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Salt effect on heat-induced physical and chemical changes of salmon fillet (*O. gorbuscha*)

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Abstract

This research studied the effect of salt on kinetics for quality changes in pink salmon fillet, during commercial sterilisation. Sample cuts from salmon fillets were placed in sealed aluminum containers and heated at 121.1 °C for 10, 30 and 60 min. Samples with 1.5% (w/w) salt addition were compared with those without added salt. Salt addition reduced cook loss, area shrinkage and shear force of the heated fillet and resulted in a slightly darker colour. Effect of salt addition in thiamin loss, degree of lipid oxidation and fatty acid profile was not significant. Peroxide (PV) and thiobarbituric acid (TBA) values slightly increased within the first 10 min of heating, followed by a significant reduction as heating progressed. No measurable loss of polyunsaturated fatty acids (PUFA) was observed. Thermally processed shelf-stable salmon investigated should be a valuable source of ω-3 PUFA, with EPA values ranging from 52 to 71 mg/100 g product and DHA ranging from 258 to 340 mg/100 g of product.

Keywords: Pink salmon; Thermal processing; Salt addition; Seafood quality; Fatty acids; Thiamin; Cook loss; Area shrinkage

1. Introduction

A substantial portion of wild pink salmon (*Oncorhynchus gorbuscha*) is thermally processed in cans or flexible pouches. Sodium chloride is commonly added to the canned products although some salmon products are processed with no added salt. The Commercial Item Description (CID) classifies canned and flexible pouched salmon products into four categories based upon salt level: regular (no more than 1.5% salt), no salt added, very low sodium (35 mg or less sodium per serving) and low sodium (140 mg or less sodium per serving) (USDA, 2004). Salt functions as a flavour enhancer, it increases the perception of fullness and thickness and enhances the perception of sweetness (Hutton, 2002). From a sensory viewpoint, 1.5–2.0% of salt in canned muscle foods is the optimum level for consumer acceptability (Hutton, 2002). It has been reported that salt addition affects cook yield, texture and lipid oxidation (Baublits, Pohlman, Brown, Yancey, & Johnson, 2006; Gallart-Jornet et al., 2007; Jittinandana, Kenney, Slider, & Kiser, 2002). There is, however, a lack of information on the influence of salt on the quality of canned salmon, particularly when newer production methods such as dielectric based commercial sterilisation processes are applied.

The most important changes that occur to the physical quality attributes of muscle foods during commercial sterilisation processes include colour, texture and cook loss. Area shrinkage ratio is also an important quality indicator for muscle foods, it quantifies the amount for muscle shrinkage caused by heat-induced protein denaturation (Kong, Tang, Rasco, Crapo, & Smiley, 2007a; Kong, Tang, Rasco, & Crapo, 2007b). Heating may also cause losses of nutrients

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such as thiamin, which is one of the least thermostable of the water soluble vitamins. Canned salmon is an important source of thiamin and its quantification provides a good indication of the nutritional integrity of the product.

The high content of the polyunsaturated fatty acids (PUFA) in marine lipids is thought to play a positive role in reducing the risk of cardiovascular diseases (Harris & Schacky, 2004). However, high temperature processing can potentially damage PUFA, generating secondary lipid oxidation products which lead to rancidity and other off flavours in foods (Aubourg & Medina, 1997). The extent of lipid oxidation in muscle foods is widely evaluated by measuring the primary oxidation products using the peroxide value (PV) method and secondary products using the TBA method which determines the content of 2-thiobarbituric acid reactive substances, primarily malondialdehyde, from the oxidation of ω-3 fatty acids. Studies on the changes of lipids during thermal treatment of fish have been reported (Aubourg & Medina, 1997; De La Cruz-García, López-Hernández, González-Castro, Rodríguez-Bernaldo De Quirós, & Simal-Lozano, 2000; Koøakowska et al., 2002), but reported data on changes of pink salmon lipids during modern canning processes is limited.

The objective of this study was to investigate the changes in the quality of pink salmon during commercial sterilization, at 121.1 °C, at two salt levels as part of a larger study to optimise processing parameters for new developed microwave heating protocols, for salmon products. New thermal processes, based on microwave heating, use much shorter heating times (~10–15 min) compared with conventional canning processes (e.g. mostly ~30–90 min depending on packaging size and shape) (Guan et al., 2003; Guan, Plotka, Clark, & Tang, 2002). Therefore, in our study, the effect of different heating times including 10, 30 and 60 min were also investigated.

2. Materials and methods

2.1. Materials

Wild, fresh whole grade A pink salmon (*Oncorhynchus gorbuscha*) were obtained from a seafood processing plant on Kodiak Island (Alaska) in August 2005 and immediately transported on ice to the Fisheries Industrial Technology Center (FITC) pilot plant. Salmon used in this study were post-rigour and less than 48 h post-mortem (Wang, Tang, Correia, & Gill, 1998). Seine caught fish, sampled the same day and from the same harvest grounds (Kodiak Island, Alaska), were transported to the processor in a fishing vessel that used a conventional fish holding tank fitted with a standard recirculation chilled seawater system. To avoid heterogeneity of fish quality due to gender, only female fish were selected for this study. Fish ($n = 12$) were 1350 ± 100 g in weight, 370 ± 10 mm in length and 120 ± 10 mm in width. Fish were gutted, frozen and stored (−31 °C) at the FITC pilot plant and shipped overnight to Washington State University, Pullman, WA.

