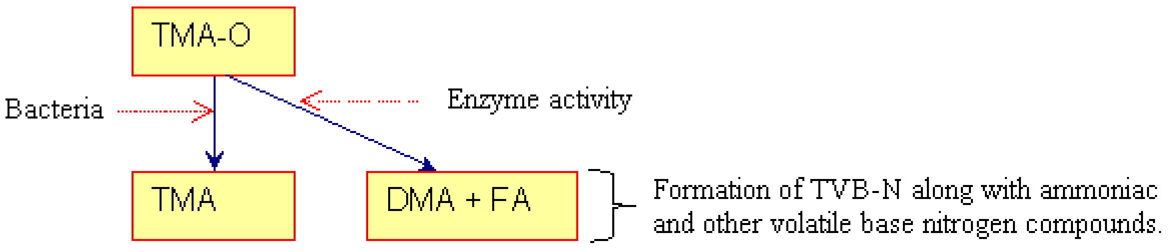

Figure 4 Decomposition of TMA-O to TMA and dimethylamine (DMA) and formaldehyde (FA).

Freshness was also evaluated by measuring total volatile base nitrogen (TVB-N) and TMA in minced fillet from each group. The measurements were determined by standard methods, AOAC no. 920.03 (2000).

Appearance

The haddock fillets were compared visually for differences in surface appearance, such as gaping and colour.

Data analysis

Statistical analyses were performed by Microsoft Office Excel 2003 (Microsoft Inc, Redmond, Wash., U.S.A.). Student *t* test were performed on the means of values. The significance level was $P<0.05$.

RESULTS AND DISCUSSION: PRELIMINARY EXPERIMENT

Yield after chilling and skin removing

After the pre-cooler/fluid-ice, containing ~2.5% salt, the fillets gained weight with yields in the interval from 101.6% to 102.7%. After the CBC super-chilling the fillets lost 1.2% - 1.4% of the weight which they gained after the pre-cooler. After the CBC super-chilling the fillets had final yields of 100.4% to 101.2%. During the pre-cooler step the fillets gained weight because of salt absorption and in the CBC step they lost some of it again. The CBC cooling causes cell rupture up to a certain point, leading to little loss of water, which is probably why there is a decrease after the CBC step.

After skin removing the fillets lost weight with yields of 88.2% to 92.8% (***Figure 5***). The fillets without refrigeration (traditional process) lost most weight (11.8%) during the skin removing process and also had the largest standard deviation. Fillets which were pre-cooled and super-chilled showed the best yield of the groups which seems to indicate that the chilling process gives higher yield than the traditional process ($P<0.05$). In figure 5 we can also see that the standard deviation is smaller for the chilling process then the traditional process. This indicates more consistency in the chilled groups.

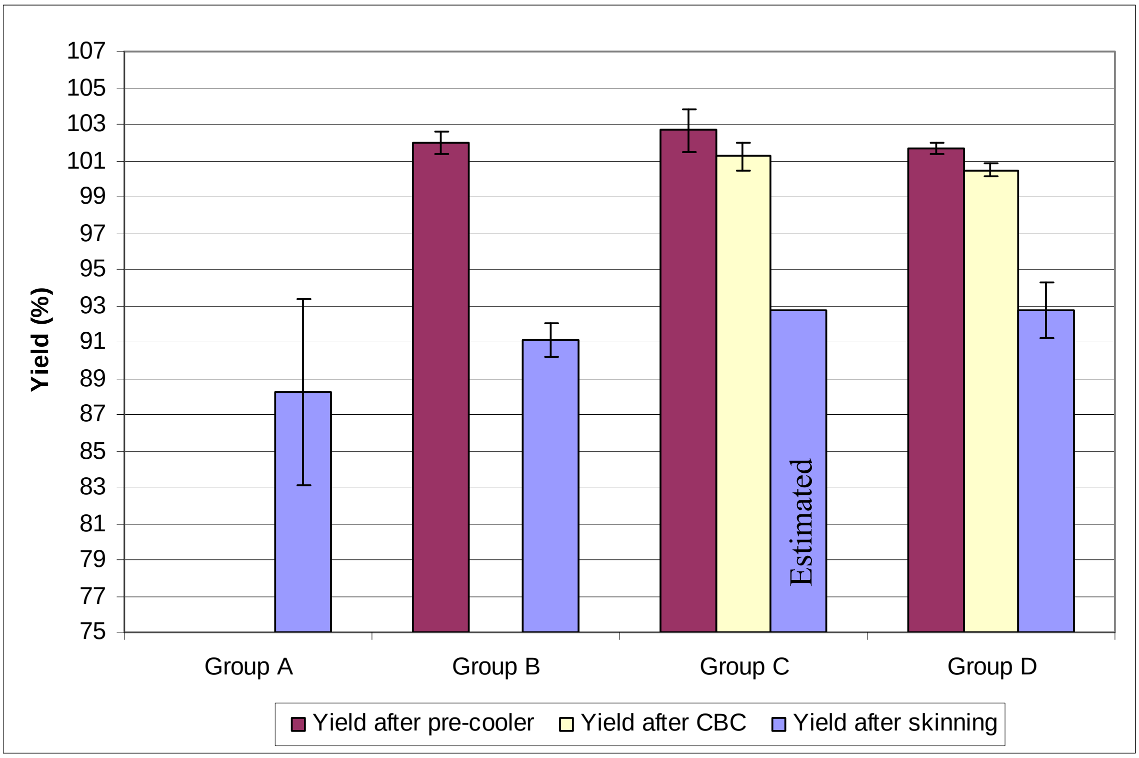

Figure 5 Yield after the processing steps. Group A=Traditional + skinless. Group B=Pre-cooler + skinless. Group C=Pre-cooler + CBC + skin on. Group D=Pre-cooler + CBC + skinless.

Drip

Drip was determined after six days storage at -1.0 °C (***Figure 6***) but drip is considered as storage deterioration.

The lowest value of drip was in group C (super-chilled + skin on), which is probably because the skin holds the muscles better together and thus leads to less water loss. The skin itself does not lose much water because of its high proportion of collagen proteins and low water content.

Groups A and D had relatively similar drip values, 3.2% and 3.9%, respectively. This difference is not statistically significant (P>0.05). A drip value below 5% during storage is considered acceptable and hence the results in this project are adequate.

The difference in drip between group C and D was because the fillets with the skin on were colder in the beginning. Temperature in group D increased after skinning and could be cooled down more with the CBC to get similar results as group C.

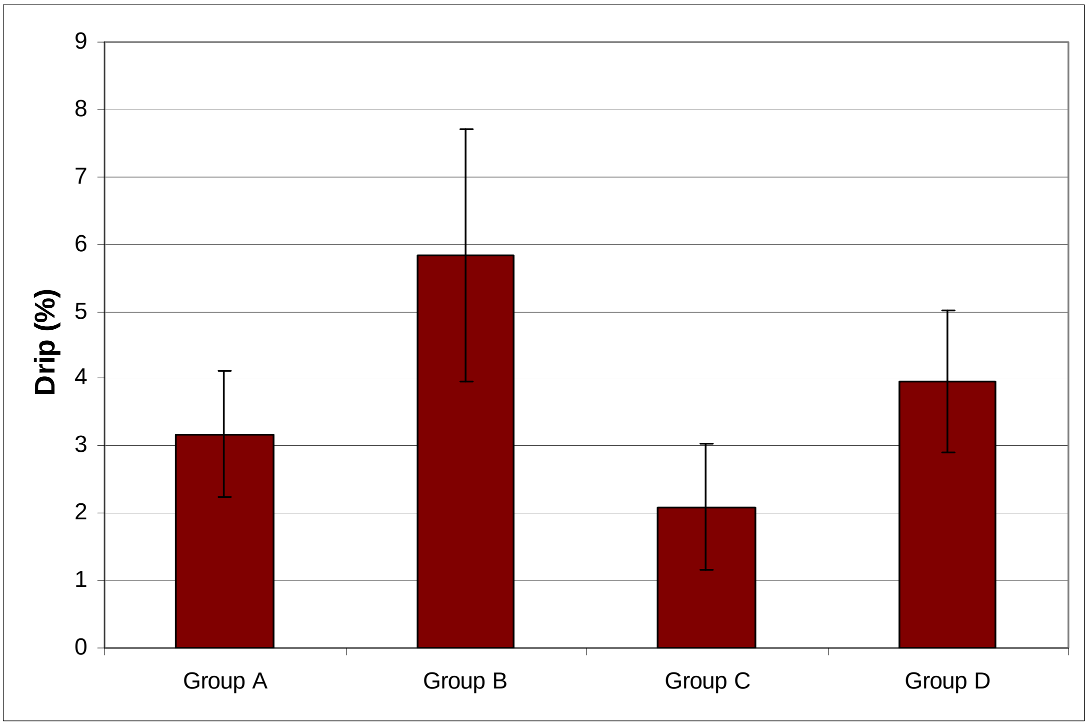

Figure 6 Drip after 6 days storage at -1.0°C. Group A=Traditional + skinless. Group B=Pre-cooler + skinless. Group C=Pre-cooler + CBC + skin on. Group D=Pre-cooler + CBC + skinless.

