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Effect of salting and cold-smoking procedures on Atlantic salmon originating from pre-or post rigor filleted raw material. Based on the measurement of physiochemical characteristics

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Abstract :

Different methods in use for cold smoking of salmon affect product yield and quality. The combinations of filleting time (pre or post), salting methods (dry or injection), salting targets (2.5 or 4%) and smoking temperatures (15 or 25 °C) were studied during 6 weeks of 4 °C cold storage. Salting method had the greatest influence on flesh quality. Injection salting led to 15% higher fillet yield, moderate to strong gaping score, softer texture, and paler fish compared with dry salting. Pre-rigor filleting reduced fillet gaping from a moderate to minor score, but only in dry salted fillets. Smoking at 15 °C reduced yield by 0.5% in injected salted fish, compared with 25 °C. The combination of pre-rigor filleting, dry salting and 15 °C smoking temperature gave the lowest gaping incidence and highest shear force and flesh colour. Liquid loss increased by 240% and the L-value by 6.5 units during 6 weeks cold storage, whereas the other quality parameters measured showed only small changes during the storage period.

Highlights

► Salting technique is more important for flesh quality than filleting time, salt target and smoking temperature. ► The combination of pre-rigor filleting, dry salting and 15 °C smoking temperature gave lower gaping, higher shear force and colour. ► Injection salting increased fillet yield. ► Liquid loss increased during cold storage.

Keywords : Salmo salar, Flesh quality, Texture, Liquid loss, Fillet yield, Cold storage

1 Introduction

In 2016, Norway produced 1233 000 metric tons of farmed Atlantic salmon (*Salmo salar* L.) (Statistics_Norway, 2017). A substantial part of this is exported to other European countries, where it is processed as cold smoked salmon for the European market. Large quantities of Norwegian salmon is exported as whole gutted fresh fish on ice, arriving 3 to 5 days post mortem at a processing company for further filleting and processing to produce cold smoked products. Modern slaughter technology reduces pre-slaughter stress allowing industrial pre rigor filleting. Pre rigor filleting has positive effects, increasing the freshness of fish at market, reducing total weight of fish handled to exported fillets only. Pre rigor filleting increases fillet thickness, reduces the incidence and severity of gaping and increases colour

score in raw Atlantic salmon compared with filleting post rigor (Skjervold et al., 2001b, Taylor et al., 2002).

The smoking process includes several steps, and for each the choice of control parameters such as salting method, concentration of brine, or smoking temperature determines specific finished product characteristics (Cardinal et al., 2001, Birkeland et al., 2003, Birkeland and Bjerkeng, 2005, Birkeland et al., 2007). Processing salmon fillets while still in pre or in-rigor state is possible, but studies have shown that salt uptake is reduced compared with post rigor fillets (Wang et al., 1998, Rørå et al., 2004). No work has addressed the effect of pre rigor filleting on the uptake of salt and smoke when processed post rigor, compared with post rigor filleting. The change in fillet shape might affect the microstructure and thereby the absorption rate of salt and smoke within the muscle, as well as gaping and colour of the final product.

Different salting methods are reported to affect the yield, fillet colour, texture and gaping in salmon (Sigurgisladottir et al., 2000, Cardinal et al., 2001, Birkeland et al., 2003, Birkeland et al., 2004a, Martinez et al., 2012). Cold smoked salmon on the European market typically contain between 1.7 % to 5.1% salt in the water phase (Cardinal et al., 2004). The uptake and distribution of salt in the fillet depends on the method used, brine concentration and brining time (Sigurgisladottir et al., 2000, Rørå et al., 2004, Birkeland et al., 2007). Salt can be added by dry salting, brine salting or injection salting. Traditionally the two first methods are commonly used by the salmon processing industry (Espe et al., 2001, Mørkøre et al., 2001). However injection salting is a rapid curing method which results in a significantly higher yield after both salting and smoking (Birkeland et al., 2003, Birkeland et al., 2007). This contrasts with dry salting where water leaks out of the fish, resulting in a lower yield after salting and smoking (Cardinal et al., 2001). The type of salting method chosen will therefore have an economic impact.

Most of the available literature on smoked salmon refers to smoking temperatures between 20 and 30°C (Sigurgisladottir et al., 2000, Cardinal et al., 2001, Espe et al., 2001, Birkeland et al., 2004b, Hultmann et al., 2004, Rørå et al., 2004, Løje et al., 2007, Varlet et al., 2007). Smoke contains several phenolic compounds imparting taste to the product, the absorption of which is dependent on smoking temperature and smoking time (Cardinal et al., 2001, Sérot et al., 2004). Texture and liquid loss of Atlantic salmon changes with smoking temperatures between 20 and 30°C, higher temperatures increasing both texture as well as liquid loss (Cardinal et al., 2001, Hultmann et al., 2004). Although there is smoked salmon on the market processed below 20°C, literature about the effect of such low temperatures on absorption of smoke components and flesh quality is sparse.