2.2. Sampling and heating

The sampling and heating of the fish fillets followed methods previously described (Kong et al., 2007a). To reduce the influence of heterogeneity of fish muscle on the cooking properties, only the white muscle in the dorsal area was sampled. Small disk shaped samples (6 mm in thickness and 30 mm in diameter) were used to reduce come-up time and improve uniform heating. The samples were taken using an electrical food slicer (Model 632, Chef'Choice Int., Germany) and a 30 mm diameter corer. The samples were loaded into custom-designed cylindrical aluminum test cells, having a 35 mm inner diameter, 6 mm inner height and 2 mm wall thickness and hermetically sealed. Prior to sealing, a 0.1 mm diameter copper-constanstan thermocouple (Type-T) was inserted through a rubber gland in the lid of the container, to measure the temperature at the geometrical center of the sample. Samples were subjected to heat in an oil bath (Model HAAKE W13, Thermo Electron Corporation, Germany) operated at 121.1 °C, using glycerol as the heating medium. During heating the signals from the thermocouple junctions were transferred to a computer equipped with a DLZe type data logger (DELTA-T Devices, Cambridge, England, UK). Time for the temperature at the center of the sample to reach within 1 °C of the total temperature rise was 2.5–3 min. After heating and upon removal from the oil bath, sample cells were immediately placed in an ice bath. Temperature dropped to below 20 °C within 0.5 min for all the samples, and the thermal effect of the cooling step on the product quality was not considered to be significant. After cooling, samples were removed from the test cells, dried with a filter paper, weighed on an analytical balance (Ohaus Analytical Plus, Pine Brook, New Jersey) and stored overnight in a cooler (4 °C) for further analysis.

2.3. Experimental design

Samples taken from 12 fish were pooled and equally divided into two groups and salt was added to one of the sample groups. Food grade sodium chloride (1.5% w/w) was evenly distributed on the sample surface immediately before sealing each test cell to stimulate industrial canning practices for salmon (FAO, 1985). Samples were heated at 121.1 °C for 10 min, 30 min or 60 min. Twelve sample replicates were used for each experimental treatment.

After heating, the physical properties (colour, shear force, cook loss and area shrinkage) were determined on each sample. Chemical analyses (thiamin, TBARS, PV and fatty acid analysis) were conducted in pooled homogenised samples which were subjected to identical heating conditions.

2.4. Physical analysis

A multiple thin bladed Kramer type texture fixture (MTB), developed by Kong et al. (2007a) for fish muscle,

was used to determine shear force through the raw and heated samples. Compared with the standard Kramer shear cell, the MTB used thinner blades (0.5 mm compared to 3 mm for the standard Kramer shear cell) to reduce compression when cutting through the samples, thus leading to more accurate and consistent results (Kong et al., 2007a). The cell was fitted to a Texture Analyzer TA-XT2 (Stable Micro Systems Ltd., Surrey, UK) equipped with a load cell of 5 kg. Raw and heated samples were allowed to equilibrate to room temperature before shear force measurements. Samples were placed on a support base with blades positioned perpendicularly to the muscle fibers. The traveling speed of the blades was 1 mm/s. The force–time graphs were recorded using the Texture Expert for Windows v.1.15 (Stable Micro Systems Ltd., Surrey, UK). The shear force was measured as the peak height in the force–time profile.

A computer vision system (CVS) described in Kong et al. (2007a) was used to capture colour images of fresh and cooked samples. Colour images were downloaded and the colour parameters (CIE L^*, a^* and b^*) determined using the Photoshop CS2 v.8.0 (Adobe, San Jose, California). Sample area was measured using the Vision IMAQ Builder v.6.1 (National Instruments, Austin, Texas). Area shrinkage ratio was calculated as the percent area reduction of cooked compared with the corresponding raw samples. Cook loss was calculated as the percent weight reduction of cooked samples compared with raw samples.

2.5. Thiamin determination

Thiamin content in the raw and heated samples was determined using the Thiochrome method (AOAC 942.23, 2000): ca. 3–5 g samples were taken in duplicate and subjected to acid extraction, enzymatic hydrolysis, column purification and subsequent oxidation. The fluorescent intensity of thiochrome–isobutanol extract was determined in a fluorometer (Model FluoroMax-3, Jobin Yvon Inc., Edison, New Jersey), at an excitation wavelength of 365 nm and an emission wavelength of 435 nm. Thiamine content was determined by comparing fluorescence intensity of the extract of the oxidised test solution with that from the oxidised standard solution of thiamine hydrochloride (0.2 μg/ml).

2.6. Lipid extraction

Lipid content (percent wet basis) was determined using the Folch method (Folch, Lees, & Sloan Stanley, 1957) as described in Iverson, Lang, and Cooper (2001): ca. 12.0 g ground sample was mixed with 20 ml methanol and 40 ml $CHCl_3$, and incubated at room temperature for half an hour. The extract was vacuum filtered and the residue was extracted one more time. The two extracts were combined and added with 28 ml of 0.88% (w/v) NaCl solution. The mixture was shaken for 30 s, transferred to a separatory funnel and left to stand for 1 h. The lower phase of the mixture was filtered through anhydrous Na_2SO_4 to remove residual water and collected in a round flask. Solvent was removed from the lipid extract at 35 °C using a rotary evaporator (Rotavapor R-114, Büchi, Switzerland).