Cooking yield

The highest value of the cooking yield was obtained in group C (chilled + skin on) both on the first day and also after six days storage, 87.0% and 82.8%, respectively (***Figure 7***). Skin contains a high proportion of collagen. This collagen is a protein with good functional properties, such as solubility, viscosity, foaming capacity, emulsifying capacity, gel-forming ability and water holding capacity (J.A Novais, 2007). The skin is approximately 11% of the fillets' weight and that is probably why the relatively loss during cooking is lower compared to the other groups (A, B and D). The skin probably also holds the muscle better together compared with skinless fillets. Groups A and D had relatively similar values, both on the first day and after six days, and had no significant difference (P>0.05). The fillets in group B had the lowest value of cooking yield which indicates that only going through the pre-cooling step does not handle the fillets very well, but if followed by CBC the cooking yield was much higher. Temperature in group D increased after skinning and could be cooled down more with the CBC to get similar results as group C. The fillets in group A (traditional) had a high standard deviation on day six. Lower standard deviation indicates more consistency and results in more similar (homogeneous) final products.

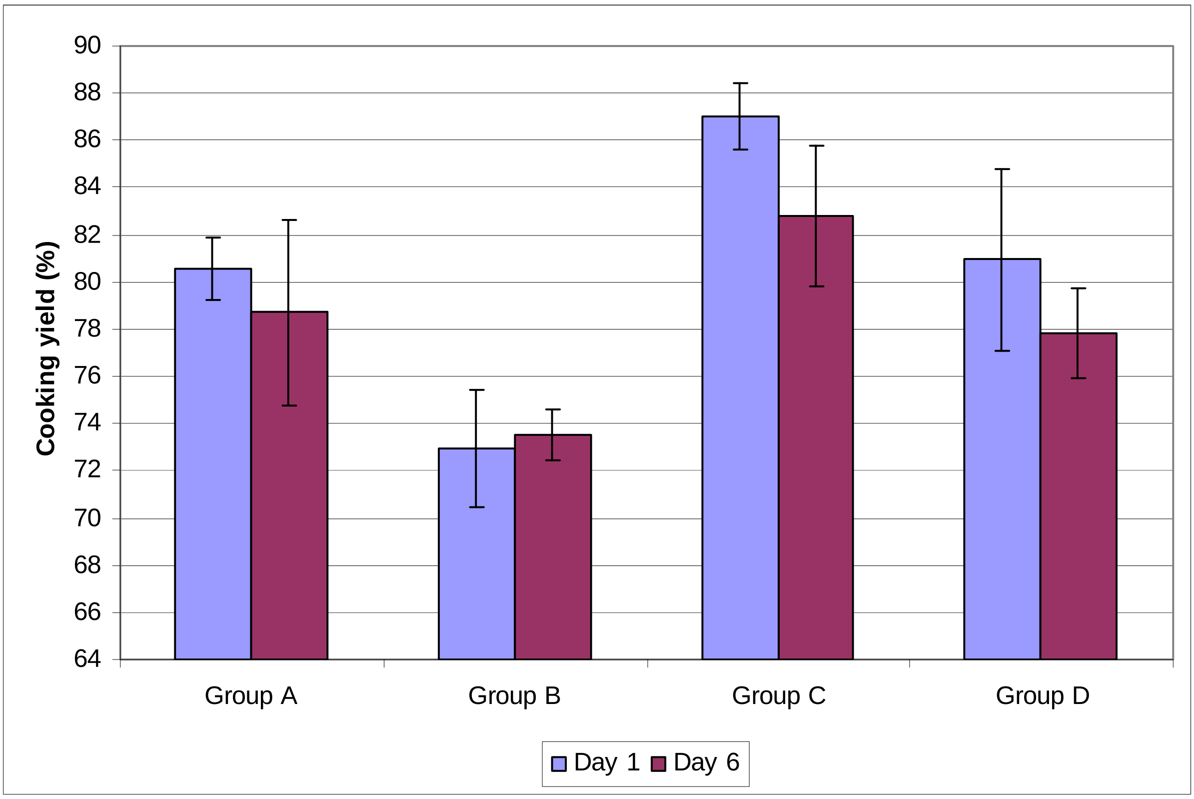

Figure 7 Cooking yield (%). Group A=Traditional + skinless. Group B=Pre-cooler + skinless. Group C=Pre-cooler + CBC + skin on. Group D=Pre-cooler + CBC + skinless.

Total yield

Evaluation of the total yield (***Figure 8***) was determined by multiplying the yield after the processing steps and the cooking yield according to equation 1. The best yield was obtained in the CBC super-chilled fillets (groups C and D) after day 1 (which makes them more valuable). The fillets in group B had the lowest total yield, which indicates that going only through the pre-cooling step does not benefit the fillets total yield, but if followed by CBC super-chilling the total yield was much higher. The total yield decreased with time among all the groups. The decrease was statistically significant ($P<0.05$) in groups B, C and D, but in group A, no significant difference was found ($P>0.05$). Overall, the super-chilling process is a better choice to increase the total yield of the fillets. On ***Figure 9*** we can see the yield over the process step by step.

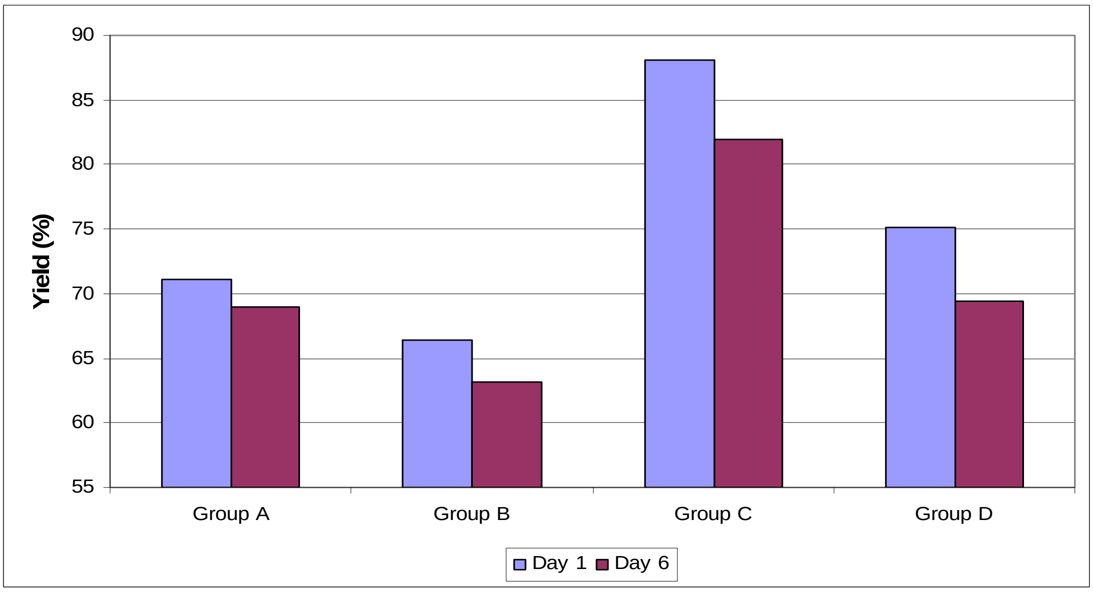

Figure 8 Total yield (%) after cooking of haddock fillets (n=3) on day 1 and day 6. Group A=Traditional + skinless. B=Pre-cooler + skinless. Group C=Pre-cooler + CBC + skin on. Group D=Pre-cooler + CBC + skinless.

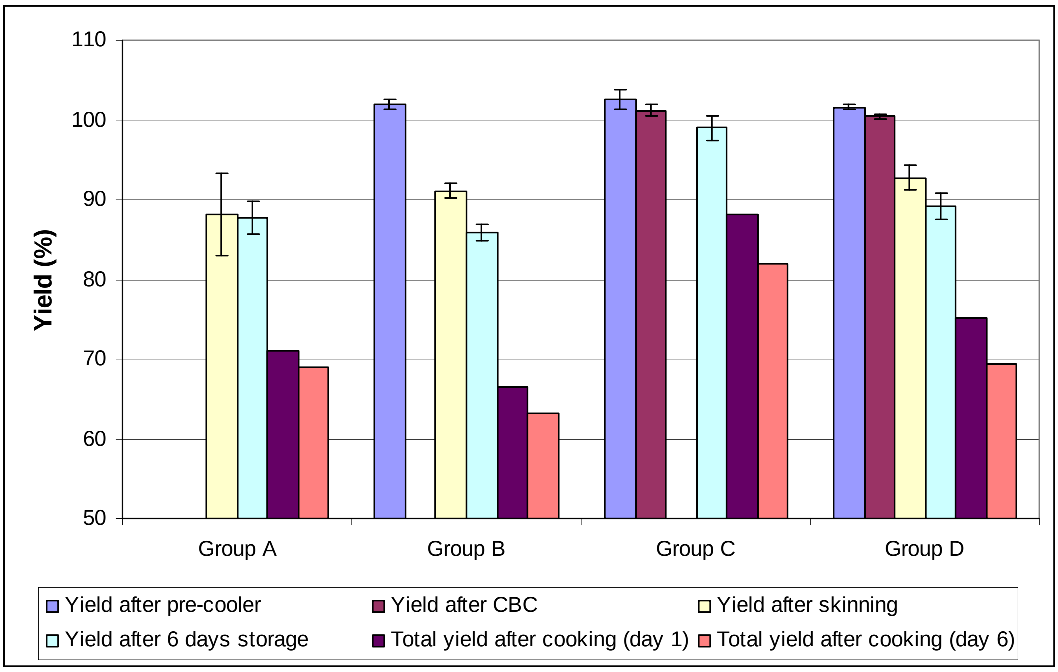

Figure 9 Yield (%) over the whole process. Group A=Traditional + skinless. Group B=Pre-cooler + skinless. Group C=Pre-cooler + CBC + skin on. Group D=Pre-cooler + CBC + skinless.

