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Stunning, pre slaughter and filleting conditions of Atlantic salmon and subsequent effect on flesh quality on fresh and smoked fillets

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ABSTRACT

The aim of this study was to investigate how stunning methods in combination with pre slaughter conditions such as pumping and live chilling influence the flesh quality in both fresh and smoked products of Atlantic salmon (*Salmo salar*). For quality measurements, a total of 181 fish were percussive stunned at the 1) cage, 2) after pumping and 3) after live chilling, where half of the fish were stimulated with 16 s of electricity in order to simulate electrical stunning. Muscle pH and rigor index were measured for 4 days in 10 fish from each group (n=60). The other 121 fish were either pre (n=57) or post rigor filleted (n=64). After 7 days on ice storage one fillets from each fish was analyzed for gaping, color, drip loss, and texture hardness, while the other fillet was dry salted and smoked and evaluated 14 days post mortem. Muscle pH and time to onset of rigor decreased according to the number of events (pumping, live chilling and electrical stunning). For fresh fillets the filleting method was the predominant factor for the end quality overshadowing the influence of pre slaughter conditions and stunning method. Salting and smoking eliminated differences caused by slaughter or filleting methods. We conclude that the quality of Atlantic salmon is influenced in following order: stunning method < pre slaughter conditions < filleting method < processing by salting and smoking.

1. Introduction

For the Atlantic salmon (*Salmo salar*) industry there is an increasing interest to use percussive force and electricity to stun the fish prior to slaughter (Kiessling et al., 2004; Lines et al., 2003; Lines and Kestin 2005; Robb et al., 2000a; Robb and Roth 2003; Roth et al., 2004, 2007a; van de Vis et al., 2003;). Besides preventing the fish from struggling, known to have negative effects on flesh quality (Boggess et al., 1973; Kiessling et al., 2004), and allowing the industry to restrain and handle the fish for exsanguinations, the issue of immediate stunning is important to meet future demands and legislations for the aquaculture industry (Anon, 1995, 2004). Several electrical and percussive stunning devices targeting salmonid species are on the market and in use at commercial slaughtering facilities.

If a sufficient alternating current (AC) or pulsed direct current (pDC) in the range of 50–1000 Hz is applied, salmonids are stunned, where frequencies in the range of 50–100 Hz are most efficient (Lines et al., 2003; Robb et al., 2002; Roth et al., 2004). If currents are sufficient, Atlantic salmon can be stunned within 1 s measured by EEG, and the unconscious state can be identified by the presence of an epileptic insult followed by ceased opercular ventilation and lack of eye rolling (Robb and Roth, 2003).

Although the different stunning methods and their effect on welfare (Lambooij et al., 2002a,b,c; 2004, 2006a,b; Robb and Roth 2003; Robb et al., 2000a, 2002; Roth et al., 2007a; van de Vis et al., 2003) and flesh quality (Azam et al., 1989; Boggess et al., 1973; Kiessling et al., 2004; Marx et al., 1997; Roth et al., 2002, 2007b) are fairly documented , the practical knowledge and documentation of how the present stunning and slaughter methods affect the fish welfare and the quality parameters in both raw and smoked products through large/commercial scale experiments are scarce. The need for large scale experiments is required to reveal a more realistic relationship between slaughter methods and product quality as there might be a discrepancy between the experimental (small scale) and commercial conditions (large scale), whereas commercial handling and processing methods might overshadow positive and negative effects of the existing pre slaughter and stunning methods. The aim of this study was therefore to investigate the effects of stunning methods in combination with pre slaughter conditions such as; 1) slaughtering at the cage, 2) slaughtering after vacuum-pumping and 3) slaughtering after vacuum-pumping and live chilling, on the quality parameters rigor mortis development, muscle pH, drip loss during storage, muscle gaping, surface color and texture hardness in raw and smoked fillets filleted either pre or post rigor.

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2. Material and methods

2.1. General

In November 2006 at the North West coast of Norway, at the commercial slaughtering facilities at Ulvan, Marine Harvest Norway, a total of 181 market sized Atlantic salmon (*Salmo salar*) equal of 4.9±0.96 kg (SD) were slaughtered in various ways combining stunning methods (percussive and electrical) and pre slaughtering conditions (at the cage, after pumping and after pumping and live chilling). All fish used in the experiment were sampled from the same population and starved for 9–11 days prior to transport. After transport approximately 80 tons of fish were pumped into two cages and allowed to rest for 24 h before the first sampling. The experiment (Table 1) started by crowding the fish as the industry started to pump and slaughter the fish according to its practice. All fish were sampled within the hour and leftovers of crowded ($n<100$) fish were released back into its cage mixing in with the rest of the population of rested fish ($n<10.000$). On day 2 (Table 1), sampling was done as described above, and after sampling this cage was terminated from the experiment and slaughtered. Same procedure was conducted on the third day (Table 1) on the second cage of fish. Similar to the fish in cage 1, a small proportion of fish had been crowded in cage 2 the day before the experiment and released mixing with a much larger population 24 h prior to the experiment on day 3. For slaughtering the fish were pumped with a MMC double-chambered vacuum-pump (distance: 120 m) into a live chilling tank containing recycled seawater (0–0.5 °C) added with CO_2 and O_2. Oxygen levels were 82–87% at the outlet and pH of the water ranged from 5.92–6.01. The temperature at sea was 9.4 °C and in the air ranging from −0.5 to −1.5 °C. All fish were tagged, immediately gutted and placed into ice slurry before filleted or packed into styrofoam (EPS) boxes with ice.