2.7. TBARS and PV analysis

TBARS assay was performed as described by Lemon (1975). A ground sample (ca. 8.00 g) was homogenised with 1:2 (w/v) extracting solution containing 7.5% trichloroacetic acid, 0.1% propyl gallate and 0.1% EDTA. The extracts were separated using a small laboratory centrifuge at 2000 rpm for 20 min. A 5 ml extract was mixed with 5 ml of 0.02 M TBA reagent. The mixture was heated in a boiling water bath for 40 min to develop a pink colour and cooled with running tap water. The absorbance of the supernatant was measured at 532 nm, using a diode array spectrophotometer (Hewlett–Packard 8452A, USA). A standard curve was prepared using 1,1,3,3-tetramethoxypropane. Results were represented as mg malondialdehyde (MDA) equivalents/kg of muscle tissue.

The peroxide value (PV) of the oil extracted from raw and heated muscle tissues were conducted using the AOAC method (965.33, 2000), as modified by Regulska-Ilow and Ilow (2002): ca. 0.2 g extracted oil was dissolved in 15 ml chloroform in a conical flask, followed by addition of 15 ml ice-cold acetic acid and 1 ml saturated potassium iodine solution. The mixture was shaken for 1 min and left in the dark for 5 min. After that, 40 ml distilled water was added, along with three drops of 1% (w/v) starch solution as indicator. The released iodine was immediately titrated with 0.001 M sodium thiosulphate solution, with the sample being constantly stirred. Titration end point was indicated by the disappearance of the blue colour.

2.8. Fatty acid profile

Fatty acid methyl esters were prepared according to the procedure of Maxwell and Marmer (1983) using tricosanoic acid (23:0) as an internal standard and quantified as described by Bechtel and Oliveira (2006). Briefly, a GC model 6850 (Agilent Technologies, Wilmington, DE) fitted with a DB-23 (60 m × 0.25 mm id., 0.25 μm film) capillary column (Agilent Technologies) was used for this analysis. Hydrogen was used as the carrier gas with an average velocity of 47 cm/s in constant flow mode. The detector and injector were held at a constant temperature of 275 °C and the split ratio was 25:1. The oven ramping programming was set as: 140–200 °C at a rate of 2 °C/min, 200–220 °C at a rate of 0.5 °C/min and 220–240 °C at a rate of 10 °C/min for a total run time of about 62 min with autosampler injections of x μl. Data were collected and analysed using the GC ChemStation program (Rev.A.08.03 [847]; Agilent Technologies 1990–2000, Wilmington, Delaware). A five-point calibration curve was established for each of the 37 fatty acid methyl esters found in the Supelco® fatty acid standard 189-19 (Bellefonte, PA)

and an empirical response factor was determined for these fatty acids. Other standards were used in the identification of peaks that were also purchased from Supelco® (Bellefonte, PA). The standards used were Bacterial Acid Methyl Esters Mix, Marine Oil #1 and Marine Oil #3. In cases where fatty acids identified did not have response factors determined empirically, the value used was the one of the fatty acid closest in structure (number of carbons and double bonds). These included 16:1 $n-11$ + 16:1 $n-13$, 16:1 $n-5$, 16:1 $n-9$, *Iso* 17:0, *Ante iso* 17:0, 18:1 $n-5$, 18:1 $n-7$, 18:4 $n-3$, 20:1 $n-11$, 20:1 $n-7$, 20:4 $n-3$ and 22:1 $n-11$. Individual fatty acids (FA) were reported in percent of the total fatty acids and in mg FA/100 g of tissue.

2.9. Statistical analysis

The data for quality attributes of raw and heated samples were compared using analysis of variance (ANOVA) in the General Linear Models (GLM) procedure of the SAS System for Windows v.8.01 (SAS Institute Inc., Cary, North Carolina) (SAS User's Guide, 1996). Differences between group means were analysed by Duncan's multiple-range test. Statistical significance was set at a 0.05 probability level.

3. Results and discussion

3.1. Cook loss

The cook loss consistently increased as heating time increased from 10 to 60 min, at 121.1 °C. Samples with added salt had significantly smaller losses compared to samples with no added salt (Fig. 1). In general, adding 1.5% salt resulted in approximately 2.4% less total cook loss for the heated salmon meat: a 15.4% reduction compared to the control samples (no salt added). A reduction in cook losses after adding salt to samples has been reported for other food products such as meat emulsions (meat balls) (Hsu & Sun, 2006), smoked rainbow trout fillets (Jittinandana et al., 2002) and salted cod (Thorarinsdottir, Arason, Geirsdottir, Bogason, & Kristbergsson, 2002). It is believed that NaCl in meat products solubilises myofibrillar proteins, which can result in increased protein–protein and protein–water interactions. When salted meat products are heated, aggregation occurs through a gelation process, contributing to meat particle binding, fat emulsification, and water-holding capacity (WHC) of the muscle tissues, thus reducing cook losses (Jittinandana et al., 2002; Sofos, 1986). On the other hand, adding too much salt would increase cook losses. In a recent study (Thorarinsdottir et al., 2002), dehydration was observed in cod when treated at salt concentrations higher than 5%. This was attributed to the phenomenon of the salting-out of proteins and the salt induced protein denaturation in muscle foods (Gallart-Jornet et al., 2007; Thorarinsdottir et al., 2002). It is, therefore, important to determine the optimal level of salt addition.

Baublits et al. (2006) found a linear reduction in cook losses in solution enhanced whole-muscle beef, as the level of NaCl increased from 0% to 1.5%. In the present study, a linear model was also developed that relates cook losses in pink salmon to salt content and heating time at 121.1 °C:

$$y = -1.586 \cdot c + 0.08788 \cdot t + 12.63 \quad R^2 = 0.962 \qquad (1)$$

where y is cook loss (%), c is salt content (0–1.5%), t is cook time (10–60 min).