Water holding capacity

The chilling process has great effects on water holding capacity (***Figure 10***). The value for the fillets in group A (traditional) was much lower than for the other groups on day 1. There is no significant difference between the chilled fillets (P>0.05).

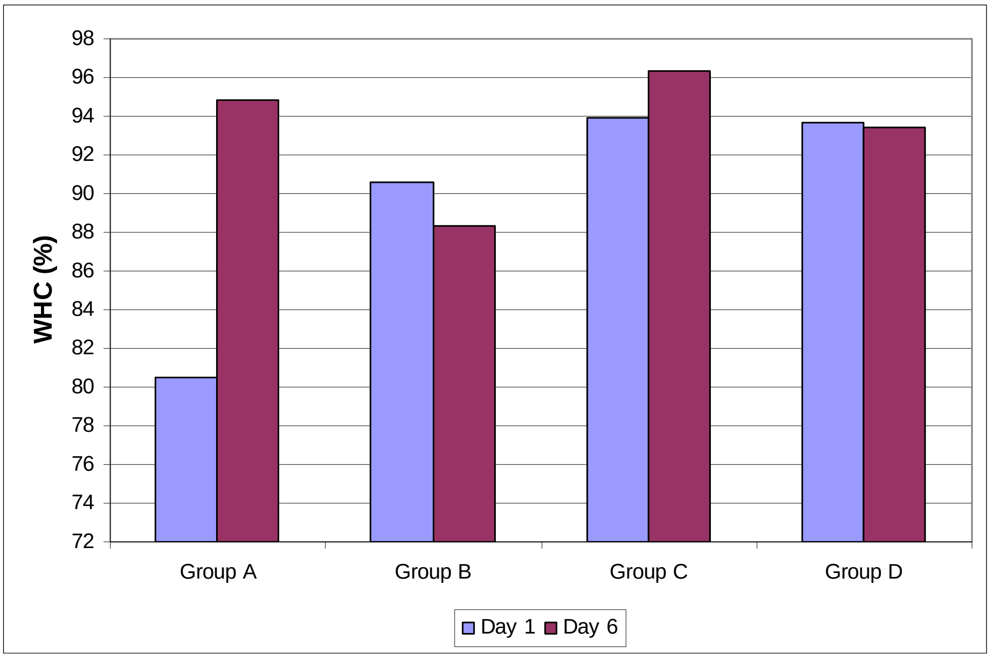

Figure 10 Water-holding capacity (%) of haddock fillets (n=3). Group A=Traditional + skinless. Group B=Pre-cooler + skinless. Group C =Pre-cooler + CBC + skin on. D=Pre-cooler + CBC + skinless

On day six the WHC increased in the traditional fillets (group A). After six days storage the fillets had lost most of their lightly bound and free moving water (as drip), while the strongly bound water, within the protein structure of the muscle, remained. The chilled fillets are therefore a better choice, because they hold better onto the water and are therefore juicier, which is a positive characteristic.

Chemical composition

Water and salt content was measured in the final products (Table 1) on day 1. There was a very small difference between the traditional fillets and the chilled fillets. According to this, the fillets did not absorb much water by going through the pre-cooler. The weight that the fillets gained after the pre-cooler step was therefore caused by salt absorption. The salt content in group A, which did not go through the pre-cooler, was 0.2% ± 0.1% which is a normal salt content in haddock and the water content, 82.6% ± 0.4% is also normal for the species. There was no significant difference in salt absorption between the fillets which went through the pre-cooler, whether they had the skin on or were skinless.

The salt content in the fillets in all the groups was ≤ 0.6% (highest in group D) and is therefore not lightly salted according to European and US standards. In Europe the maximum salt content is ~0.7% for fish to be considered fresh but ~1.1% in USA.

Table 1 Water and salt content (n=3) on day 1. Group A=Traditional + skinless. Group B=Pre-cooler + skinless. Group C=Pre-cooler + CBC + skin on. Group D=Pre-cooler + CBC + skinless.

	Water content [%]	Salt content [%]
Group A	82.6 ± 0.4	0.2 ± 0.1
Group B	82.6 ± 0.4	0.4 ± 0.1
Group C	82.7 ± 0.4	0.5 ± 0.1
Group D	82.5 ± 0.4	0.6 ± 0.1

Appearance of the fillets

The fillets were compared visually after the process (Figures 11-14). There were some differences in the surface appearance of the fillets. Group B had the most prominent gaping, compared with the other groups (Figure 12). Fillets in this group went only through the pre-cooler before the skin was removed.

The traditional fillets (group A) had gaping problems (Figure 11), but less so than the fillets in group B. There were also differences in appearance when fillets in group A and D were compared. The fillets in group D had less gaping, had less damage after the skinning and held their original shape better (***Figure 14***).

Overall, the fillets in group C and D showed the best surface appearance (Figure 13-14) and they had no gaping problems. The CBC super-chilling makes the fillets more homogeneous, which, e.g. leads to less gaping.

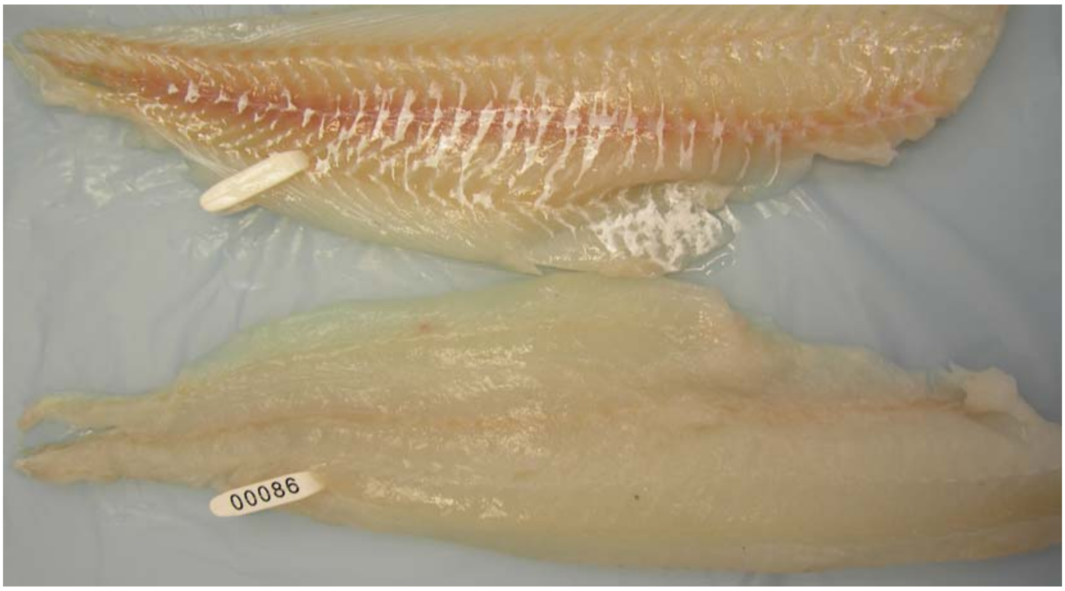

Figure 11 Appearance of the fillets surface. This is group A (traditional + skinless).