2.2. Quality experiments

For quality experiments, a total of 181 fish were percussive stunned at the cage (C), after pumping (P) or after pumping and live chilling (L). From each slaughter location approximately 30 fish were used as a control (p) while the other 30 fish were exposed to 16 s of electricity (e), giving following combinations along the slaughtering line (Table 1):

1) At the cage (C) (Cp and Ce)
2) After pumping (P) (Pp and Pe)
3) After vacuum pumping and live chilling (L) (Lp and Le).

For electrical stimulation the fish was killed by a percussive blow in order to render the brain unconscious independent of the sample location (cage, after pumping or after live/CO_2 chilling), removing handling stress and thereby give the fish an equal start at electrical stimulation. The carcasses were within minutes exposed for 40 V_{rms}, 100 Hz AC+DC for 16 s, an setting known to stun the animals unconscious.

Of the 30 fish in the (p) and (e) groups sampled at each slaughtering point, 10 fish were used for pH and rigor measurements, while the other 20 fish were either pre rigor filleted ($n=10$) by hand or gutted ($n=10$) and stored on ice until post rigor filleting (7 days). Pre rigor fillets were wrapped in aluminum foil and stored on ice until quality analysis 7 days post mortem.

After 7 days of ice storage the gutted fish were mechanically filleted using a Carnitech™ fillet machine (Carnitec AS, Støvring, Denmark). All fillets (pre and post) were wiped with paper towels and weighted to estimate drip-loss, gaping score and color assessments. From each fish one fillet was used for texture analysis, while the other fillet was salted, smoked and vacuum packaged and stored in a refrigerated room (3 °C) for 1 week before assessment of color, drip-loss and texture (day 14).

Table 1
Number of fish sampled and average weight±SE of Atlantic salmon percussive (p) or electrical (e) stunned at the cage (Cp and Ce) or after pumping (Pp and Pe) or after live chilling (Lp and Le) on each experimental day

Experimental day	Slaughter method	Weight (g)		Filleting (*n*)		Total
		Mean	SE	Pre	Post	*n*
Day 1 Rigor/pH	Cp	4700	260.6	–	–	10
	Ce	4671	531.9	–	–	10
	Pp	4576	257.0	–	–	10
	Pe	4596	336.8	–	–	10
	Lp	4398	196.3	–	–	10
	Le	4408	289.9	–	–	10
Day 2 Flesh quality	Cp	4601	205.6	6	6	12
	Ce	4616	307.7	6	6	12
	Pp	5147	286.6	6	6	12
	Pe	4936	193.6	6	7	13
	Lp	5420	236.7	6	6	12
	Le	5253	335.3	5	7	12
Day 3 Flesh quality	Cp	5706	314.5	4	4	8
	Ce	4936	211.9	4	4	8
	Pp	4875	272.1	4	4	8
	Pe	5575	418.7	2	6	8
	Lp	5143	160.5	4	4	8
	Le	5564	220.5	4	4	8

The fish were either pre rigor filleted or stored gutted on ice for 7 days before post rigor filleting.

2.3. Salting and smoking

All fillets were dry salted on grids (18 h, 3–4 °C) with pure NaCl (Akzo Nobel, Fint Raffinert Salt, min. 99.8% NaCl, Dansk Salt AS, Mariager, Denmark). When dry salting was completed, excess salt was removed by careful rinsing of the fillets with cold water. Before smoking the fillets were set to rest at 12–13 °C for approximately 30 min.

A Bastramat C1500 smoking cabinet equipped with a MC700 Microprocessor and a Bastra FR 100 smoke generator with automatic ignition and dosing (Bayha Strackbein GmbH, Arnsberg, Germany) were used for the smoking of the fillets. Reho Raucher Gold HBK 750/2000 woodchips (J. Rettenmaier & Sohne GmbH, Rosenberg, Germany) were moistened (200 mL kg^{-1} chips) and used for smoke generation.

The fillets were dried for 120 min before smoked and dried six times consecutively in alternating intervals of 50 and 10 min (total processing time=480 min). The chamber temperature, relative humidity and air velocity during drying and smoking were 24.2±1.4 °C, 61±7% and 0.5–1.0 m/s, respectively. After smoking the fillets were vacuum-packaged (99% vacuum, Webomatic C60 D/W/U, Webomatic Machinenfabrik GmbH, Bochum, Germany).

3. Analytical methods

3.1. Rigor mortis and pH

The fish were individually tagged and stored ungutted on ice in EPS boxes. At 0, 6, 12, 24, 48 and 72 h after slaughter, rigor index (I_r) and muscle pH was measured. The rigor index (I_r) was obtained using Cutting's method (tail drop). The rigor index was calculated from $I_r=[(L_0-L_t)/L_0]\cdot 100$ (Bito et al., 1983); L represents the vertical drop (cm) of the tail, when half of the fish fork length is placed on the edge of a table. L_0 is the tail drop at the beginning of the experiment, while L_t represents measurements throughout the experiment. For measuring muscle pH, an X-Mate portable meter and Inlab 489 pH probe from Mettler Toledo™ was used. Muscle pH was obtained from the white muscle tissue in the loin at the dorsal part of the fillet, where initial pH