

Quality Assessment of Lightly Salted Atlantic Salmon Fillets Injected With Brine Solutions Containing Sodium Bicarbonate

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Abstract

The objective of this study was to produce lightly salted Atlantic salmon (*Salmo salar* L.) fillets with improved technical and sensory attributes. Brine containing 0, 50, 150 or 250 g/L NaCl with or without additional 25 g/L sodium bicarbonate (NaHCO₃) was injected into the fillets. 24 hours after injection, the muscle NaCl concentration ranged from 0.2 to 2.4%, and pH ranged from 6.18 to 6.48. Untreated fillets lost 1% weight, whereas the weight increase was 4% of the fillets injected with NaCl or a combination of NaCl and NaHCO₃. Liquid loss (LL) during storage at 4°C for three days were similar for the untreated fillets and the fillets injected with 50 g/L NaCl (LL 12%), while LL was reduced to 7.5% with the addition of NaHCO₃ to the 50 g/L brine. LL was the lowest for the groups injected with 250 g/L NaCl. Injection of NaCl resulted in higher lipid oxidation compared with untreated fillets, determined as doubled levels of alkanals (4.3 vs. 10.4 ng/g) and pentenols (8.0 vs. 15.1 ng/g), but addition of NaHCO₃ counteracted the action of NaCl as a pro-oxidant. Furthermore, NaHCO₃ addition of the 50 g/L brine significantly improved the color of raw and cooked fillets (higher a*-value, Salmo Fan score, red/orange color tone). Sensory assessment of cooked fillet revealed that brine added NaHCO₃ gave superior odor (less rancid), flavor (less metallic) and higher scores for tenderness. In conclusion, addition of NaHCO₃ to the brine solutions improved liquid retention, storage stability, color, odor and flavor of lightly salted salmon fillets.

Keywords: Salmon, fish quality, lightly salted, color, taste, smell, water holding capacity (WHC), yield

1. Introduction

The global supply of salmonids exceeded three million tonnes in 2010, of which approximately two thirds was farmed (Food and Agriculture Organization of the United Nations [FAO], 2013). Improved efficiency in the aquaculture industry has resulted in declining real prices, making farmed salmon products an attractive source of protein (Asche & Guttormsen, 2009; Norwegian Seafood Council, 2012). However, value added products are not exploited to their full potential, especially in regard to the retail sector, where consumers demand tasty and easily prepared products (Bergersen & Iversen, 2011; Norwegian Seafood Council, 2012).

Historically, fish products have been heavily salted for preservation purposes, whereas currently, lightly salted fish products (< 6% NaCl) are common due to the sensory enhancing properties of sodium chloride (NaCl) (Albarraçin, Sánchez, Grau, & Barat, 2011; Gillette, 1985; Huss, 1994; Thorarinsdottir, Bjørkevoll, & Arason, 2010). With exception of the European Union, Russia and Japan are the major importers of Norwegian farmed salmonids (Norwegian Seafood Council, 2013). In Russia, nearly all processed salmon products are lightly salted and consumed uncooked (60-80%) or smoked (20-40%) (Johannesen, 2012; Tribilustova & Aandahl, 2007). Japan is the world's largest market for salmonids, and over 40% of the processed products are salted (Japanese Ministry of Internal Affairs and Communications [MIC], 2013). Lightly salted salmon is commonly broiled and eaten for breakfast or sold as ready-to-eat food products such as "bento" (packed lunch) or sushi (Nakamoto, 2000). However, the public's increased awareness of negative health associated with excessive dietary intake of sodium (Na) (e.g. elevated blood pressure and cardiovascular diseases), has escalated the demand for low Na

products. The recommended maximum dietary intake of Na per day for healthy adults is 2000 mg according to the World Health Organization (WHO); yet the average consumption is higher in most industrialized countries (WHO, 2006).

Methods for reducing the Na content in food typically encompass substitution of Na with other ions, or a gradual temporal reduction of NaCl content so that consumers have time to adjust to a lower salt flavor (Pedro & Nunes, 2007). However, both strategies have disadvantages. Partial replacement of NaCl with other salts such as KCl, MgCl₂ or CaCl₂ often has a negative effect on either flavor, liquid retention or texture properties (Albarracín et al., 2011; Gelabert, Gou, Guerro, & Arnau, 2003; Martinez-Alvarez, Borderias, & Gomez-Guillen, 2004; Weinberg, Regenstein, & Baker, 1984), while reducing the salty flavor result in declining consumer acceptability (Pedro & Nunes, 2007).