Although there are many published studies on cold smoked salmon, few deal with the combined effects of different processing procedures. There is no published literature on differences in salt and phenolics uptake in pre and post rigor filleted salmon, when both are salted post rigor, or the effect of smoking temperatures below 20°C. There are also few studies dealing with the stability of liquid loss, colour and texture in smoked salmon during cold storage for more than 2 weeks. Therefore, this study aimed to examine the effects of time of filleting (pre or post rigor) and different aspects of the smoking process on smoked salmon quality. We assessed the combined effects of dry versus injection salting, 2.5 versus 4.0% salt concentration, and 15°C versus 25°C smoking temperature on yield, texture, fillet gaping, colour, chemical content and microstructure, during both the manufacturing process and cold storage for up to 6 weeks.

2 Materials and methods

2.1 Raw materials

Farmed superior Atlantic salmon (*Salmo salar*, weight 4267 ± 247g, n=208) were slaughtered locally at Marine Harvest, Sotra, Norway. The fish had been fed commercial feed from Skretting (Atlantic XE 2000 and Orion XE 12mm, both containing 50 mg astaxanthin and 40% lipid), during the last 6 months before slaughter. All fish were dispatched on the same day using the slaughterhouse commercial procedure for slaughtering, bled in chilled seawater, gutted and washed. One half of the group (104 fish) was immediately filleted and trimmed manually at Institute of Marine Research (IMR), Matre, Norway. Before onset of *rigor mortis* (pre rigor), fillets from both sides were individually marked, packed in plastic and covered with ice. The remaining 104 fish were gutted, packed on ice, and shipped to IFREMER (French Research Institute for the Exploration of the Seas), Nantes, France. Here they were kept for 5 days post harvest, to ensure fish were out of *rigor mortis* (post rigor), before being filleted and trimmed manually and both fillets individually marked. All salting and smoking procedures took place at IFREMER.

2.2 Processing

Salting methods

Two salting methods (dry or injection; DS or IS), two salt targets (2.5% or 4.0% in smoked fish muscle; S2.5% and S4.0%) and two smoking temperatures (15°C or 25°C; T15°C and T25°C) were trialled, resulting in 16 different treatment groups with 22 fillets per group. The two fillets from the same fish were processed using the same salting procedure, and thereafter right and left fillet were smoked randomly at either 15°C or 25°C. A total of 32 fish, 16 pre rigor and 16 post rigor, were left unprocessed and used for raw material analyses (Figure 1).

For dry salting fillets were placed on grids and covered with rock salt (Salinor) with E535 and ferronitrite (20 mg/kg). Fillets were dry salted for 5 hours to achieve 2.5% salt concentration in the smoked salmon muscle, and for 12 hours to achieve 4.0% salt concentration. Afterwards the fillets were rinsed briefly with water (15°C). Brine-injection, 160 g L^{-1} or 300 g L^{-1} (to achieve 2.5% or 4% salt concentration in smoked salmon muscle respectively) was carried out with a Injecstar B 152/72 injector modified for fish (equipped with 72 needles, 2 mm in diameter). Injection pressure was < 2 bar, and all fish were injected for 60 seconds.

Cold smoking

Smoking was carried out in a closed air-conditioned cabinet equipped with an auto-combustion independent generator using beech sawdust with 20% (w/w) water added to the wood, air speed 2 m/s. Fillets were randomly distributed on the cabinet's grids and smoked at 15°C for 4h, or at 25°C for 2h. Brine-injected fillets were dried before smoking to control the final water content of the product: 3 hours at 15°C for the 15°C samples and 2 hours at 22°C for the 25°C samples.

Slicing and storage

All fillets were stored at 4°C overnight before one fillet from each fish was sliced and vacuum packed, three slices per packet, 4-5 packets per fillet. The other fillet was kept whole. Both vacuum-packed slices and whole fillets were cold stored at 4ºC for 1, 2, 4 or 6 weeks before further analysis (Attachment 1). Five or six fish per group was analysed for each storage time.

2.3 Analysis

Each fillet was weighed and analysed for gaping and colour before and after processing. From the raw unprocessed fillets (64 fillets) and from the whole processed fillets (176 fillets), the entire section under the dorsal fin was sent to Technological Institute of Iceland, Iceland (IceTec), for analysis of texture shear force and microstructure. IMR received the remainder of each fillet for analyses of astaxanthin, water and fat.

Shear force was analysed in raw and processed fillets immediately on arrival at IceTec (4 days after smoking), and after 1, 2, 4 and 6 weeks of cold storage. Microstructure was analysed in injection salted fillets only, 32 raw and 32 processed fillets. Vacuum-packed slices with processed salmon were analysed for salt and phenol content after 1 week, pH after 2 weeks, and colour and liquid loss after 1, 2, 4 and 6 weeks of cold storage. Fat, water and astaxanthin content were analysed in raw fillets immediately after arriving IMR, and in vacuum packed slices of processed fish after 1 and 4 weeks of cold storage (Attachment 1).