3.2. Area shrinkage as affected by heating

During heating, sample area shrunk consistently. But samples containing added salt had less shrinkage than the ones with no added salt at all heating times (Fig. 2). The average area shrinkage ratio of the added salt samples was 3.5% less than the control, equal to a 24.6% reduction. Hsu and Sun (2006) reported similar observation for meat emulsions (meatballs) which had significantly higher product diameters when 1–3% salt was added. Wierbicki, Howker, and Shults (1976) reported that adding 1% and 3% salt

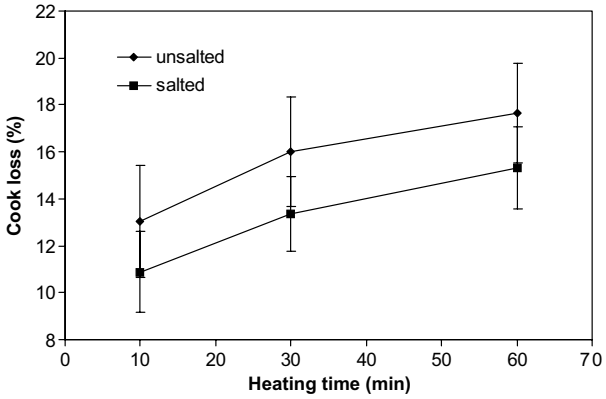

Fig. 1. Cook loss of pink salmon muscle at 0% and 1.5% added salt during heating at 121.1 °C ($n = 12$). Whiskers represent standard deviations.

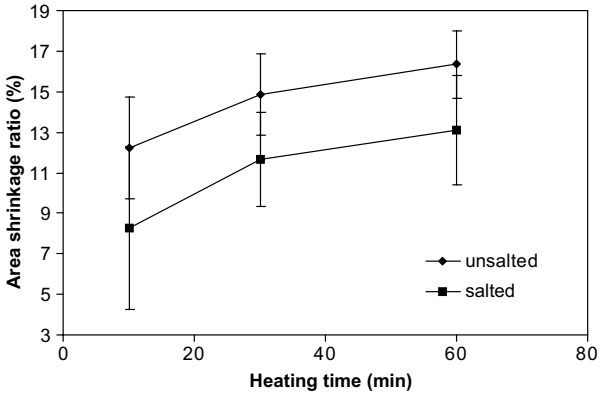

Fig. 2. Area shrinkage ratio of pink salmon muscle at 0% and 1.5% added salt during heating at 121.1 °C ($n = 12$). Whiskers represent standard deviations.

reduced lean pork meat shrinkage by 14% and 34%, respectively.

Area shrinkage is a result of protein denaturation and liquid loss. Protein denaturation causes shrinkage of muscle fiber diameter and sarcomere length, resulting in water soluble proteins and fats being expelled from the tissue (Bertola, Bevilacqua, & Zaritzky, 1994). Salt changes the ionic strength of the fluids within the muscle tissues, which may lead to an increase in the denaturation temperature of proteins (Baublits et al., 2006; Gallart-Jornet et al., 2007). The lower degree of protein denaturation and greater moisture retention in the tissues with salt addition favored a reduction in muscle shrinkage. The opposite effect caused by high salt level has also been reported by Wierbicki et al. (1976) who recorded a continuous increase of the meat shrinkage with increase of the salt addition from 5% to 10%. High salt concentrations enhance muscle shrinkage due to the formation of stronger protein–protein bonds and subsequent protein denaturation and dehydration (Sigurgisladottir, Sigurdardottir, Torrissen, Vallet, & Hafsteinsson, 2000).

Similar to cook loss, a linear equation relating area shrinkage ratio to salt content and heat time was developed:

$$y = -2.313 \cdot c + 0.08633 \cdot t + 11.60 \quad R^2 = 0.944 \qquad (2)$$

where y is area shrinkage ratio (%), c is salt content (0–1.5%), t is cook time (10–60 min).

3.3. Colour

Fig. 3 compares the colour change with heating time between the samples, with and without salt addition. As heating time increased from 10 to 60 min, the sample colour became more brown, as reflected by a decreased CIE L^* and increased b^*, resulting from Maillard reactions between sugars, fish proteins or amines as well as protein–lipid reactions (Kong et al., 2007a, 2007b). For all the sampling times, the samples with added salt were darker with lower CIE L^* and less yellow b^* values than the samples without added salt (Fig. 3). No obvious trends were observed for CIE a^* between the two group of samples. As similar colour effect has been reported on other heated muscle food products, such as frankfurters, emulsified meatballs and whole-muscle beef (Baublits et al., 2006; Hand, Hollingsworth, Calkins, & Mandigo, 1987; Hsu & Sun, 2006). Baublits et al. (2006) reported the decreases in CIE L^* and b^* values of salt solution injected beef muscle as the salt level increased and suggested that the darker surface colour of salted samples may have been caused by greater water retention.