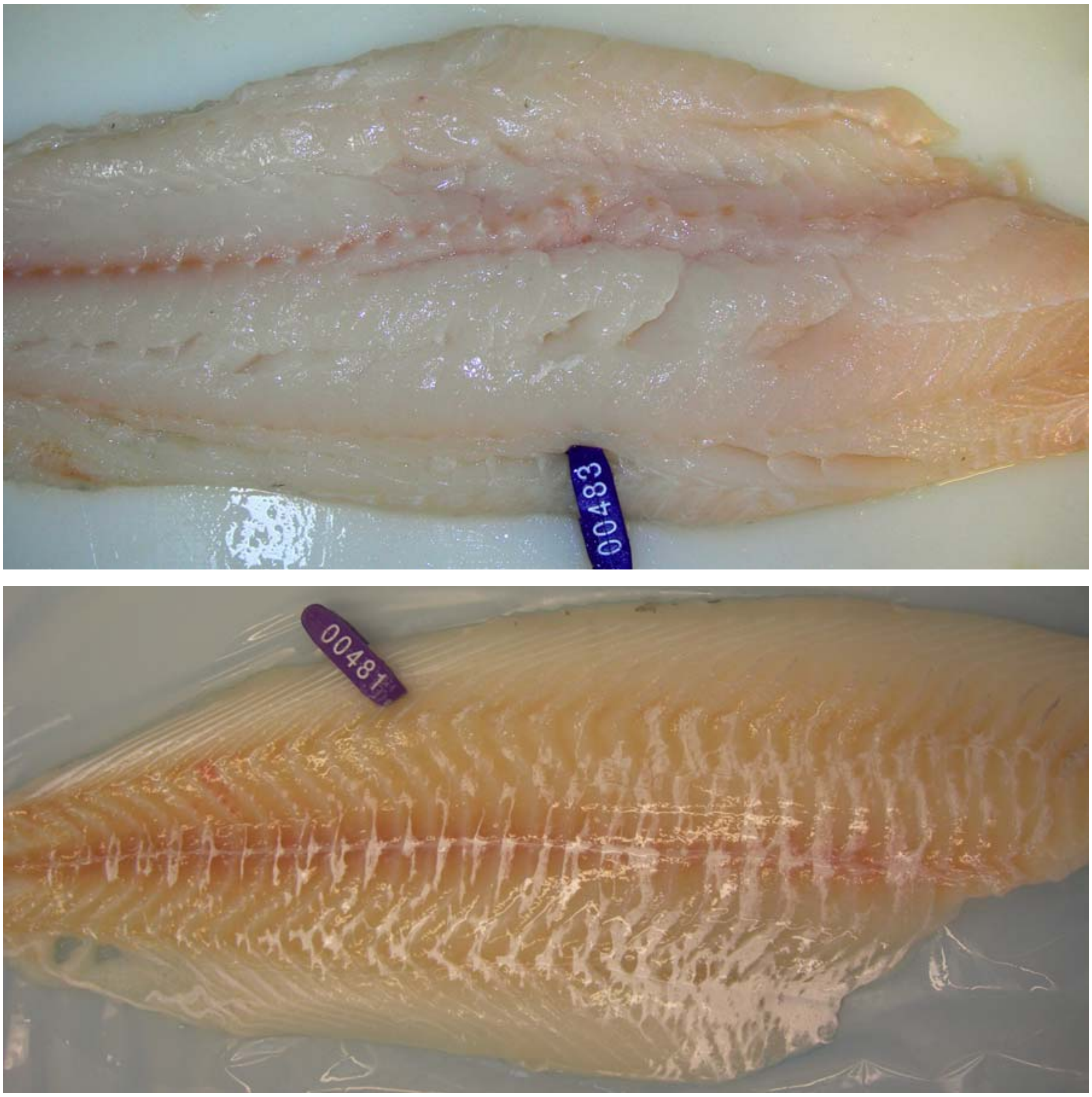

Figure 12 Appearance of the fillets surface. This is group B (pre-cooler + skinless).

Figure 13 Appearance of the fillets surface. This is group C (pre-cooler + CBC + skin on).

Figure 14 Appearance of the fillets surface. This is group D (pre-cooler + CBC + skinless).

Additional measurements

Additional measurements (***Figure 15***) were performed to examine if there were any difference in yield between Baader 51 and Skaginn Skinner skinning machines. The additional measurements indicated that there was a difference in yield between skinning of traditional and CBC super-chilled fillets with Baader 51. However, a comparison between CBC super-chilled fillets skinned with Baader 51 and Skaginn-skinner showed no statistical difference in yield.

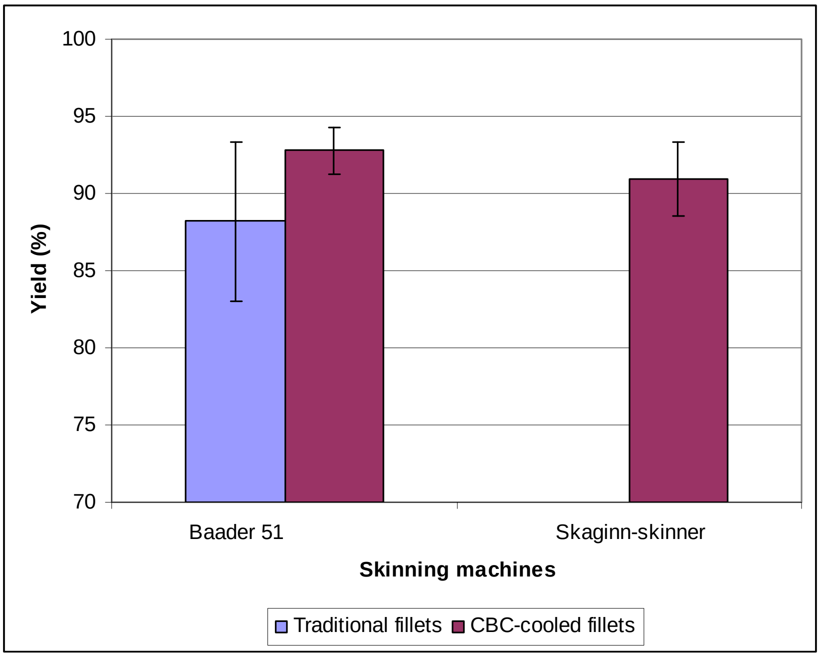

Figure 15 The difference in yield between Baader 51 and Skaginn-skinner S3 skinning machines. Skaginn-skinner is a continuous part of the CBC-cooling process.

RESULTS AND DISCUSSION: THE MAIN EXPERIMENT

Weight determination and yield after each processing step

The average weight of the gutted fish used in the experiment was 1.57 kg (±0.09). The yield after deheading and filleting was 46.6% (±1.19) with an average fillet weight of 0.37 kg. Yield was calculated as a function of raw fillets after each processing step. After the pre-cooler/fluid-ice, containing ~2.5% salt, the fillets gained weight with yields of 102.0% (±1.95). After the CBC super-chilling the fillets lost 1.6% (±0.69) of the weight which they gained after the pre-cooler. After the CBC super-chilling the fillets had final yields of 100.3%

(±2.05). During the pre-cooler step the fillets gained weight because of salt absorption and in the CBC cooling step they lost some of it again, probably due to certain cell interruption.

After skin removing the fillets lost weight giving yields of 88.0% to 91.0% (Figure 16). The fillets without refrigeration (traditional process) lost more weight (12.0%) during the skin removing process than the pre-cooled and super-chilled fillets. This indicates that the chilling process gives a significantly higher yield than the traditional process ($P<0.05$). The yield after the fine-trimming (outlines) was also higher ($P<0.05$) for the super-chilled fillets than the traditional fillets, 87.9% and 82.8%, respectively. These results show that the CBC super-chilled process leaves the material more intact than the traditional process, which leads to less cut-offs and waste. The average cut-offs after the fine trimming was 18.5 g (±11.3) and 11.3 g (±7.7) for traditional and super-chilled fillets, respectively.

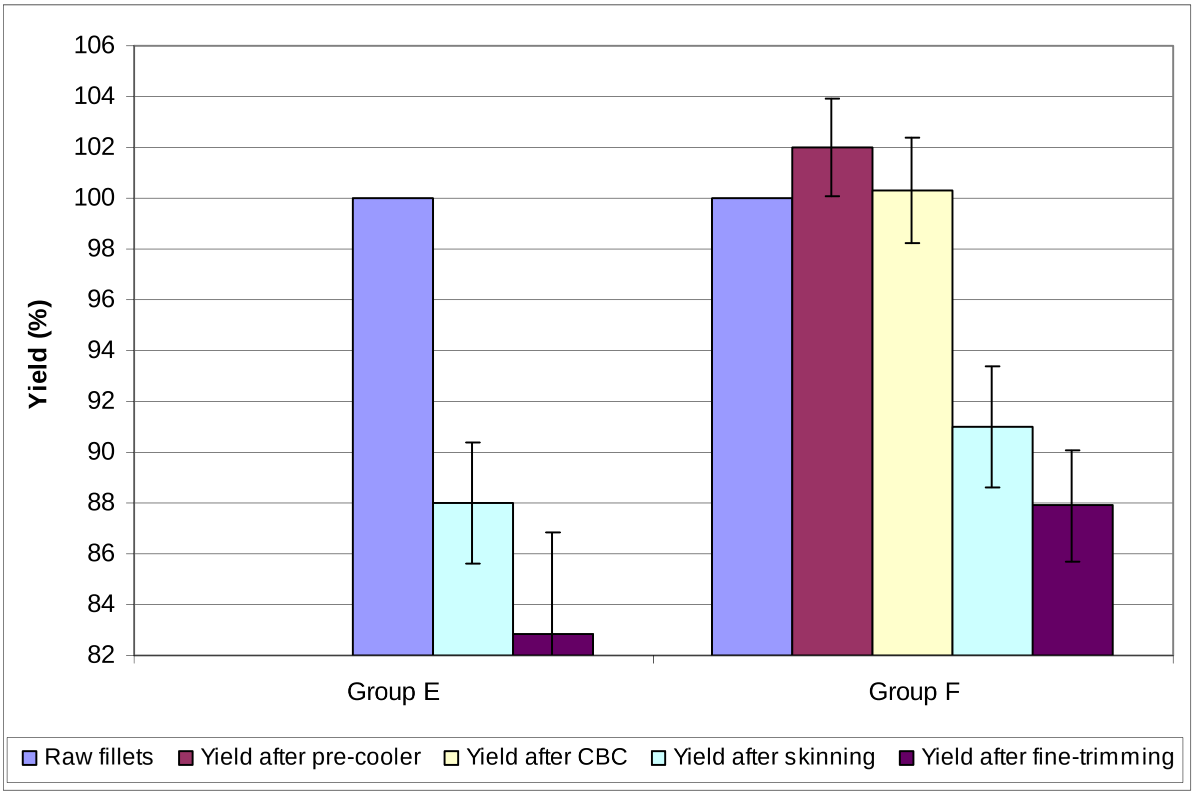

Figure 16 Yield after the processing steps. Group E = Traditional process. Group F = CBC super-chilling process.