2.3.1 Fillet yield

Fillet yield is a measure of the change in fillet weight during salting and smoking. Total fillet weight was measured on raw fillets (5 days post mortem) and after processing. Fillet yield was calculated according to the formula:

Fillet yield %: = (Wprocessed - Wraw) x $Wraw^{-1}$ x 100%

Where Wraw = weight (g) of raw fillet and Wprocessed= weight (g) of processed fillets.

2.3.2 Gaping score

Gaping score was assessed visually on whole fillets, along the head-tail axis and was independent of fillet length. A scale from 1 to 4 was used; where 1 is no gaping, 2 minor gaping (gaping covering 1-5 cm longitudinally of the fillet), 3 moderate gaping (6-10 cm) and 4 strong gaping (> 10 cm). Fillets were not subjected to removal of pin bones.

2.3.3 Flesh colour

Flesh colour was measured at six locations evenly spread over the whole raw and newly smoked fillet. During cold storage, colour was measured at three locations in each of three vacuum packages per treatment group and storage time. The colour was quantified using a portable Hunterlab Miniscan/EX instrument (10° standard observer, illuminant D65, Hunter Associates Laboratory Inc, 11491 Sunset Hills Road, Reston, Virginia, USA) calibrated to a white and a black standard. The L* variable represents lightness (L* = 0 for black, 100 for white), the a* scale represents the intensity of red and the b* scale the intensity of yellow.

2.3.4 Shear force

Shear force was assessed using a Texture Analyser (TA-XT2 Texture Analyser; Stable Micro system, Haslemere, Surrey, UK), equipped with a V-shaped blade with a thickness of 3.2 mm, height 125 mm and width 70 mm. The blade cut into fillet samples at a speed of 3 mm/s. The maximum peak force (N) required to shear through the sample was recorded as shear force, and was regarded as the toughness of the fillet.

2.3.5 Microstructure

Samples for microstructure analysis were collected from the white muscle below the dorsal fin. Preparation of samples, cryo-sectioning, staining and image viewing was as described by Sigurgisladottir et al. (2001). Samples were taken from the fillets using a cork knife and frozen in liquid nitrogen. Specimens were sectioned frozen at -27°C in a cryostat (Leica CM1800, Heidelberg, Germany) for transverse cuts, 10 μm thick, and stained with Orange G and then methyl blue. The samples were examined under a microscope (Leica DMRA2) at

100x and 200x magnification. A minimum of 300 cross sections of white muscle fibre were measured from each fish.

2.3.6 Chemical analysis

Duplicates of 1 g (±0.0001 g) fish muscle homogenate were weighed into extraction tubes for analysis of astaxanthin, and 1.5-2 grams of anhydrous Na_2SO_4 added and adjusted to 10 ml with acetone. Astaxanthin was separated from other carotenoids on an HPLC system (Hewlett Packard Series 1100, Hewlett Packard Company, Germany) using acetonitrile/ dichlormethane/methanol/water/propionic acid (68:22:4:3:3, v/v/v/v/v) as the mobile phase, flow rate was 1.0 ml min^{-1}, temperature 1°C, and absorption of astaxanthin determined at 476 nm. The concentration of astaxanthin was determined using external standards. Crystalline astaxanthin (Hoffmann-La Roche, Basle, Switzerland), was dissolved in an acetone/chloroform mixture (85:15) to produce a stock solution containing 120 μg ml^{-1} astaxanthin, and further diluted with acetone to provide working standards. The astaxanthin content of the standard solutions was determined with a spectrophotometer at 476 nm, assuming an extinction coefficient of 2100.

The other chemical analyses were performed in triplicate. Dry matter content was analysed by oven drying of 3 g salmon at 105°C until a constant weight was reached, while total fat was determined gravimetrically after extraction with ethyl acetate. Total phenol was quantified by the method described in the French standard for smoked salmon (NF V 45-065, 1995). Salt content was measured with a Chloride Analyser 926 (Corning, Halstead UK).

2.3.7 Liquid loss

Slices of 16 g (±0.0001g) processed salmon were placed on pre-weighed absorbent pads (13x9 cm), made of perforated plastic and filled with absorbent material (Cryovac Norway,

A/S, Oslo, Norway). The fish and pad were covered with aluminium foil, left at 20°C for 20 hours, the aluminium foil and fish removed, and the pad weighed for calculation of liquid loss (Mørkøre et al., 2002). Liquid loss % = Increase in pad weight x (fish weight)$^{-1}$ x 100.