Quality traits including color, texture, liquid retention, odor and flavor are considered to be of great importance to the aquaculture industry due to consumer desirability and their attributes for secondary processing (Alfnes, Guttormsen, Steine, & Kolstad, 2006; Robb, 2001; Sveinsdottir, Hyldig, Martinsdottir, Jorgensen, & Kristbergsson, 2003). In salmonids, a post mortem rapid reduction in muscle pH in addition to a low ultimate pH may result in poor quality attributes such as pale flesh (Robb, Kestin, & Warriss, 2000; Richards & Hultin, 2000), reduced liquid retention and deteriorated texture (Kiessling, Espe, Ruohonen, & Mørkøre, 2004; Robb, 2001).

Sodium chloride improves water holding capacity (WHC) in meat with a maximal effect at approximately 6% NaCl (Fennema, 1990; Offer & Trinick, 1983). Additionally, increasing the pH above the protein iso-electric point (*pI*), results in swelling of the muscle (Offer & Trinick, 1983).

Atlantic salmon is a fatty species high in health beneficial polyunsaturated fatty acids (PUFA). However, PUFAs are very susceptible to peroxidation, which is a primary cause of deprived sensory quality (Refsgaard, Brockhoff, & Jensen, 1998; Undeland, Hall, & Lingnert, 1999). While NaCl may promote oxidation of PUFA (Pedro & Nunes, 2007), elevating an acidic pH may reduce lipid oxidation (Richards & Hultin, 2000).

Several studies have shown that treating meat with an alkali brine containing sodium bicarbonate (NaHCO₃) results in higher pH, darker color, improved liquid retention and texture including Atlantic cod (Åsli & Mørkøre, 2012), poultry (Sen, Naveena, Muthukumar, Babji, & Murthy, 2005), pork (Kauffman et al., 1998; Wynveen et al., 2001) and beef (Sultana et al., 2008).

Given the challenges facing the food industry to reduce dietary Na consumption, this project aimed to develop a method for production of low-salt salmon fillets, while simultaneously improving fillet quality and sensory characteristics.

2. Materials and Methods

2.1 Raw Materials and Salting

Atlantic salmon (*Salmo salar* L.) were raised at the Nofima research station (Averøy, Norway) (Group A, n = 54), and at a commercial fish farm (Bremnes Seashore AS, Bremnes, Norway) (Group B, n = 18). The fish were killed with a blow to the head, filleted within 30 minutes after slaughtering, and stored on ice for three days prior to injections with brine solutions. The mean fillet weight of the salmon studied were 1.6 kg (SD 0.25). Group A fillets were weighed and labeled subsequent to being randomly divided into nine groups of six fillets. Brine solutions at concentrations of 0, 50, 150 or 250 g/L NaCl were prepared using refined NaCl (99.8% NaCl, CG Rieber Salt AS, Ålesund, Norway) with or without the addition of 25 g/L NaHCO₃ (Ph.Eur., VWR, Haasrode, Belgium). The solutions (4°C) were injected into the fillets using a salt injection machine (16/64F, Fomaco Food Machinery Co. A/S, Køge, Denmark) with an injection pressure of 80 kPa. The salt content of the respective brine solutions and their acronyms are given in Table 1. Subsequent to injection, the fillets were air-dried for 10 minutes and individually packed in plastic bags. One group was randomly assigned as an untreated Control. The fillets were stored on ice and analyzed 24 hours following injection.

Fillets for sensory assessment (Group B) were injected using the same procedures and equipment as described above. The brines used for injection were 50 g/L NaCl, with or without the addition of 25 g/L NaHCO₃. Untreated fillets were used as Control (n = 6/treatment).

Table 1. Composition of brine solutions injected into farmed Atlantic salmon (*Salmo salar* L.) fillets

Abbreviation	NaClg/L	NaHCO ₃ g/L	Injected
Control	0	0	-
0-NaCl*	0	0	X
50-NaCl	50	0	X
150-NaCl	150	0	X
250-NaCl	250	0	X
0-NaHCO ₃	0	25	X
50-NaHCO ₃	50	25	X
150-NaHCO ₃	150	25	X
250-NaHCO ₃	250	25	X

*Injected with water only.