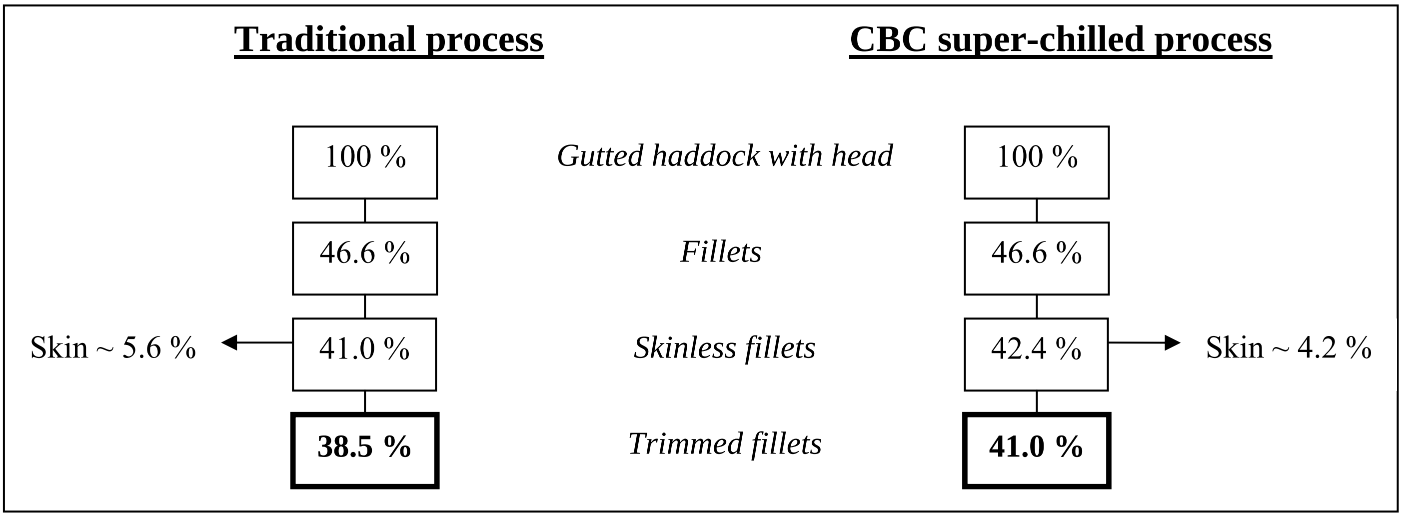

Figure 17 The process yield from whole gutted haddock with head.

Drip

Drip was determined after two, six and 13 days storage at -1.5 °C and after 1 month storage at -24°C (Figure 18). The drip value after day six, 13 and a 1 month storage was very similar (P>0.05) for both of the groups (E and F). On day two the traditional fillets showed slightly lower value of drip (P<0.05). We expected to observe greater difference in drip value between the groups. The trial process took a much longer time than expected and therefore, the temperature in the fillets rose to approximately 3°C in the super-chilled fillets. This adversely affected the fillets, since this temperature increase in the fillets decreases the effect of the CBC super-chilling on the fillets.

On day six and 13, the CBC super-chilled fillets were partially frozen. On day 13, the central temperature in the CBC super-chilled and traditional fillets was -1.1°C and 1.9°C, respectively. Before measurement, the fillets were defrosted at room temperature (22°C), or until the central temperature reached 0°C. ***Figure 21***-23 are taken of the groups in the containers (expanded polystyrene), and visually shows the difference in drip between the groups.

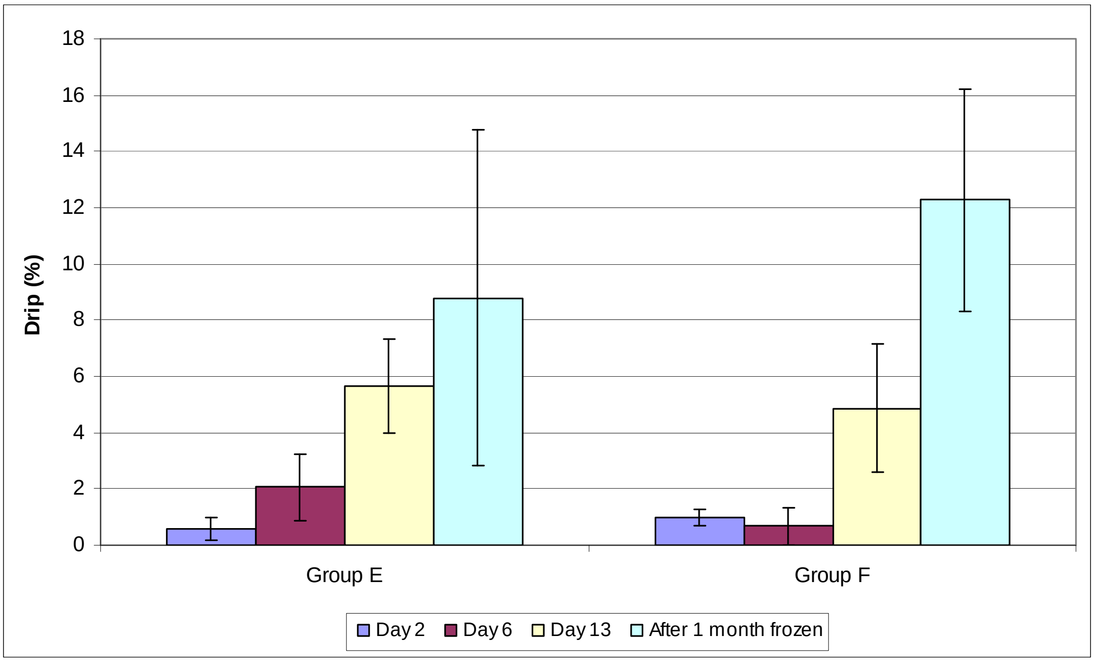

Figure 18 Drip after 2, 6 and 13 days storage at -1.5°C. Thaw drip after 1 month storage at -24°C. Group E = Traditional. Group F =CBC super-chilled.

Figure 19 The CBC super-chilled fillets on day 6 in the container.

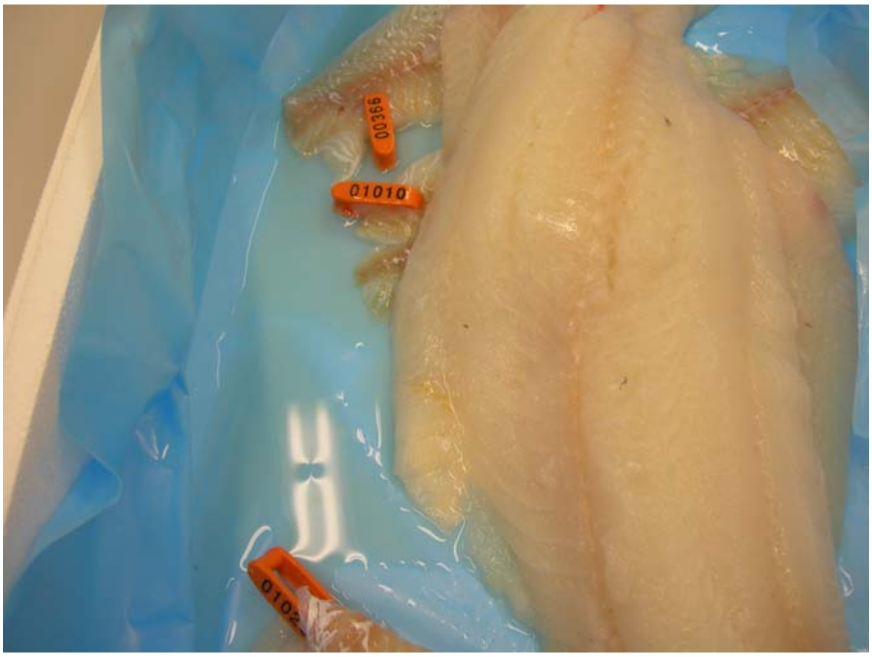

Figure 20 The traditional fillets on day 6 in the container

Figure 21   The CBC super-chilled fillets on day 13 in the container.

Figure 22 The traditional fillets on day 13 in the container.

The yield after various storage times is shown in Figure 23 (weight of the stored fillets over weight of raw fillets). CBC super-chilled fillets showed better yield, which indicates that the chilling process gives higher yield than the traditional process ($P<0.05$). There was no significant difference in yield after frozen storage (1 month) between the groups, but the traditional fillets had much greater standard deviation than the super-chilled fillets. It indicates more consistency and homogeneity in the super-chilled group.