2.4 Statistical analyses

Analysis of variance was carried out using the General Linear Model (GLM) module of the IBM SPSS Statistics software package (Version 20, 2011) The time of filleting (pre or post rigor), salting method (dry or injection salting), salt target (2.5 or 4%) and smoking temperature (15 or 25°C) were entered as treatment factors into full factorial models. Separate univariate analyses were performed for each response variable. Storage time (1, 2, 4, and 6 weeks) was used as a covariate in the model when analysing parameters measured during storage. Only significant interactions are reported. Data presented in figures and tables, except for fillet yield, are mean values based on those effects with highest significance in the GLM. Fillet yield was analysed using the non-parametric Mann Whitney U-test. Other data analysed using one-way anova, followed by a Student-Newman_Keul *post hoc* test. Correlation between selected parameters was analysed using a Pearson correlation test. Treatment group averages are reported as mean ± standard deviation in tables, figures and text. A significance level of $p<0.05$ was chosen.

3 Results

The raw fillet mean weight was 1408±91 g, and the mean values of astaxanthin, fat and water in the raw fillets 5.33±0.79 mg kg^{-1}, 15.8±1.8 g kg^{-1} and 64.2±1.6 g kg^{-1} respectively. The mean colour of raw fillets were 55±1, 26±1 and 23±1 for L*-, a*- and b*-values respectively. The salt target chosen (S2.5% and S4.0 %), was only achieved for IS fish,

242 whereas DS had 25 % and 40% lower salt content than the respective levels of IS fish (Tab.2).
243 Mean pH values were 6.1±0.1 after processing and 6.3±0.1 after 2 weeks of storage.
244 Treatment effects analysed with anova and their interactions on processed fish are shown
245 in table 1.
246

247 *3.1 Fillet yield*

248 Salting method had a strong influence on the fillet yield in smoked fish (Fig.2). Fillet yield
249 was 92.7±0.7% in DS groups, equivalent to a 7 % weight reduction compared with raw fillets.
250 The yield for IS fillets was 106.7±1.8%, or a 6-7% weight increase compared with raw fillets.
251 In total, the weight differences between IS and DS fillets after smoking was 14-15% (Fig 2)
252 (Independent Mann-Whitney U-test, $p<0.001$). There was a significant effect of salting target
253 and smoking temperature on fillet yield, but this was small. S2.5% gave 1% higher fillet yield
254 than S4.0%, and IS-T25°C fillets had 0.5% higher fillet yield than IS-T15°C (effect of
255 temperature on yield in dry salted fish = NS).
256

257 *3.2 Gaping and microstructure*

258 Gaping score was significantly affected by filleting time and salting method (Fig.3A). IS
259 resulted in 1-2 higher gaping score, independent of filleting time. In DS fish, pre-rigor
260 filleting reduced the gaping incidence compared with post-rigor filleting, whereas no such
261 effect was seen in the IS fish. Significantly larger white muscle fibre area characterised pre-
262 rigor filleted fish (Fig. 3B).
263

264 *3.3 Shear force, liquid loss, L- and a*-value)*

265 Shear force, liquid loss, L-value and a*-value over 6 weeks of cold storage are shown in
266 Fig.4. Shear force was affected by filleting time, salting method and smoking temperature

(Tab.1). Post rigor filleting DS-T15°C, was characterised by higher shear force than pre-rigor filleting IS-T25°C. Shear force was not affected by storage, remaining consistent throughout the 6 weeks of cold storage. There was a significant interaction between salting method and salt target, where a slightly higher shear force was apparent at S2.5% in DS fish, but this was reversed in IS fish. In the IS group, S4.0% resulted in 1 newton higher shear force compared with S2.5%. Liquid loss (LL) was affected by salting method and storage (Tab.1). LL increased during storage and was higher in DS than IS after 6 weeks of storage. DS resulted in significantly lower L-value and higher a-value, (Fig.4C, 4D, Tab.1). The L-value was also affected by salt target and smoking temperature. Approximately the L-value was one unit higher at S2.5% compared with S4.0% (mean values not shown), and similarly one unit higher at T25°C compared with T15°C.

3.4 Chemical content

Filleting time had no significant effect on salt and phenol content, but phenol was affected by salt target and smoking temperature. Phenol content was higher in fillets smoked at 15°C compared with 25°C. At T25°C phenol content was affected by salt target, being lower at S4.0% (Fig.3C).

Table 2 shows the result for astaxanthin, salt, fat and water in processed fillets. Retention of astaxanthin through the smoking process was affected by both salting method and smoking temperature (Tab.1). DS-T15°C had 1.5 mg kg^{-1} higher astaxanthin content than IS-T25°C after the first week of storage. DS fillets had 2% higher fat content than IS fillets in the first week after smoking, but the differences disappeared during 4 weeks of storage. DS fillets also had significantly lower water content than IS. There was a significant effect of increased salt target, resulting in lower water content.

3.5 Correlation

Shear force showed a negative overall significant relationship with gaping ($r=-0.33$, $p<0.001$, $n=46$) and with the L-value ($r=-0.44$, $p<0.001$), which means firmer fish has less gaping, and darker flesh. Liquid loss was not related to fat or water content, but was positively related with the L-value.