2.2 Fillet Yield

The fillets were weighed prior to (W_1), immediately after (W_2), and 24 hours after injection salting (W_3). The volume injected was calculated as the increase from W_1 to W_2 (%), and the yield was calculated 24 hours after injection (W_1 to W_3).

2.3 Liquid Loss (LL)

Approximately 15 g muscle was stored for three days at 4°C on a cellulose absorber pad in a sealed polyethylene bag as described by Mørkøre, Netteberg, Johnson and Pickova (2007). The liquid loss was determined gravimetrically as the amount of weight lost from the muscle during storage.

2.4 Muscle pH

The fillet pH was measured using a muscle electrode (Schott pH-elektrode, Blueline 21, Schott instruments, Mainz, Germany) and a temperature probe (TFK 325, WTW, Weilheim, Germany) connected to a 330i pH meter (WTW, Weilheim, Germany).

2.5 Chloride and Sodium Determination

The NaCl concentration of all the fillets were determined stoichiometrically as water soluble Cl⁻ with the use of a Corning 926 Chloride Analyzer (Corning Medical and Scientific, Halstead, U.K.), as described by Engdahl and Kolar (1993).

The content of sodium in selected treatments (Control, 50-NaCl, 50-NaHCO₃, 150-NaCl and 150-NaHCO₃, n = 5/treatment) were determined by the use of atom absorption spectroscopy according to the standard method described in AOAC (2003). Sodium and chloride analyses were determined as an average of three measurements/sample.

2.6 Color and Fat

Triplicate color analyses were performed photometrically on the dorsal section of the fillet using the PhotoFish™ apparatus as described by Folkestad et al. (2008). The fillet lightness is presented as L* (100 = white, 0 = black), a* describing color intensity on the red/green axis (a* > 0 = red, a* < 0 = green), and b* describing the color intensity on the yellow/blue axis (b* > 0 = yellow, b* < 0 = blue). The visual SalmoFan™ color score and fat content of the Control is based on predicted values in the PhotoFish™ software.

2.7 GC-MS Headspace Volatiles

Gas chromatogram phymass spectrometry (GC-MS) was used to identify and quantify volatile organic components as described by Olsen, Vogt, Veberg, Ekeberg and Nilsson (2005). Samples from 150-NaCl, 150-NaHCO₃ and Control (n = 6/treatment) were frozen at -80°C, thawed, pooled and homogenized before they were stored on ice for five days prior to analysis. The samples were analyzed in duplicate, and the volatile components were identified according to retention time and mass spectra of the sample peaks using heptanoic acid ethyl ester as an internal standard.

2.8 Sensory Analysis

Fillets injected with 50 g/L NaCl with or without the addition of 25 g/L NaHCO₃, and untreated Control fillets (Group B) were assessed by a sensory panel consisting of ten members trained according to ISO guidelines 8586-1 (1993), and with a minimum of four years' experience in sensory evaluation. A modified quantitative descriptive profile method, ISO 6564 (1985), was used by the assessors, and the evaluations were carried out according to the guidelines in ISO 8589 (1988) in a sensory laboratory with separate booths and electronic registration of data (CSA, Compusense Five, Version 4.6, Guelph, Ontario, Canada, 1999). Cutlets of 20 mm thickness were vacuum packed in coded bags prior to heating (75°C) for 10 minutes. When served to the assessors, the sample temperature was approximately 60°C, and each assessor was served samples from the same region of the evaluated fillets. Prior to the sensory analysis, the assessors were calibrated using cooked salmon fillets that were injection salted with or without the addition of NaHCO₃. The samples were evaluated in random order. Each bag was individually opened by the assessor for immediate registration of sample odor, while appearance, flavor and texture attributes were recorded when the sample was removed from the bag. A computer transformed the responses into numbers between 1 and 9 for low and high intensity, respectively. The heated samples were evaluated for 20 attributes (Table 2).