3.4. Shear force

Fig. 4 shows the changes of shear force with heating time for samples with and without salt addition. For both groups, the shear force decreased from 10 to 30 min and then increased from 30 to 60 min. This confirmed our previous finding that the change of shear force in canned pink salmon included two peaks, the first approximately at 5 min and the second at 60 min (Kong et al., 2007a, 2007b). Shear force was significantly lower in the samples with added salt (Fig. 4). Salt increases protein solubilisation and water retention and facilitates formation of protein–water matrix in the muscle, which in turn can reduce cook loss (Baublits et al., 2006) and increase lipid retention. A reduction in shear force was reported for pork chop and whole-muscle beef when salt was added (Baublits et al., 2006; Huffman, Ly, & Cordray, 1981). Baublits et al. (2006) reported a linear reduction in shear force for salted beef decreasing as the level of NaCl in the solution

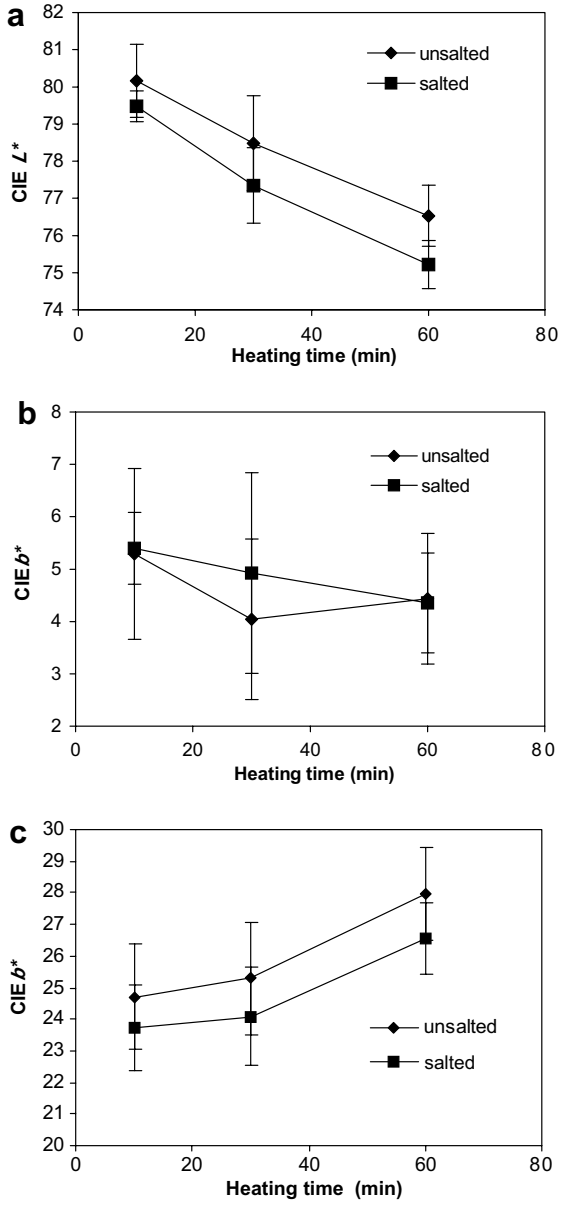

Fig. 3. CIE colour values ($n = 12$) of pink salmon muscle at 0% and 1.5% added salt during heating at 121.1 °C: (a) CIE L^*, (b) CIE a^*, and (c) CIE b^*. Whiskers represent standard deviations.

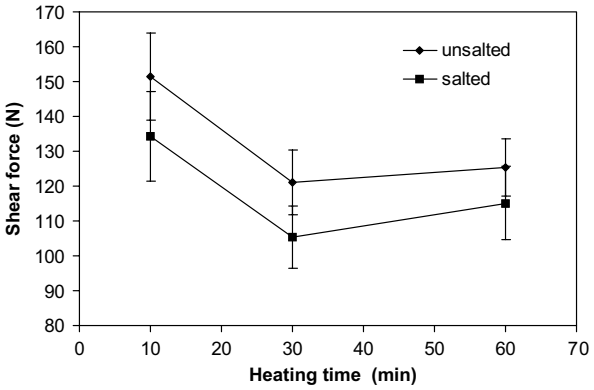

Fig. 4. Shear force of pink salmon muscle at 0% and 1.5% added salt during heating at 121.1 °C ($n = 12$). Whiskers represent standard deviations.

increased from 0% to 1.5%. In our study, the salt addition (1.5%) resulted in a 10–18 N decrease in the shear force for heated samples, corresponding to an average reduction of 10.8%. These results confirmed those of others that fish higher in lipid or moisture content were softer in texture (Dunajski, 1979; Jittinandana et al., 2002).

3.5. Thiamin

The effect of heating and salt addition on the thiamin content in commercially sterilised pink salmon is shown in Table 1. Thiamin content decreased from 2.03 μg/mg in fresh muscle to 0.35–0.38 μg/mg (>80% losses) in cooked muscle after 60 min heating. But reducing heating time to 10 min with the microwave process described in Guan et al. (2002, 2003) would retain about 70% of the thiamin.

The thiamin loss was mainly due to heat-induced thiamin oxidation and the loss of thiamin in the exudates. The thiamin degradation rate is a function of temperature, time of heating and the pH of the medium (Tannenbaum, 1976). No significant difference was observed in thiamine loss as a function of salt, at the significance level tested in this study. Thiamin loss in heated products is most likely product dependent. Szymandera-Buszka and Waszkowiak (2003) found that addition of salt increased the loss of both free and bound thiamin in ground turkey burgers during cooking and storage by approximately 6%, while Stepanov (1972) found loss of thiamin in legumes was slightly reduced by cooking with salt.