4 Discussion

4.1 Effect of filleting time

Pre-rigor filleting reduced fillet gaping, which has been observed in raw salmon fillets (Skjervold et al., 2001b). The phenomenon of gaping, the process where a fillet separates into myocomata, renders the flesh unsuitable for production of high value products such as slices of cold-smoked salmon. Fillet gaping, texture, and colour are important issues for the smoked processing industry, and are reason for complaint. Earlier studies have shown that pre-rigor filleting results in firmer texture (Skjervold et al., 2001a). This was not the case in our study, as lower shear force was found in pre-rigor fillets after smoking. When muscles are going through rigor mortis without being attached to the backbone, the myofibres can shorten, with an increase in white muscle fibre area or diameter as a result, as apparent in our study. Skjervold comparing fresh pre and post rigor filleted Atlantic salmon 7 days post mortem found no differences in muscle fibre diameter between groups (Skjervold et al., 2001b).

4.2 Effect of salting method

The salting method, dry or injection, was the factor most strongly influencing quality of smoked salmon. IS resulted in 14-15% higher yield than DS. Yield is a crucial economic issue for smoking companies, and similar differences in product yields have been reported in previous studies (Sigurgisladottir et al., 2000; Cardinal et al., 2001; Torrissen et al., 2001;

Mørkøre et al., 2001; Birkeland et al., 2003; Birkeland et al., 2004). In DS the initial brine film on the fillet surface will transfer water from the fish, dissolving salt crystals near the surface. Water will leak from the fish reducing fillet weight. During IS, water and salt are injected into the fish muscle. With salt concentrations below 1M brine, as in our study, salt will bind to protein, so the water added will stay inside the muscle dissolving salt crystals and leading to an increase in fillet weight (Barat et al., 2003). This contention is supported by the higher water content of injection-salted fillets, which also led to a lower percentage of fat in this product.

Reduced gaping in DS compared with IS has previously been reported (Birkeland et al., 2004a). IS involves needles piercing the flesh, as well as brine being forced into the fillets. It is not unexpected that such treatment may affect the fine connection between muscle fibres and connective tissue, thereby increasing gaping score. A combination of pre rigor filleting and DS resulted in the lowest gaping score in our study, whereas post rigor filleting and IS increased gaping score by 1.5 - 2 units. Higher shear force in DS compared to IS is in agreement with other studies (Birkeland et al., 2004a). The shear force in DS was 25% higher than in IS.

Darker colour score and higher astaxanthin content in DS salmon has been reported previously (Choubert et al., 1992, Cardinal et al., 2001, Birkeland et al., 2004a, Birkeland et al., 2004b, Martinez et al., 2012). Colour is affected by changes in the fillet surface, contingent upon changes in surface structure or water content, making dry salted fish appear darker. A higher astaxanthin content may be due to higher preservation and less pigment oxidation in DS compared with IS. But it can also be a consequence of water loss during dry salting, as argued by Choubert et al. (1992). In contrast Birkeland et al. (2004b) found no influence of salting method (dry or injection) on astaxanthin in Atlantic salmon.

The leaking of liquid in vacuum-packed smoked salmon is a well-known issue and may lead to downgrading of the product. The higher liquid loss in DS fish after 6 weeks might be related to higher protein denaturation in this group. Increasing salt content has been shown to increase liquid loss in cooked salmon, but at higher salt content levels than in our experiment (Ofstad et al., 1995).

4.3 Effect of salt target

The lower salt concentration achieved in the DS groups may have prevented direct comparison of the groups. Salt target had little influence on salmon fillet quality, only affecting fillet yield, water content and L-value.

The lower water content and fillet yield with increasing salt content are in agreement with previous work (Jittinandana et al., 2002, Birkeland and Bjerkeng, 2005, Birkeland et al., 2007, Rizo et al., 2013). Increase in salt content decreases the stable hydrophilic surface and increases protein-protein interaction, leading to water leaking out of the fillet (Arason et al., 2014), explaining the decrease in yield with increasing salt target.

The salt content is comparable with what is normally found in French Manufacture, where 2-3% NaCl are reported. Salt together with phenol content and storage temperature are important factors controlling microbiological growth, and thereby both sensory quality and the food safety (Hwang, 2009). Though microbiology data are not available, salt level below 6 % in the water phase are not sufficient to prevent growth of the pathogen bacteria Listeria monocytogensis (Peterson et al., 1993, Truelstrup Hansen et al., 1995). But the higher salt content in the IS group should prevent any microbial growth more than in the DS group (Hwang, 2009). The salting method itself, dry or brine injection, is not found to effect growth of L.monocytogenesis (Niedziela et al., 1998).