Table 2. Sensory attributes of farmed Atlantic salmon fillets

Attribute	Definition
<i>Odor</i>	
Fresh	Fruity/fresh and sour/sweet. Also known as acidic
Metallic	Ferro sulphate, blood, iron
Seawater	Fresh, salty, sea, ocean
Rancid	Oxidized fat (like hay, stearin, paint)
Chemical	Chemical
<i>Appearance</i>	
Gloss	Shiny surface
Color tone	Red/orange
<i>Taste</i>	
Saltiness	Typical salt flavor e.g. sodium chloride
Bitter	Like quinine
<i>Flavor</i>	
Fresh	Fruity/fresh and sour/sweet. Also known as acidic
Metallic	Ferro sulphate, blood, iron
Seawater	Fresh, salty, sea, ocean
Rancid	Oxidized fat (like hay, stearin, paint)
Chemical	Chemical
<i>Texture</i>	
Hardness	Force required to bite through sample
Juiciness	Moist, perception of water released during chewing
Tenderness	Effort needed to prepare the sample ready for swallowing
Fatty	Oily mouth feeling
Fibrousness	Perception of long particles oriented in the same direction
Flakiness	Visual gaping of fillet when cut with a knife

As shown in Table 2, attributes of farmed Atlantic salmon fillets evaluated by a trained sensory panel after heating to 75°C. The fillets were untreated or injected with 50 g/L NaCl brines with or without addition of 25 g/L NaHCO₃, and stored for 24 hours on ice prior to heating.

2.9 Statistical Analyses

The effect of NaCl inclusion was analyzed using one-way ANOVA (0-NaCl to 250-NaCl and 0-NaHCO₃ to 250-NaHCO₃), while the effect of adding NaHCO₃ to the respective brine concentrations was analyzed using a paired t-test. Differences among means were separated by Tukey's studentized range test (HSD) or the t-test, $P < 0.05$ (SAS software, SAS Inst. Inc., Cary, N.C., U.S.A). To identify the most informative parameters for description of differences between experimental and Control groups (50-NaCl, 50-NaHCO₃ and Control), linear discriminant analysis was performed using Unscrambler v.9.8 (Camo Process A/S, Oslo, Norway). The best combinations with minimum values of Wilkins lambda were selected from all possible subsets of the sensory and instrumentally measured data. Each subset included 3 to 15 variables. This procedure resulted in 130 combinations of variables, and frequency of representation in this list (%) was determined for each variable.

3. Results

3.1 Fillet Yield

The untreated fillets had a weight reduction of 1.1% during the first 24 hours of storage (Table 3). In comparison, the yield of the injected groups ranged from 1.7 to 4.2% with significant differences between treatments. Adding NaHCO₃ to the water that was injected into the fillets (0-NaHCO₃) resulted in 1.5 % greater weight increase compared with injecting water only (0-NaCl). No significant effects were observed when NaHCO₃ was added to brine solutions.

Table 3. Yield, pH, NaCl and color parameters of salmon fillets

		Control	NaCl concentration in brine, g/L				ANOVA	
			0	50	150	250	Pooled SE	Effect of [NaCl]
Yield (%)	NaCl	-1.1	1.7 ^{†b}	3.7 ^{†a}	4.1 ^{†a}	3.8 ^{†a}	0.3	**
	NaHCO ₃		3.2 ^{†b}	3.9 ^{†ab}	4.2 ^{†a}	3.8 ^{†ab}	0.2	**
	Effect of NaHCO ₃		**	ns	ns	ns		
Muscle pH	NaCl	6.46	6.35 ^{†a}	6.31 ^{†a}	6.22 ^{†b}	6.18 ^{†b}	0.02	**
	NaHCO ₃		6.41 ^{ab}	6.48 ^a	6.38 ^{†b}	6.32 ^{†b}	0.02	**
	Effect of NaHCO ₃		*	**	**	**		
NaCl (%)	NaCl	0.2	0.2 ^c	0.6 ^c	1.5 ^{†b}	2.4 ^{†a}	0.2	**
	NaHCO ₃		0.2 ^c	0.7 ^{†c}	1.5 ^{†b}	2.3 ^{†a}	0.2	**
	Effect of NaHCO ₃		ns	ns	ns	ns		
<i>L</i> *-value (lightness)	NaCl	41.3	42.4	43.7 [†]	43.7 [†]	42.2	0.5	ns
	NaHCO ₃		42.2	41.1	41.8	41.2	0.6	ns
	Effect of NaHCO ₃		ns	**	*	ns		
<i>a</i> *-value (redness)	NaCl	29.1	28.6	27.3 [†]	26.6 [†]	26.7 [†]	0.6	ns
	NaHCO ₃		27.7	29.5	27.6	27.6	0.6	ns
	Effect of NaHCO ₃		ns	*	ns	ns		
<i>b</i> *-value (yellowness)	NaCl	22.9	23.6 ^a	22.8 ^{ab}	21.8 ^{†bc}	20.8 ^{†c}	0.4	**
	NaHCO ₃		22.6 ^{ab}	23.2 ^a	22.4 ^{ab}	21.6 ^{†b}	0.3	**
	Effect of NaHCO ₃		ns	ns	ns	ns		
Visual color score	NaCl	27.8	27.5	27.1	26.8 [†]	27.2	0.3	ns
	NaHCO ₃		27.3	28.0	27.2	27.4	0.3	ns
	Effect of NaHCO ₃		ns	*	ns	ns		