3.6. Lipid retention

Total lipid contents of raw and processed salmon samples are reported in Table 1. The low lipid content determined for raw salmon samples is not unusual for spawning female fish due to the mobilisation of muscle lipids to the maturing eggs (Zhou, Ackman, & Morrison, 1996). The total lipid content in the dorsal muscle of pink salmon caught in the Gulf of Alaska in May 1999 was between 0.8% and 6.5% (Nomura et al., 2001). The fat content of the belly flap is higher than in the flesh and in Atlantic salmon, the dorsal white muscle contains only one tenth of the oil as the belly flap tissue (Ackman, Zhou, & Heras, 1994). The data in Table 1 shows that the lipid in the salmon fillet was retained for samples with and without added salt and no significant differences between treatments were observed. The increase of total lipid content from 1.24% in raw muscle to 1.70–1.79% after 60 min of heating time was due to losses in moisture of the heat treated samples and exclusion of the exudates from the pooled samples, used for chemical analysis (Saghir, Wagner, & Elmadfa, 2005). Exudates were excluded from the analysis because generally this portion of the product is not consumed, thus not contributing to the nutritional value of the food item.

3.7. Lipid oxidation

To assess the level of lipid oxidation of salmon meat during canning, both primary (PV) and secondary oxidation products (TBA) were measured. The PV significantly increased from 30.3 meq/kg fat in the raw muscle to 65–87 meq/kg fat after 10 min heating (Table 1), indicating the initiation of lipid oxidation. This was followed by a decrease in PV to 31–33 meq/kg fat after 60 min of heating time indicating decomposition of peroxides and hydroperoxides to secondary products as lipid oxidation progressed. At temperatures above 100 °C, the initial hydroperoxides

Table 1
Summary of lipid content, thiamin content, PV and TBA values ($n = 2$) in pink salmon muscle at 0% and 1.5% added salt during heating at 121.1 °C [values are means ± standard deviation (SD)][A]

Salt (%)	Heating time (min)	Thiamine (μg/g tissue)	Oil content (%)	TBA (mg MDA/kg tissue)	PV (meq/kg fat)
Raw		2.03 ± 0.07^{a}	1.24 ± 0.01^{b}	4.59 ± 0.11^{a}	30.3 ± 3.6^{c}
0	10	1.44 ± 0.08^{b}	1.52 ± 0.02^{ab}	4.84 ± 0.20^{a}	65.3 ± 6.9^{b}
	30	0.73 ± 0.02^{c}	1.72 ± 0.16^{a}	1.22 ± 0.08^{bc}	39.2 ± 6.5^{c}
	60	0.38 ± 0.06^{d}	1.70 ± 0.14^{a}	0.97 ± 0.02^{cd}	31.4 ± 1.8^{c}
1.5	10	1.42 ± 0.05^{b}	1.34 ± 0.09^{b}	4.75 ± 0.16^{a}	87.0 ± 2.8^{a}
	30	0.69 ± 0.02^{c}	1.81 ± 0.14^{a}	1.32 ± 0.07^{b}	34.0 ± 9.2^{c}
	60	0.35 ± 0.07^{d}	1.79 ± 0.24^{a}	0.84 ± 0.03^{d}	32.8 ± 6.4^{c}

[A] Different letters within a column indicate significant differences ($p < 0.05$).

formed exist only transiently and decompose rapidly into volatile and non-volatile products (Frankel, 1998). Saghir et al. (2005) investigated the influence of braising on lipid oxidation of beef fillets, and found that the PV decreased and *p*-anisidine value increased simultaneously, suggesting a progressive stage of lipid oxidation. Additionally, it is possible that some of the lipid oxidation products may have been lost into the exudates not recovered for measurement (Aubourg & Medina, 1997; Saghir et al., 2005).

The formation of thiobarbituric acid reactive substances (TBA) followed a similar trend as PV, with a slight increase in the first 10 min heating from 4.59 mg MDA/kg raw muscle to 4.75–4.84 mg MDA/kg cooked muscle, followed by a significant decrease to 0.84–0.97 mg MDA/kg muscle at the end of 60 min heating (Table 1). TBA values reflect the amount of certain secondary oxidation products generated from the degradation of polyunsaturated fatty acids and the production of carbonyl compounds which create an unpleasant aroma and flavour in oxidised foods. The decrease of TBA values during heat-treatment was previously reported for muscle foods but not for canned pink salmon. Huang and Greene (1978) reported that beef subjected to high temperature and long heating times developed lower TBARS numbers than samples subjected to lower temperature and shorter time processes. Aubourg and Medina (1997) found that TBA values in canned tuna decreased from 8.13 to 1.70 mg MDA/kg muscle after 60 min of heating at 115 °C. The secondary products (aldehydes, ketones, epoxides and other carbonyl compounds) tend to react with amino acids, phospholipids and the

Table 2
Results of fame analysis ($n = 2$) for raw and heated pink salmon muscle (percent total fatty acids) [values are means ± standard deviation (SD)][a]