4.4 Effect of smoking temperature

The weight gain measured as fillet yield in IS fillets was lower at T15°C than at T25°C. This is in agreement with Cardinal et al (2001), who reported higher total weight loss after smoking at 20°C compared with 30°C. This can be related to lower moisture loss in fillets smoked at higher temperatures due to case hardening, which prevents effective drying. If this is so, we would have expected higher shear force with higher smoking temperature, whereas the reverse was observed. The difference could also be an effect of the longer smoking time at 15°C.

The higher astaxanthin content at T15°C could reflect less breakdown and oxidation of astaxanthin at lower temperature, thus preserving colour. However, Birkeland and co-authors (2004b) found higher astaxanthin retention at higher temperature, 30 vs 20°C, suggesting higher temperatures cause firmer binding of astaxanthin to the protein binding sites, thereby reducing its degradation.

The higher phenol content in the T15°C group is counter to reports of phenol content increasing with smoking temperature, from 20 to 30°C for salmon (Cardinal et al., 2001), and from 16 to 32°C for herring, *Clupea harengus* (Sérot et al., 2004). The differences in phenol content between smoking temperatures in our experiments could also be affected by duration of exposure rather than the difference in temperature. This is supported by Sérot et al. (2004), who reported increased phenol content with longer duration, from 60 to 240 minutes in the smokehouse. Phenolic compounds are of considerable importance for the preservation and organoleptic properties of smoked products and increased phenol content will increase shelf life (Kjällstrand and Petersson, 2001, Hwang, 2009). The sensorial and microbiological shelf life would therefore be expected to increase with increased phenol content, as achieved with longer duration time in the smoke oven at 15°C.

4.5 Effect of storage

The acceptable shelf life of commercial smoked salmon depends on the country of export, varying from 21 to 60 days (Cardinal et al., 2004). Acceptable shelf life is normally connected to sensory deterioration (Truelstrup Hansen and Huss, 1998, Leroi et al., 2001). But also other quality issues, such as stability of colour, texture, fillet gaping and liquid loss can change during storage and are important to the consumer. Our data showed that shear force, gaping and chemical content was stable up to 6 weeks, which covers the shelf life set in many European markets. Our results are in agreement with others, finding minor changes in salmon texture during cold storage (Schubring, 2006, Martinez et al., 2012). Liquid loss is a problem in vacuum packed smoked salmon, and, in agreement with earlier studies, we found liquid loss increased with storage time (Rørå et al., 2003, Løje et al., 2007). Liquid loss is also reported to increase with higher fat content (Mørkøre et al., 2001, Birkeland et al., 2004a), but our results did not support this. It has been reported that colour of vacuum packed salmon is stable during cold storage (Bugueño et al., 2003), but our results show an increase in both redness and lightness during storage.

5 Conclusion

The combined analysis of effects of different filleting and processing methods showed that salting method has a greater impact on physio-chemical quality than filleting time, salt target or smoking temperature. Pre-rigor filleting reduces gaping in DS fillets, whereas in IS this effect was not visible. Filleting time had no effect on the absorption of phenol and salt in the fillet. IS increases yield, but leads to lower shear force, paler colour and more gaping. DS lowers yield, but gives higher shear force, more colour and less gaping. Smoking at 15°C results in lower yield and L-value, but higher shear force, phenol and astaxanthin compared with T25°C. The higher phenol content, possible due to longer exposure time at T15°C, can

increase shelf life. The combination of DS-T15°C maintained higher astaxanthin content than IS-T25°C. Liquid loss and L-value increases during cold storage up to 6 weeks, whereas only small changes are seen in other quality parameters.

Summing up, our results show injection salting is preferred if yield is the only economic issue for the producer. However, as texture, gaping and pale colour are responsible for consumer complaints about smoked salmon, the combination of pre-rigor filleting, dry salting and smoking at 15°C should be considered a viable option.

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566

Table 1. Results from analyses of variance of the data in Fig. 1, 2 and 3, where P_F, P_M, P_S, P_T are the significance level for the effects of filleting time, salting method, salting target and smoking temperature, and the interaction between selected effects respectively. Gutted body weight and storage time is used as covariate in the model for all parameters, except for gaping, microstructure and phenol where only gutted body weight is used.

						Interactions			
	P_F	P_M	P_S	P_T	$P_{store\ as\ covariate}$	$P_{F\ x\ M}$	$P_{M\ x\ S}$	$P_{F\ x\ S}$	$P_{S\ x\ T}$
Gaping	<0.001	<0.001	ns	ns	-	<0.05	ns	ns	ns
Microstructure	<0.05	-	-	-	-	-	-	-	-
Phenol	ns	ns	<0.002	<0.001	-				
Shear force	<0.01	<0.001	ns	<0.001	ns	ns	<0.05	ns	ns
Liquid loss	ns	<0.001	ns	ns	<0.001	ns	ns	ns	ns
L-value	ns	<0.001	<0.001	<0.001	<0.001	ns	ns	ns	ns
a*-value	ns	<0.001	ns	ns	<0.001	ns	ns	ns	ns
Astaxanthin	ns	<0.005	ns	<0.001	ns	ns	ns	ns	ns
Fat content	ns	<0.001	ns	ns	ns	ns	ns	ns	ns
Water content	ns	<0.001	<0.001	ns	ns	ns	ns	ns	ns

Table 2. Chemical content of astaxanthin, salt, fat and water in Atlantic salmon fillet, 1 and 4 weeks after processing. DS=dry salting, IS= injection salting, S2.5 and S4.0 refers to 2.5% and 4.0% salt target in the muscle, T15 and T25 refers to smoking temperature 15 or 25 °C. Different small letters indicate differences between groups at the same week, analysed with one-way ANOVA.