As shown in Table 3, yield, pH, NaCl and color parameters of raw salmon (*Salmo salar* L.) fillets injected with brines containing 0-250 g/L NaCl or the aforementioned brine solutions added 25 g/L NaHCO₃ (n = 6 fillets/treatment). * denoted differences of $P < 0.05$, ** denotes significant differences of $P < 0.01$. ns = no significant differences. † indicate significant difference from Control. Different letters indicate significant differences between NaCl concentration [NaCl] in brines.

3.2 Liquid Loss (LL)

The injected samples had a LL ranging from 4.6% to 12% relative to the initial sample weight (Figure 1), and was negatively correlated to NaCl concentration in the muscle ($r^2 = 0.67$). The 50-NaCl treatment did not differ significantly from the Control that had an average LL of 12.3%. The addition of NaHCO_3 to the brine solution containing 50 g/L NaCl resulted in lower LL compared to both the 50-NaCl and the Control. The lowest observed LL of 4.6% was found in the 250- NaHCO_3 treatment; however it was not significantly different from the 250-NaCl treatment.

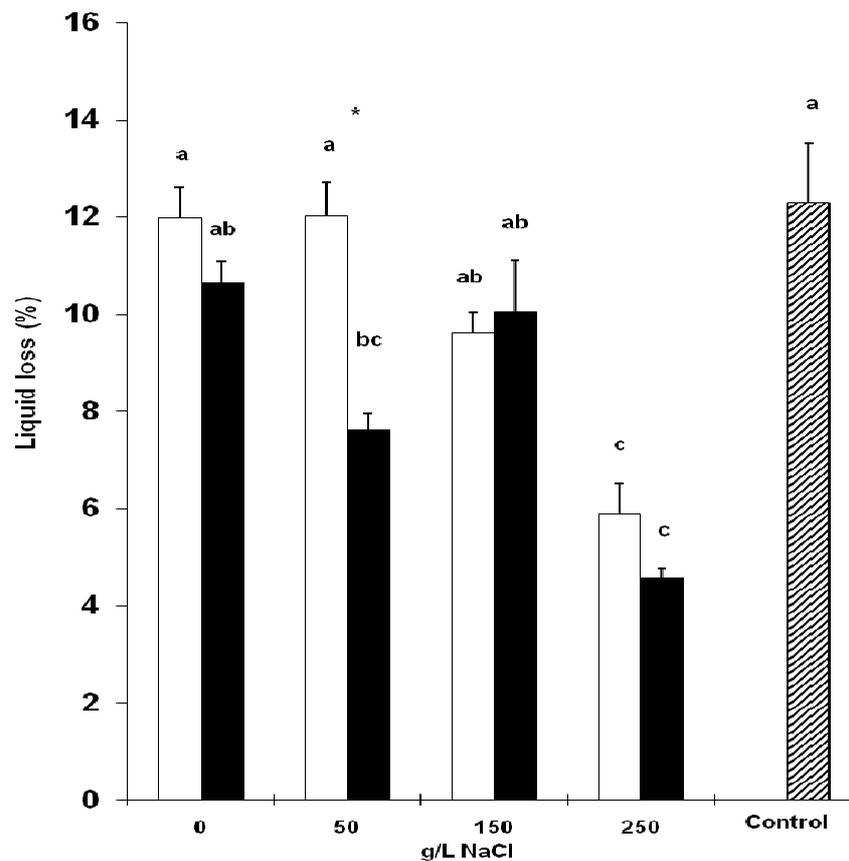


Figure 1. Liquid loss (LL) of farmed Atlantic salmon muscle during three days of storage at 4°C

The fillets were previously injected with NaCl brines (0, 50, 150 or 250 g/L) with (■) or without (□) addition of 25 g/L NaHCO_3 , or stored as untreated Control (▨). Different letters indicate significant differences ($P < 0.05$) between brine concentrations (0-250 g/L NaCl), and * denotes significant differences ($P < 0.05$) between fillets injected with NaCl and NaHCO_3 or NaCl only within brine concentration.