FA	Raw	0% Salt			1.5% Salt		
		10 min	30 min	60 min	10 min	30 min	60 min
14:0	2.19 ± 0.22	1.90 ± 0.46	2.04 ± 0.37	1.94 ± 0.63	2.13 ± 0.06	2.20 ± 0.21	2.00 ± 0.31
Iso 15:0	0.08 ± 0.12	0.07 ± 0.10	0.07 ± 0.10	0.08 ± 0.11	0.13 ± 0.00	0.14 ± 0.01	0.07 ± 0.10
15:0	0.53 ± 0.09	0.51 ± 0.08	0.53 ± 0.07	0.51 ± 0.09	0.53 ± 0.03	0.54 ± 0.03	0.52 ± 0.05
16:0	12.1 ± 0.71	12.9 ± 1.50	12.8 ± 1.32	12.8 ± 2.07	12.8 ± 1.15	12.9 ± 1.50	13.2 ± 0.98
16:1 $n-11$ + 16:1 $n-13$	0.30 ± 0.04	0.29 ± 0.02	0.29 ± 0.01	0.29 ± 0.02	0.30 ± 0.01	0.31 ± 0.02	0.30 ± 0.01
16:1 $n-9$	0.13 ± 0.01	0.11 ± 0.00	0.11 ± 0.00	0.11 ± 0.00	0.12 ± 0.02	0.12 ± 0.02	0.11 ± 0.01
16:1 $n-7$	1.67 ± 0.09	1.50 ± 0.13	1.62 ± 0.15	1.51 ± 0.23	1.71 ± 0.09	1.77 ± 0.10	1.62 ± 0.07
16:1 $n-5$	0.26 ± 0.05	0.26 ± 0.07	0.27 ± 0.07	0.26 ± 0.07	0.29 ± 0.11	0.30 ± 0.13	0.27 ± 0.08
Iso 17:0	0.13 ± 0.01	0.00 ± 0.00	0.13 ± 0.03	0.06 ± 0.09	0.13 ± 0.03	0.13 ± 0.03	0.00 ± 0.00
Ante iso 17:0	0.48 ± 0.08	0.45 ± 0.07	0.46 ± 0.06	0.45 ± 0.07	0.45 ± 0.06	0.46 ± 0.06	0.46 ± 0.06
17:0	0.68 ± 0.06	0.63 ± 0.03	0.67 ± 0.04	0.64 ± 0.05	0.67 ± 0.07	0.65 ± 0.06	0.70 ± 0.04
17:1 $n-9$	0.37 ± 0.07	0.36 ± 0.05	0.39 ± 0.09	0.35 ± 0.06	0.39 ± 0.04	0.39 ± 0.03	0.37 ± 0.05
18:0	3.93 ± 0.21	4.17 ± 0.59	4.01 ± 0.46	4.18 ± 0.97	4.12 ± 0.29	3.96 ± 0.48	4.31 ± 0.35
18:1 $n-9$t	0.93 ± 0.27	0.91 ± 0.37	0.94 ± 0.35	0.94 ± 0.42	1.01 ± 0.19	0.95 ± 0.40	0.96 ± 0.38
18:1 $n-9$	5.48 ± 0.70	5.02 ± 0.54	5.23 ± 0.51	5.06 ± 0.41	5.55 ± 1.00	5.56 ± 1.01	5.32 ± 0.62
18:1 $n-7$	1.65 ± 0.42	1.67 ± 0.46	1.69 ± 0.45	1.66 ± 0.51	1.72 ± 0.46	1.68 ± 0.51	1.73 ± 0.47
18:1 $n-5$	0.44 ± 0.02	0.42 ± 0.04	0.42 ± 0.04	0.43 ± 0.05	0.46 ± 0.11	0.48 ± 0.12	0.43 ± 0.05
18:2 $n-6$	1.03 ± 0.03	0.96 ± 0.09	1.01 ± 0.07	0.97 ± 0.13	1.05 ± 0.04	1.09 ± 0.03	1.00 ± 0.04
18:3 $n-3$	0.91 ± 0.18	0.88 ± 0.18	0.91 ± 0.20	0.87 ± 0.15	0.98 ± 0.31	1.02 ± 0.35	0.91 ± 0.24
18:4 $n-3$	1.90 ± 0.33	1.79 ± 0.43	1.87 ± 0.27	1.76 ± 0.53	1.92 ± 0.05	2.05 ± 0.07	1.82 ± 0.10
20:1 $n-11$	4.67 ± 0.48	3.77 ± 1.57	3.91 ± 1.42	3.85 ± 1.98	3.89 ± 1.14	3.97 ± 1.71	3.73 ± 1.41
20:1 $n-9$	2.19 ± 0.44	1.81 ± 0.78	1.88 ± 0.65	1.92 ± 0.97	1.92 ± 0.49	2.02 ± 0.76	1.97 ± 0.54
20:1 $n-7$	0.13 ± 0.02	0.14 ± 0.00	0.16 ± 0.01	0.08 ± 0.11	0.15 ± 0.02	0.15 ± 0.01	0.07 ± 0.10
20:2 $n-6$	0.46 ± 0.02	0.41 ± 0.00	0.43 ± 0.00	0.43 ± 0.00	0.47 ± 0.03	0.46 ± 0.05	0.44 ± 0.00
20:4 $n-6$	1.15 ± 0.05	1.24 ± 0.01	1.19 ± 0.02	1.22 ± 0.10	1.20 ± 0.10	1.17 ± 0.05	1.23 ± 0.05
20:3 $n-3$	0.10 ± 0.14	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.11 ± 0.16	0.11 ± 0.16	0.00 ± 0.00
20:4 $n-3$	1.31 ± 0.03	1.28 ± 0.04	1.30 ± 0.02	1.27 ± 0.09	1.34 ± 0.07	1.38 ± 0.08	1.27 ± 0.00
20:5 $n-3$ (EPA)	6.62 ± 0.58	7.14 ± 1.17	7.08 ± 1.00	7.01 ± 1.21	7.01 ± 0.88	6.99 ± 1.04	7.02 ± 1.03
22:1 $n-11$	9.49 ± 3.20	8.03 ± 4.79	8.37 ± 4.27	8.45 ± 5.89	8.25 ± 3.49	8.72 ± 4.74	8.16 ± 3.67
22:1 $n-9$	0.84 ± 0.29	0.71 ± 0.43	0.76 ± 0.36	0.76 ± 0.52	0.75 ± 0.27	0.80 ± 0.37	0.76 ± 0.28
24:0	2.34 ± 0.33	2.42 ± 0.44	2.37 ± 0.37	2.39 ± 0.44	2.40 ± 0.33	2.36 ± 0.38	2.40 ± 0.35
22:6 $n-3$ (DHA)	33.8 ± 2.70	36.8 ± 5.03	34.9 ± 3.51	35.3 ± 6.95	34.5 ± 1.14	33.6 ± 2.94	34.7 ± 3.27
24:1 $n-9$	0.73 ± 0.20	0.72 ± 0.24	0.86 ± 0.19	0.92 ± 0.23	0.75 ± 0.14	0.90 ± 0.17	0.89 ± 0.15
∑FAME ID	99.0 ± 0.14	99.3 ± 0.43	98.6 ± 0.50	98.5 ± 0.79	99.2 ± 0.25	99.1 ± 0.40	98.8 ± 0.11
∑SAT	22.4 ± 0.81	23.0 ± 1.85	23.1 ± 1.60	23.1 ± 2.54	23.3 ± 1.72	23.0 ± 2.14	23.7 ± 1.20
∑MUFA	29.3 ± 3.86	25.7 ± 7.25	26.9 ± 6.42	26.6 ± 9.40	27.3 ± 3.95	28.1 ± 6.27	26.7 ± 5.43
∑PUFA	47.2 ± 3.18	50.5 ± 5.83	48.7 ± 4.32	48.9 ± 7.65	48.6 ± 2.48	47.9 ± 4.53	48.4 ± 4.34
∑$n-3$	44.6 ± 3.25	47.9 ± 5.90	46.0 ± 4.42	46.2 ± 7.68	45.9 ± 2.51	45.2 ± 4.50	45.7 ± 4.43
∑$n-6$	2.63 ± 0.06	2.61 ± 0.08	2.62 ± 0.10	2.63 ± 0.03	2.72 ± 0.03	2.72 ± 0.03	2.66 ± 0.09