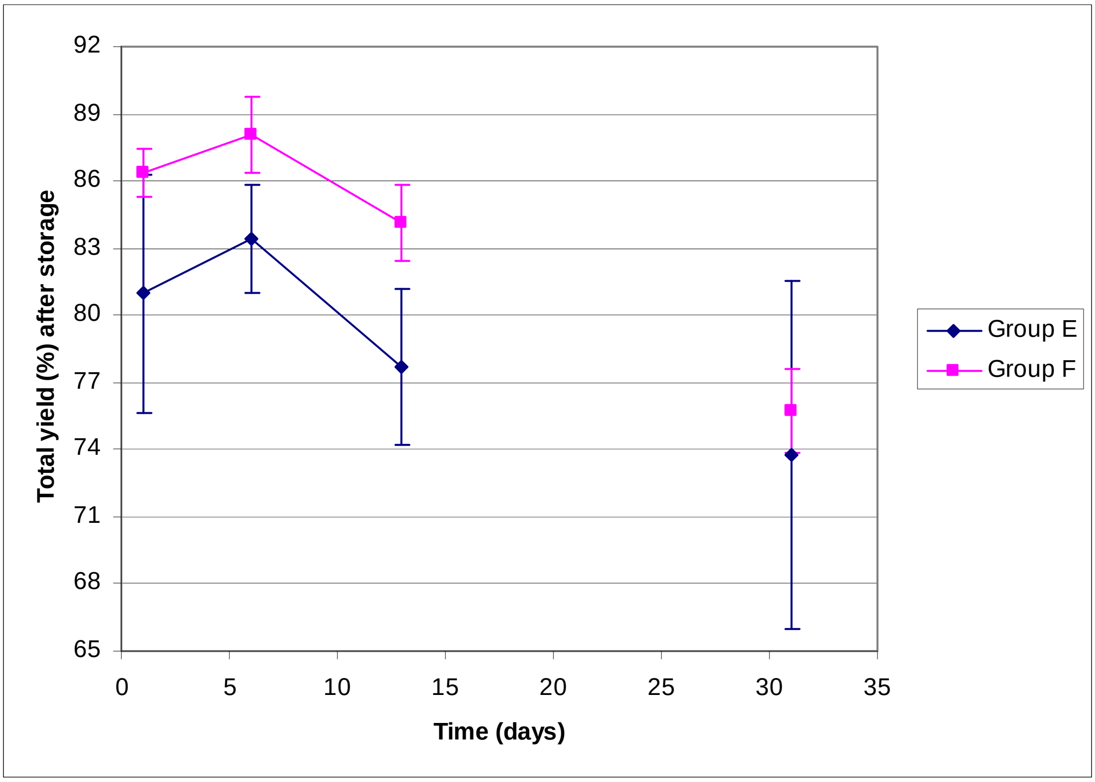

Figure 23 Yield of the fillets after various storage times (n = 8) at -1.5°C. The samples on day 31 were frozen (-24°C) for 1 month (n = 5). Group E = Traditional fillets. Group F = CBC super-chilled fillets.

Cooking yield

The cooking yield (***Figure 24***) was very similar (P>0.05) for both groups on day two and six. On day 13, the traditional fillets observed higher cooking yield (P<0.05) and increased the yield from 77% to 88%. This dramatic increase in cooking yield is most likely due to the fact that these fillets had lost most of their lightly bound and free moving water during storage, while the strongly bound water remains. In other words, the traditional fillets had less water to lose on day 13 than the super-chilled fillets.

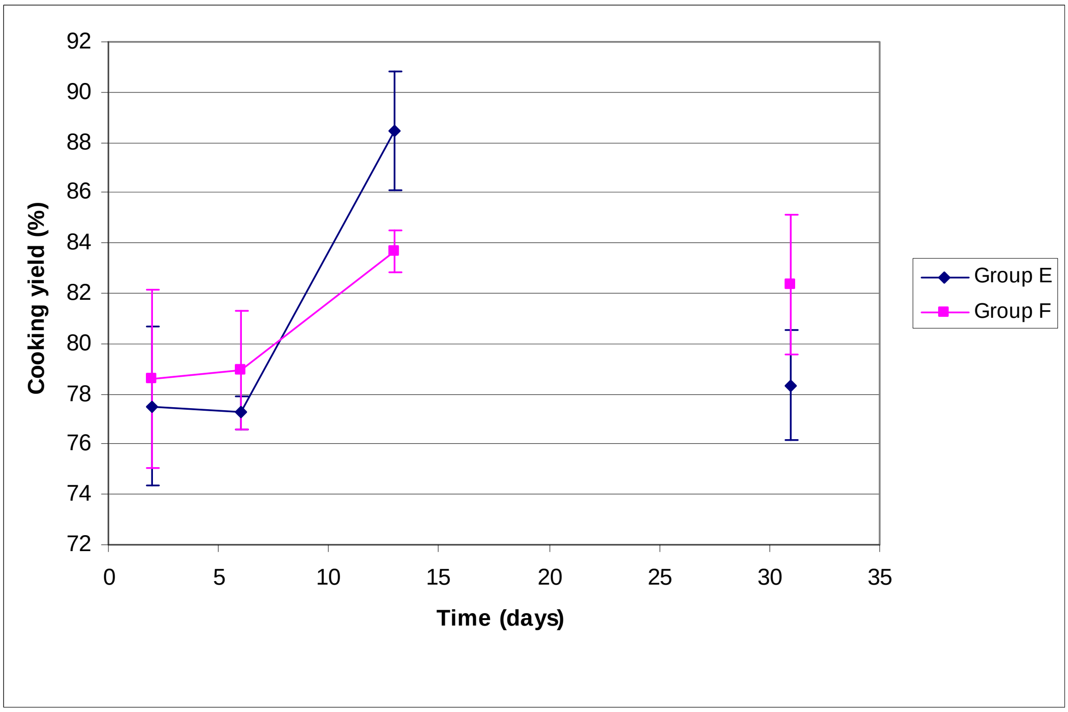

Figure 24 Cooking yield (%) of the fillets after various storage times (n = 3) at -1.5°C. The samples on day 31 were frozen (-24°C) for 1 month (n = 3). Group E = Traditional. Group F = CBC super-chilled

Total yield

Evaluation of total yield (Figure 25) was determined by multiplying the yield after the processing steps and the cooking yield according to equation 1. The CBC super-chilled fillets showed better total yield on each sampling day, but the difference was not quite as much as the prior trial had indicated. The explanation is probably, as mention before, because of the longer processing time and increased temperature during the trial. Overall, the CBC super-chilling process leads to an increase in total yield and therefore value of fillets through cooling and frozen storage.

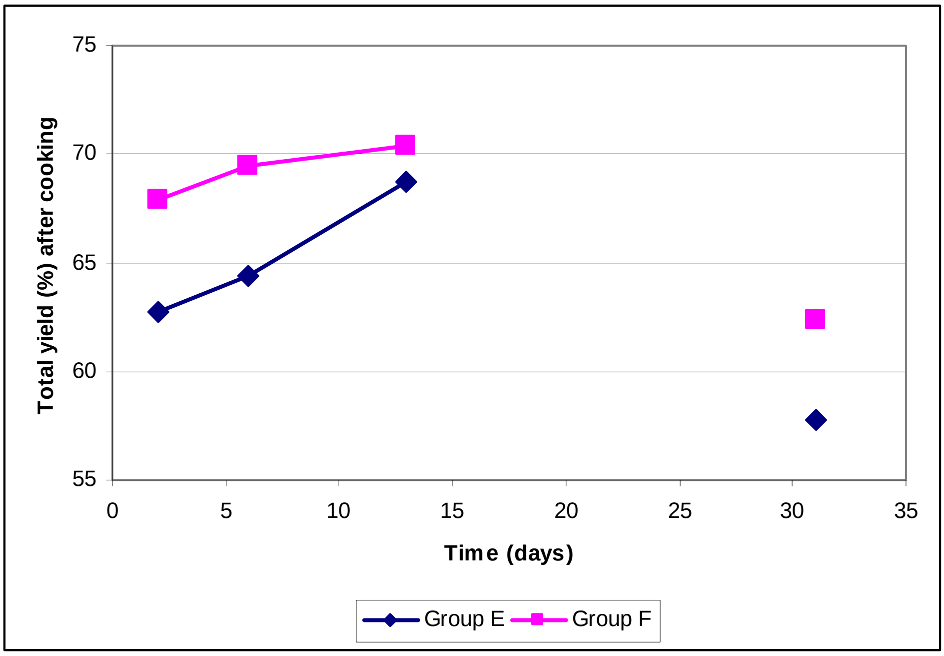

Figure 25 Total yield (%) after cooking of the haddock fillets after various storage times (n = 8) at -1.5°C. The samples on day 31 were frozen (-24°C) for 1 month (n = 5). Group E = Traditional. Group F = CBC super-chilled

Water holding capacity

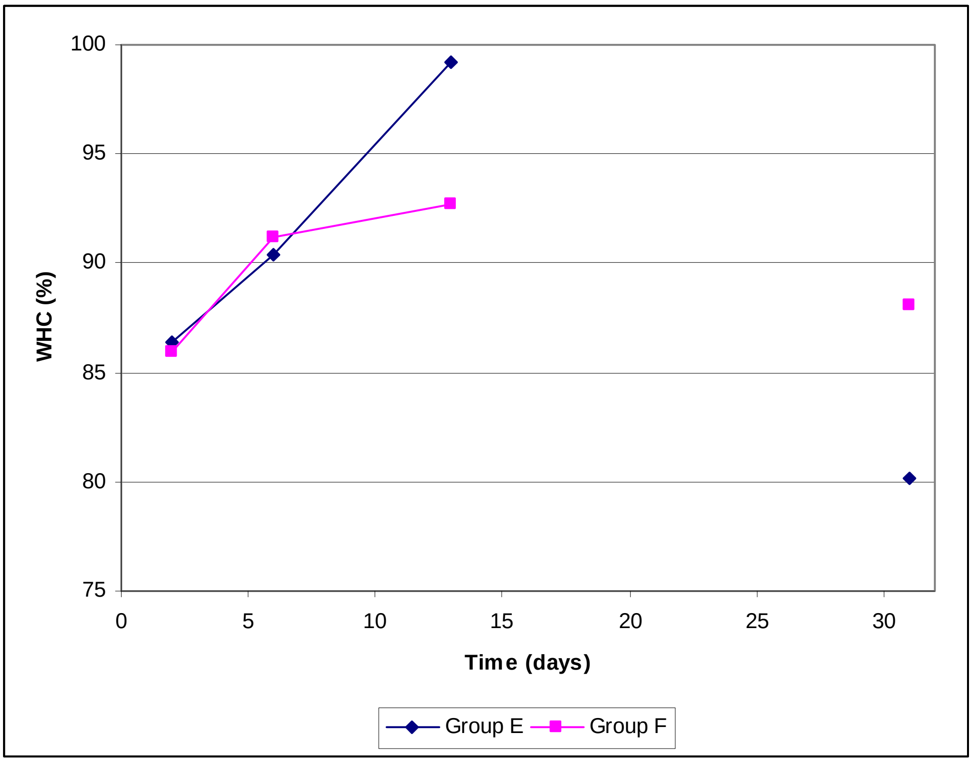

Figure 26 Water holding capacity (%) of haddock fillets after various storage times (n = 3) at -1.5°C. The samples on day 31 were frozen (-24°C) for 1 month (n = 3). Group E = Traditional. Group F = CBC super-chilled.