3.3 Muscle pH

The muscle pH ranged from 6.18 to 6.48 with significant differences between treatments (Table 3). The pH decreased with increasing brine concentration. Adding NaHCO_3 to the solutions resulted in significantly higher pH of all treatment groups. The most pronounced effect of the NaHCO_3 addition was seen between the 50-NaCl and 50- NaHCO_3 treatments, where the pH increased by 0.17 units.

3.4 Chloride and Sodium Determination

The Cl^- analysis corresponded to a NaCl level ranging between 0.2 to 2.4%, and was significantly affected by brine concentration (Table 3). Adding NaHCO_3 to the brine resulted in similar NaCl concentrations compared to fillets salted with NaCl brine only. No significant differences were observed between the Na content of the 50-NaCl and 50- NaHCO_3 (220 vs. 264 mg/100 g), or between 15-NaCl and 15- NaHCO_3 (601 vs. 640 mg/100 g). The Na concentration of the Control was 37 mg/100 g.

3.5 Color and Fat

Injecting fillets with brine containing only NaCl increased L*-value (lightness), and reduced a*-value (redness) compared with the Control, while the addition NaHCO₃ to the brines counteracted this color shift (Table 3). Inclusion of NaHCO₃ in the brines resulted in significantly lower L*-values for the 50-NaHCO₃ and 150-NaHCO₃ treatments compared with 50-NaCl and 150-NaCl. The a*-values were higher for brine injected fillets with NaCl in combination with NaHCO₃, although only significantly higher for the 50-NaHCO₃ treatment. The b*-value decreased significantly with increasing brine concentration, while addition of NaHCO₃ to the brine had no significant effect. The visual color scores, SalmoFan™ values, showed higher scores for fillets injected with NaCl added NaHCO₃ compared with NaCl only (significant between 50-NaCl and 50-NaHCO₃). The fat content of the Control group was 18.9% (SE ± 0.4).

3.6 GC-MS Headspace Volatiles

The levels of volatile components were similar for the Control and the 150-NaHCO₃ groups, except from nonanal which was significantly higher of the 150-NaHCO₃ treatment (Table 4). 1-penten-3-ol was 41-44% higher of the 150-NaCl treatment, whereas the content of hexanal was 70-82% higher than the Control and 150-NaHCO₃ treatment. Moreover, the sum of alkanals and pentenols were higher in the 150-NaCl treatment compared to the 150-NaHCO₃ treatment and the Control (Figure 2).

Table 4. Volatiles (ng/g) identified by GC-MS in salmon fillets

	Control	Treatment	
		NaCl	NaCl & NaHCO ₃
<i>Volatiles ng/g</i>			
Propanal	0.4±0.4 ^b	4.4±0.3 ^a	0.6±0.6 ^b
Butanal	0.3±0.0	0.5±0.1	0.3±0.0
Hexanal	1.0±0.1 ^b	3.3±0.0 ^a	0.6±0.6 ^b
Heptanal	0.0±0.0	0.2±0.0	0.1±0.1
Nonanal	2.5±0.4 ^b	2.0±0.1 ^b	3.8±0.9 ^a
2-penten-1-ol	0.3±0.3 ^b	2.0±0.3 ^a	0.8±0.2 ^b
1-penten-3-ol	7.7±1.0 ^b	13.1±1.2 ^a	7.3±0.2 ^b

As shown in Table 4, volatiles identified by GC-MS in untreated salmon fillets, or fillets injected with 150 g/L NaCl brine with or without the addition of 25 g/L NaHCO₃. Prior to analysis, samples (n = 6/treatment) were frozen at -80°C, thawed, pooled, homogenized and stored on ice for five days. Different letters denote significant differences between groups.