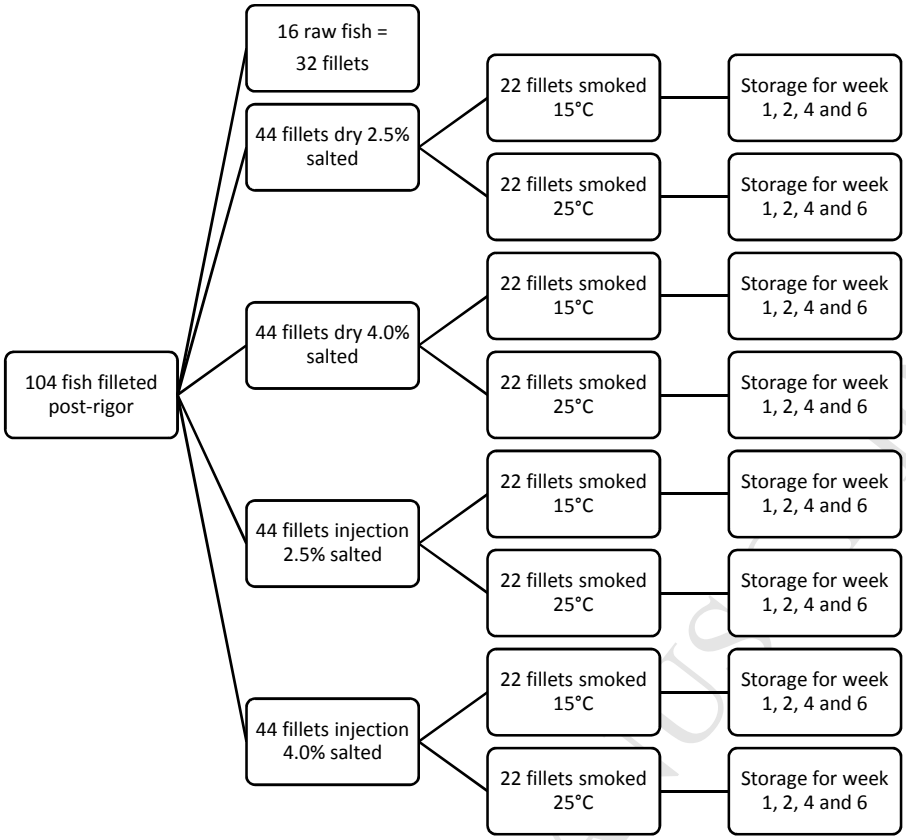
	Week	DS-T15	DS-T25	IS-T15	IS-T25
Astaxanthin	1	4.6±0.8^{ac}	3.9±1.0^{c}	4.2±0.7^{bc}	3.0±0.7^{d}
mg kg^{-1}	4	4.2±0.8^{a}	3.5±0.7^{b}	3.8±0.7^{a}	3.4±0.6^{a}
		DS-S2.5	DS-S4.0	IS-S2.5	IS-S4.0
Salt g/100g	1	1.8±0.2	2.4±0.3	2.4±0.2	4.0±0.4
Fat g/100g	1	12.4±1.7^{a}	12.1±2.1^{a}	10.3±2.3^{b}	10.4±1.8^{b}
	4	10.6±1.3^{a}	11.5±1.6^{a}	10.5±1.5^{a}	11.2±1.7^{a}
Water g/100g	1	62.9±1.0^{a}	62.1±1.1^{a}	68.2±1.6^{b}	66.6±1.5^{b}
	4	63.3±1.2^{a}	62.0±0.8^{a}	67.5±1.5^{b}	65.0±1.6^{b}