The water holding capacity (***Figure 26***) was similar for both groups on day two and day six ($P>0.05$). On day 13 the traditional fillets showed better water holding capacity ($P<0.05$). This is due, as explained above, to the fact that the traditional fillets had lost most of their lightly bound and free moving water during storage. The CBC super-chilled fillets are therefore a better choice, because they hold better onto the water and are therefore juicier. After 1 month stored at -24 °C the CBC super-chilled fillets showed much better water holding capacity ($P<0,05$) than the traditional fillets. This also confirms that the CBC super-chilled fillets hold better onto the water.

Chemical composition

Water and salt content was measured in the final products was measured at each sampling day (Table 2). There was a small difference between the traditional fillets and the CBC super-chilled fillets. According to this, the fillets did not absorb much water by going through the pre-cooler. The weight the fillets gained after the pre-cooler step was therefore caused by salt absorption.

The salt content in the CBC super-chilled fillets was 0.6% at the highest and the fillets are therefore qualified as fresh unsalted fillets according to European and US standards. In Europe the maximum salt content in the flesh is ~0.7% for fish to be considered fresh but ~1.1% in USA.

Table 2 Water and salt content (n = 3), in the final products, fillets after various storage times (n = 3) at -1.5°C. The samples on day 31 were frozen (-24°C) for 1 month (n = 3).

	Traditional fillets (Group E)		***CBC super-chilled fillets (Group F)***	
	Water [%]	**Salt [%]**	**Water [%]**	**Salt [%]**
Day 2	83.4 ± 0.4	0.2 ± 0.1	83.4 ± 0.4	0.4 ± 0.1
Day 6	83.0 ± 0.4	0.2 ± 0.1	82.6 ± 0.4	0.5 ± 0.1
Day 13	83.3 ± 0.4	0.2 ± 0.1	81.4 ± 0.4	0.4 ± 0.1
Day 31	81.06 ± 0.4	0.3 ± 0.1	80.4 ± 0.4	0.6 ± 0.1

By applying mass balance calculations (2) we can determine the yield of water and salt free dry matter after each storage time. The yield after storage (Figure 23) is used in the calculations.

$$\text{Yield of water} = \frac{\text{Yield after storage x measured water content}}{\text{Water content in raw fillets}} \quad (2)$$

Table 3 Yield of water and salt free dry matter, when massbalance calculations are applied. Sampling after 2, 6 and 13 at -1.5°C, and 1 month at -24°C. Group E = Traditional fillets. Group F = CBC super-chilled fillets.

		Water yield (%)	**Yield of salt free dry matter (%)**
Day 2	*Group E*	81.0	81.0
	Group F	86.4	85.3
Day 6	*Group E*	83.0	85.4
	Group F	87.2	90.7
Day 13	*Group E*	77.6	78.2
	Group F	82.1	93.4
Day 31	*Group E*	71.3	81.4
	Group F	71.3	87.8

According to table 3 the CBC super-chilled fillets showed higher water yield at each sampling day. This points to better water binding properties in the CBC super-chilled fillets, which gives a juicier product. In fish with low fat content, like haddock (~1.5%), salt free dry matter is considered to contain mostly proteins. Salt free dry matter is therefore a very valuable component of the product. The CBC super-chilled fillets showed higher yield of salt free dry matter on each of the sampling days.

Bacterial count and freshness

Microorganism is one of the main factors that limit products' shelf life. Bacterial count was determined on the fillets after each storage period with Iron agar. 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. The results (***Figure 27***) from day two and 13 showed slight difference in bacterial count between the groups (within the same log). On day six, there was a higher bacterial count for the traditional fillets than the CBC super-chilled, showing one log difference. This indicates more stability within the CBC super-chilled fillets. Results for the H_2S producing bacteria (black colonies) (Figure 27) from day six and 13 showed also approximately 1 log difference, but the difference in counts on day two were within the same log. These results show that the super-chilling process (CBC) can extend the shelf life of fresh haddock fillets.

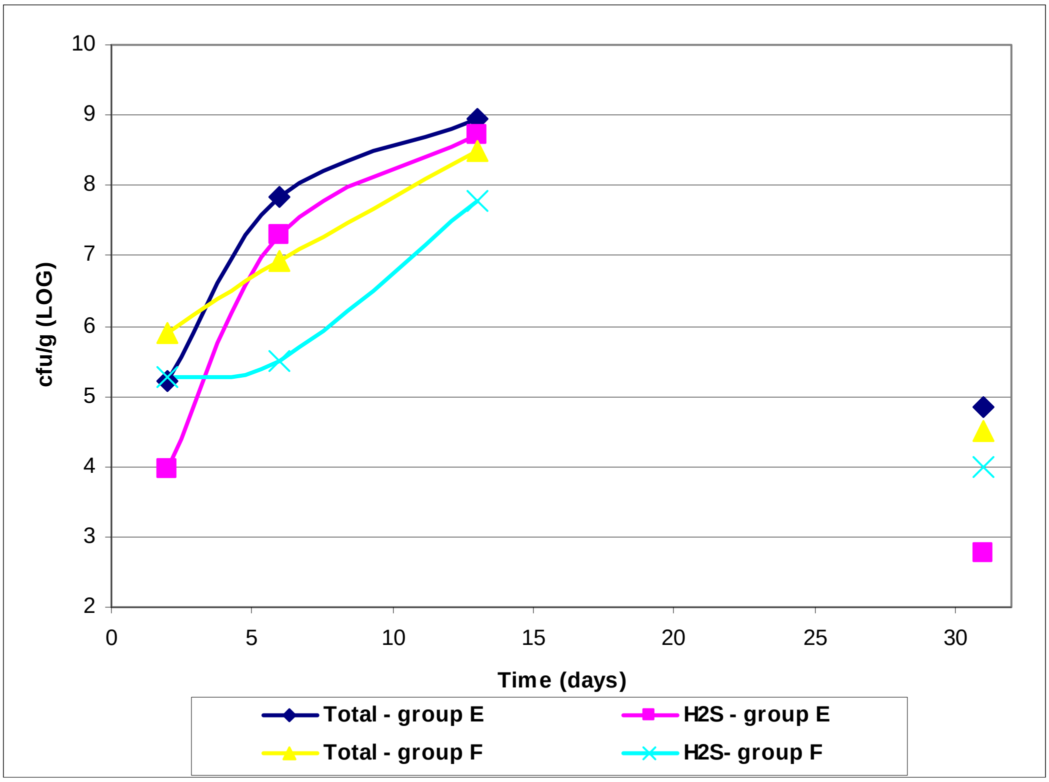

Figure 27 Total bacterial count and H_2S-producing (black) bacteria in haddock fillets (n = 3) after various storage times at -1.5°C. The samples on day 31 were frozen (-24°C) for 1 month (n = 3). Group A = Traditional fillets. Group B = CBC super-chilled fillets.

The value of TMA and TVB-N (TVN) was determined in the fillets (n = 3) after two, six and 13 days of storage (Figure 28). The value of TMA and TVN was very similar on the first days (day two and six). On day 13, however, the values for the traditional fillets ($P<0.05$) were higher. The traditional fillets also had stronger damage odour on day 13, in correlation to the increased TMA and TVB-N formation. TMA and TVN are used to determine freshness and therefore the shelf life of chilled fish. Connel (1990) reported that the threshold of TVB-N/100 g, for fish like cod or haddock for human consumption is 35-40 mg TVB-N/100 g. These results show that CBC super-chilling gives longer shelf life.