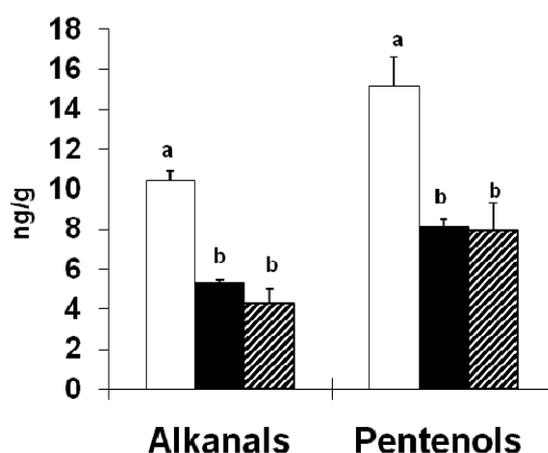


Figure 2. Volatile components (ng/g) identified by Gas chromatography-mass spectrometry in salmon fillets injected with brines with (■) or without (□) the addition of 25 g/L NaHCO₃, or untreated Control (▨). Alkanals include propanal, butanal, hexanal, heptanal and nonanal, whereas the pentenols encompass 1-penten-3-ol and 2-penten-1-ol. Different letters denote significant differences (P < 0.05) between treatments

3.7 Sensory Evaluation

Significantly stronger rancid odor was found in the Control compared to the 50-NaHCO₃ treatment (Table 5). The saltiness was highest for the injection salted samples, while metallic flavor was highest of the Control, and lowest of the 50-NaHCO₃ treatment. The 50-NaHCO₃ treatment scored significantly higher on glossiness, juiciness, and tenderness, and lower on hardness compared to the Control. Further, adding NaHCO₃ to the 50 g/L NaCl brine gave a higher red/orange color tone.

Table 5. Sensory attribute scores for salmon fillets

Attribute	Control	Treatment	
		NaCl	NaCl & NaHCO ₃
Odor			
Fresh	2.9±0.1	3.2±0.1	2.9±0.1
Metallic	4.0±0.1	4.1±0.1	4.0±0.1
Seawater	2.5±0.1	2.7±0.1	2.5±0.1
Rancid	2.8±0.1 ^a	2.5±0.2 ^{ab}	2.3±0.2 ^b
Chemical	1.9±0.1	1.9±0.2	1.8±0.1
Taste			
Saltiness	2.1±0.1 ^b	3.1±0.2 ^a	3.1±0.1 ^a
Bitter	4.6±0.1	4.4±0.1	4.5±0.1
Flavor			
Fresh	3.2±0.1	3.5±0.2	3.4±0.1
Metallic	4.4±0.1 ^a	4.2±0.0 ^b	4.1±0.0 ^c
Seawater	2.6±0.1	2.9±0.2	2.7±0.1
Rancid	3.0±0.1	2.6±0.2	2.9±0.3
Chemical	1.8±0.1	1.6±0.2	1.7±0.1
Appearance			
Glossy	3.1±0.1 ^b	3.1±0.1 ^b	3.4±0.1 ^a
Color tone (red/orange)	5.2±0.1 ^{ab}	5.1±0.1 ^b	5.3±0.1 ^a
Texture			
Hardness	4.4±0.1 ^a	4.2±0.1 ^{ab}	4.1±0.1 ^b
Juiciness	5.0±0.1 ^b	5.3±0.1 ^{ab}	5.5±0.1 ^a
Tenderness	5.2±0.2 ^b	5.4±0.1 ^{ab}	5.6±0.1 ^a
Fatty	4.4±0.1	4.4±0.1	4.5±0.1
Fibrousness	5.6±0.1	5.5±0.1	5.4±0.1
Flakiness	4.8±0.2	4.7±0.2	5.0±0.1

As shown in Table 5, mean sensory attribute scores for odor, flavor, appearance and texture on Atlantic salmon (*Salmo salar* L.) injected with 50 g/L NaCl brines with or without the addition of 25 g/L NaHCO₃. Fillets were stored for 24 hours on ice prior to analysis. Different letters denotes significant differences between groups.

3.8 Discriminant Analysis

Multivariate statistical analysis of the 50-NaCl, 50-NaHCO₃ and the Control revealed that metal flavor gave the greatest contribution in discrimination of treatments (81%), followed by pH (62%), liquid loss (60%), photometrically measured color (53%) and tenderness (46%).

4. Discussion

The physiochemical changes observed in this study were connected to dissimilar ionic concentrations in the muscle, elevated muscle pH, and possibly a favorable interaction between NaCl and NaHCO₃.