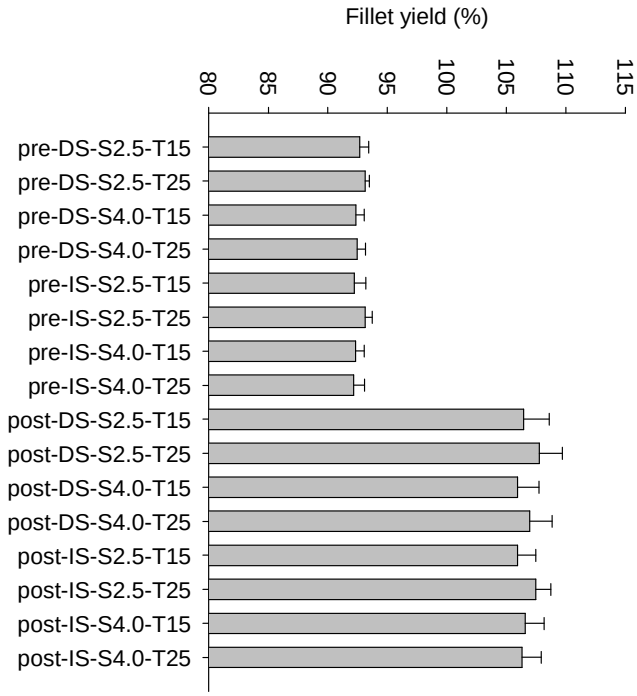
Figure 1. Flow chart for processing of post rigor filleted Atlantic salmon. Similar procedure was performed for 128 pre-rigor filleted Atlantic salmon.

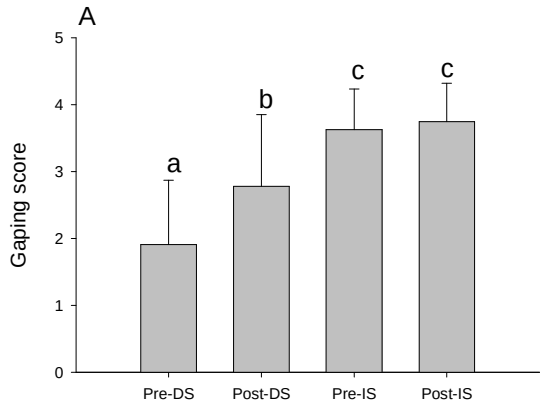
Figure 2. Fillet yield in Atlantic salmon introduced to different processing procedures; pre=pre rigor filleting and post=post-rigor filleting, DS=dry salting and IS=injection salting; S2.5=2.5% salt target and S4.0=4.0% salt target, T15=smoked at 15°C and T25= smoked at 25°C.

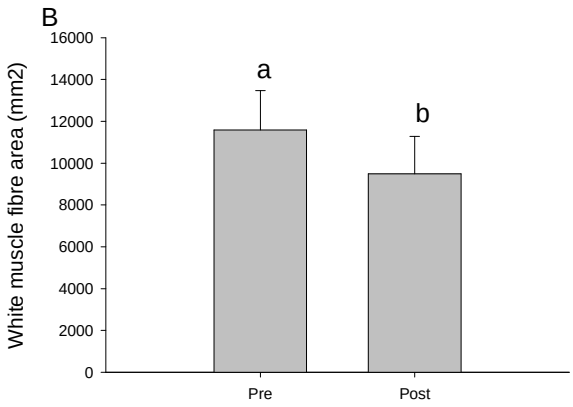
Figure 3. A) Gaping score, B) white muscle fibre cross sectional area and C) phenol content in fillets of Atlantic salmon introduced to different processing procedures; pre=pre rigor filleting and post=post-rigor filleting, DS=dry salting and IS=injection salting; S2.5=2.5% salt target and S4.0=4.0% salt target, T15=smoked at 15°C and T25= smoked at 25°C. Different letters indicate significant differences between means.

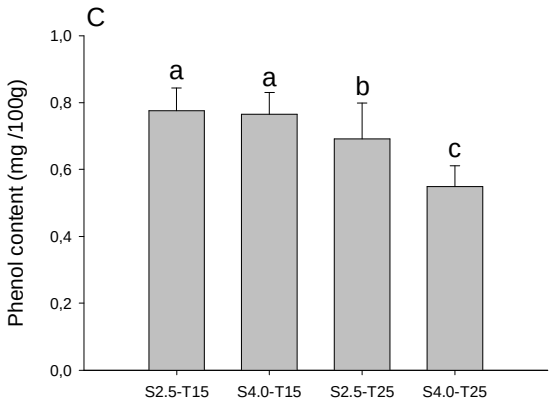
Figure 4. A) Shear force, B) liquid loss, C) L-value and D) a*-value in fillets of Atlantic salmon introduced to different processing procedures: —●— dry salting 15˚C smoking temperature, ···○··· dry salting 25˚C smoking temperature,---▼--- injection salting 15˚C smoking temperature, ---△--- injection salting 25˚C smoking temperature.






A
Gaping score
0
1
2
3
4
5
a
b
c
c
Pre-DS
Post-DS
Pre-IS
Post-IS


B
White muscle fibre area (mm2)
0
2000
4000
6000
8000
10000
12000
14000
16000
a
b
Pre
Post


C
Phenol content (mg /100g)
0,0
0,2
0,4
0,6
0,8
1,0
a
a
b
c
S2.5-T15
S4.0-T15
S2.5-T25
S4.0-T25