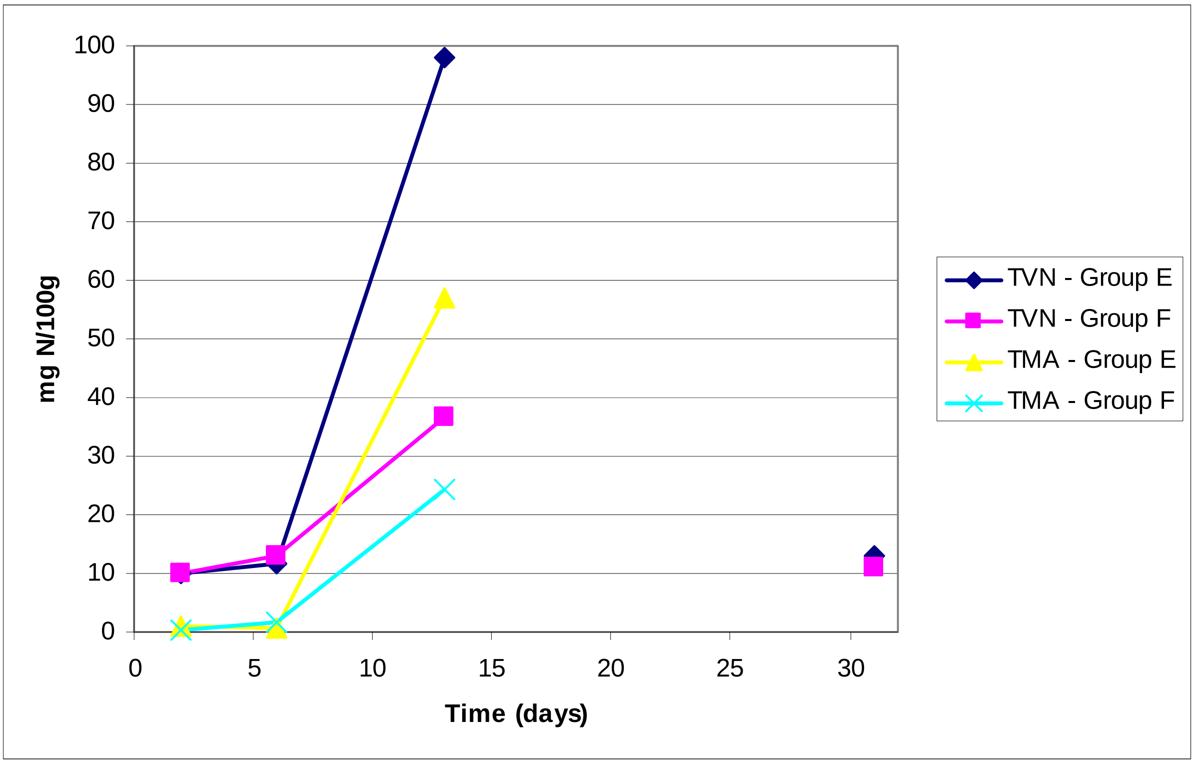

Figure 28 TMA and TVN in haddock fillets (n = 3) after various storage times at -1.5°C. The samples on day 31 were frozen (-24°C) for 1 month (n = 3). Group A = Traditional fillets. Group B = CBC super-chilled fillets.

Appearance of the fillets

The fillets were compared visually after the process (***Figure 29***-32) and various storage times at -1.5°C (***Figure 33***-36) and 1 month at -24°C. A comparison of appearance of the fillets after skinning did not show much difference in gaping but the traditional fillets had more ragged outlines, and the ratio of cut-offs after fine-trimming was therefore higher for the traditional fillets than the CBC super-chilled fillets.

Appearance of the traditional fillets showed a little yellow tinge which increased during the storage time. The CBC super-chilled fillets had a whiter and a more "fresh" appearance and were therefore more attractive.

Figure 29 The traditional fillets (group E) after skinning and before fine-trimming

Figure 30 The CBC super-chilled fillets (group F) after skinning and before fine-trimming.

Figure 31 The traditional fillets (group E) after fine-trimming (outlines).

Figure 32 The CBC super-chilled fillets (group F) after fine-trimming (outlines).

Figure 33 The traditional fillets (group E) on day 2, stored at -1.5°C.

Figure 34 The CBC super-chilled fillets (group F) on day 2, stored at -1.5°C.

Figure 35 The traditional fillets (group E) on day 6, stored at -1.5°C.

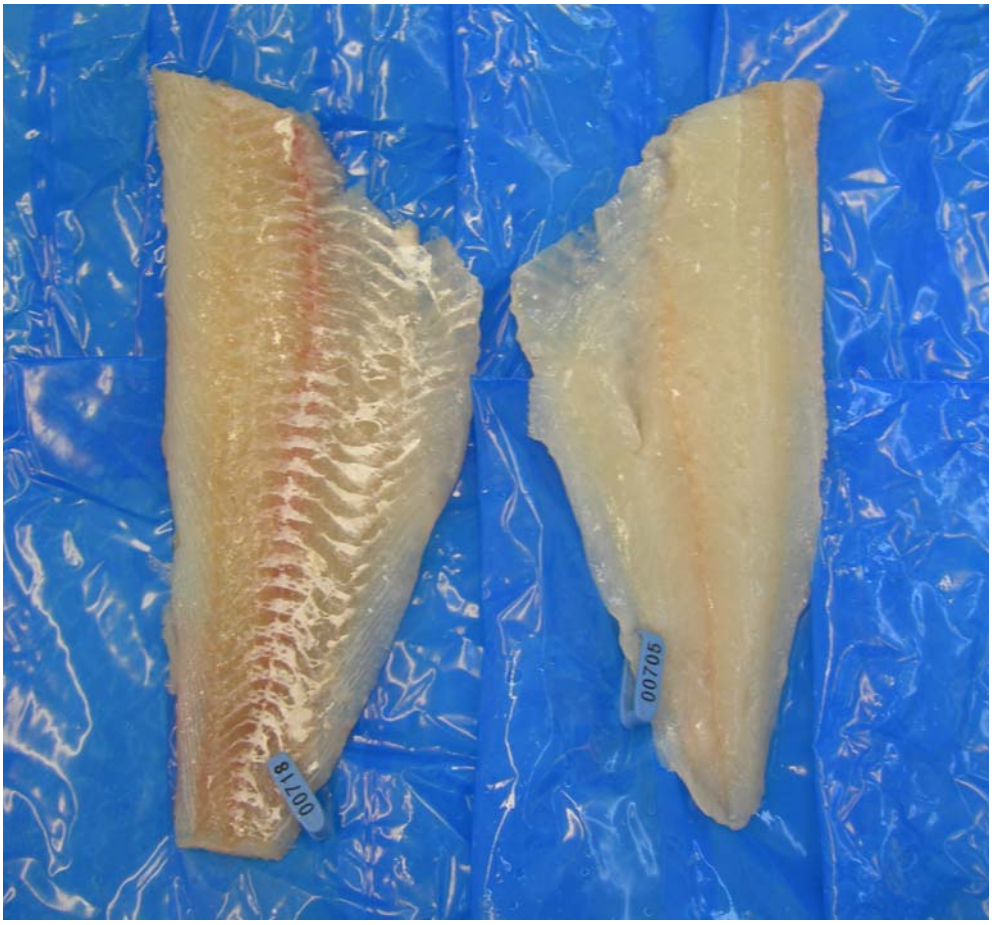

Figure 36 The CBC super-chilled fillets (group F) on day 6, stored at -1.5°C.

Figure 37 The traditional fillets (group E) on day 13, stored at -1.5°C.

Figure 38 The CBC super-chilled fillets (group F) on day 13, stored at -1.5°C.

Figure 39 The traditional fillets (group E) after 1 month at -24°C.

Figure 40 The CBC super-chilled fillets (group F)s after 1 month at -24°C.

CONCLUSION

After the pre-cooler step the fillets gained weight with yields of 101.6% to 102.7%. After the CBC super-chilling the fillets had final yields of 100.3% to 101.2%. After skinning the fillets without refrigeration (traditional process) lost most weight. Fillets which were pre-cooled and CBC super-chilled showed the best yield of the groups which indicates that the chilling process gives a higher yield than the traditional process. The process yield from whole gutted haddock is higher for the CBC process than the traditional, 41.0% and 38.5%, respectively.

The highest value of cooking yield was obtained in CBC super-chilled fillets with skin on. Skinless traditional and CBC super-chilled fillets showed similar cooking yield ($P>0.05$). CBC super-chilling increased the total yield of the fillets. The difference between the traditional fillets and the super-chilled fillets was significant.

The CBC super-chilling increased the water holding capacity of the fillets, but that means that super-chilled fillets have a greater water holding capacity, an important quality attribute which gives a more juicy final product.

The appearance of the CBC super-chilled fillets was much better and with less gaping than the traditional fillets. The traditional fillets had more ragged outlines, and the ratio of cut-offs after fine-trimming was therefore higher for the traditional fillets than the CBC super-chilled fillets. Appearance of the traditional fillets showed a little yellow tinge which increased during the storage time. The CBC super-chilled fillets had a whiter and more “fresh” appearance and were therefore more attractive.

Examination of total bacterial count, and amount of TMA and TVN showed that the CBC super-chilling process can extend the shelf life of fresh haddock fillets.

The overall assessment is that the CBC super-chilling process has more advantages than a traditional process without any additional refrigeration. The CBC creates better yields and therefore more valuable products with extended shelf life. Increased shelf life of fresh fish leads to more potential for export, which is very important for the fishing industry.

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APPENDIX

Table 4 Total bacterial count on Iron agar and H_2O producing (black) bacteria.

	Traditional fillets		***CBC super-chilled fillets***	
Day	**Total [cfu/g]**	**Black [cfu/g]**	**Total [cfu/g]**	**Black [cfu/g]**
2	160,000	9,000	810,000	190,000
6	68,000,000	20,000,000	8,300,000	310,000
13	890,000,000	53,000,0000	310,000,000	60,000,000