Increasing NaCl concentration in the muscle reduced liquid loss (LL), which was expected as NaCl induce swelling of the myofibrils (Offer & Trinick, 1983). The highest LL was seen in untreated fillets and the fillets injected with water, probably because of the low NaCl concentration (< 0.5%) (Fennema, 1990).

pH values above the proteins iso-electric point correlate positively with liquid retention due to an increased negative charge of the myofibrillar proteins, causing repulsion of the myofilaments and an enlarged myofilament lattice (Hamm, 1986; Offer & Trinick, 1983; Regenstein, Jauregui, & Baker, 1984). LL is most affected by NaCl and pH changes when the ionic strength and muscle pH is low (Bertram, Kristensen, & Andersen, 2004; Ofstad, Kidman, Myklebust, Olsen, & Hermansson, 1995). In this study, the effect on LL was more pronounced in fillets injected with low salt concentrations compared to fillets injected with higher NaCl concentrations. The difference in LL between the NaCl injected groups and the NaHCO₃ groups are probably caused by differences in pH, and also a cooperative effect of NaCl and NaHCO₃, similar to NaCl and phosphates as explained by Offer and Trinick (1983). Kaufmann et al. (1998) argue that lower LL in meat treated with phosphates or NaHCO₃ is caused by increased protein solubility, while Wynveen et al. (2001) suggest that NaHCO₃ and phosphates may work with different mechanisms. Future research is needed to elucidate the impact of NaHCO₃ on protein solubility in salmon muscle, and to further examine possibilities for greater reductions of Na.

Improved color of raw and cooked salmon fillets demonstrate that the addition of NaHCO₃ to brine may counteract the negative effect on appearance caused by brine injection. Low pH may give a lighter color of fish fillets due to changes in the protein conformation, resulting in altered light reflection pattern (Stien et al., 2005; Robb et al., 2000). Further, low pH accelerate the oxidation of myoglobin, and metmyoglobin has been coupled with deteriorated color of salmonids (Ottestad, Sørheim, Heia, Skaret, & Wold, 2011; Richards & Hultin, 2000). The characteristic pink color of salmon flesh is a major determinant for consumers preferred choice of product (Alfnes et al., 2006). The findings in this study show that the practical implication of adding NaHCO₃ to brine may be of great importance for the salmon farming and processing industry; also to avoid quality downgrading due to pale flesh (Michie, 2001).

The lower levels of alkanals and pentenols in the NaHCO₃ treated fillets suggest a preservative effect on NaCl induced lipid oxidation. 1-penten-3-ol and hexanal are volatile components known to correspond with early lipid oxidation and off-odor/flavor (Alghazeer, Saeed, & Howell, 2008; Olsen, Vogt, Veberg, Ekeberg, & Nilsson, 2005). For n-3 PUFA oxidation, the level of 1-penten-3-ol was halved, while for n-6 FA oxidation, the reduction of hexanal indicated an even greater effect of the added NaHCO₃. Åsli and Mørkøre (2012) found similar levels of alkanals and pentenols in cod fillets injected with brine added NaHCO₃, but the relevance of reducing oxidation may be of greater importance for the shelf-life of a high fat species such as salmon.

Unpleasant odors and flavors were lower of the NaHCO₃ treated fillets, and coincide with studies on sow meat (Sindelar et al., 2003) and pork (Sheard & Tali, 2004). In line with a study on cod (Åsli & Mørkøre, 2012), the NaHCO₃ treatment significantly altered the texture with higher scores for juiciness and tenderness, and lower scores for hardness compared with the untreated fillets. These attributes are probably connected with increased protein solubility of the NaHCO₃ treated fillets.

A wider range of low sodium products is required to meet the WHO recommendations regarding a reduced dietary sodium intake (maximum 2000 mg Na/day) (WHO, 2006). The Na content (mg/100 g) of smoked salmon is typically in the range of 780-1372, beef burgers 290-590, and low sodium ham 969 (Bannerman & Horne, 2001; Desmond, 2007; Pedro & Nunes, 2007). In comparison, injecting a 50 g/L or 150 g/L brine with or without the addition of NaHCO₃ resulted in a sodium content of 220-263 mg/100 g and 601-640 mg/100 g respectively, and would comply with consumer demands of lowered sodium content in salted salmon products.

5. Conclusion

Injecting salmon fillets with brine added sodium bicarbonate is an efficient and economically beneficial method of producing attractive low salt products with improved flavor and color.

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