[a] *Abbreviations:* FAME ID, fatty acids methyl esters identified; SAT, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; DHA, docosahexaenoic acid; EPA, eicosapentaenoic acid.

amino groups of nucleic acids during heat treatment and this may lead to the observed decrease in TBA value (Tironi, Tomás, & Añón, 2002).

Addition of salt to meat products is known to greatly enhance lipid peroxidation (Hutton, 2002). However, in this study, both PV and TBA values showed no significant differences between the salt levels tested (Table 1) and this may be due in part to the low levels evaluated.

3.8. Fatty acid profile

Table 2 shows the fatty acid profiles of the raw and heated salmon samples reported as percent total fatty acids, as well as the total amount of saturated fatty acids (SFA), monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA). The changes in the content of fatty acids after heating were marginal and no significant differences in the total amount of SFA, MUFA and PUFA were observed between raw and heated samples, or between samples with and without added salt (Table 2). These results confirm that thermal process, when optimised to reduce the changes in the nutritional profile of foods, may not lead to a significant change in the fatty acid content of the product (De La Cruz-García et al., 2000; Koøakowska et al., 2002).

The docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA) were the predominant PUFA accounting for 33.6–36.8% and 6.6–7.1% of total fatty acids, respectively (Table 2). Other abundant fatty acids were palmitic acid (16:0), stearic acid (18:0), cetoleic acid (22:1 $n-11$), gadoleic acid (20:1 $n-11$) and oleic acid (18:1 $n-9$) (Table 2). In the raw samples, the SFA, MUFA and PUFA accounted for approximately 22%, 29% and 47% of the total fatty acids. The $n-3$ and $n-6$ ranged about 45–48% and 2.6–2.7%, respectively. SFA, MUFA and PUFA determined in our study were comparable to the values reported by the United States Department of Agriculture (USDA, 2001). According to USDA nutritional data, raw pink salmon contains approximately 19.6%, 32.8% and 47.6% of SFA, MUFA and PUFA, respectively (USDA, 2001).

Table 3 shows the fatty acid contents represented as mg/100 g of product. No significant difference was observed between salt-added and no-salt added samples in the level of retained lipid. Per 100 g product (after 60 min heating) contained about 210 mg SFA, 240 mg MUFA, 440 mg PUFA, 320 mg DHA and 65 mg EPA. The $n-3$ and $n-6$ were 420 and 24 mg/100 g product, respectively. The raw fish contained 0.27 g DHA + EPA/100 g product, while the cooked products provided about 0.4 g DHA + EPA/100 g (DHA/EPA ratio 5.1). Nutrition experts recommend a daily intake of 500 mg of EPA and DHA to reduce the risk of coronary heart disease (Harris & Schacky, 2004). Our result indicates that consuming 130 g of canned pink salmon is sufficient to obtain the recommended amount of EPA + DHA. It is notable that this number is based on the dorsal muscle of female pink sal-

Table 3
Summary of fame analysis ($n = 2$) results for raw and heated pink salmon muscle (mg/100 g of tissue) [values are means ± standard deviation (SD)][A]

Salt (%)	Heating time (min)	SFA	MUSA	PUFA	DHA	EPA	$n-3$	$n-6$	$n-3/n-6$
Raw		148.7 ± 1.3^{c}	194.6 ± 31.0^{a}	312.9 ± 12.4^{c}	223.7 ± 11.7^{b}	43.9 ± 2.6^{b}	295.5 ± 13.3^{b}	17.5 ± 0.9^{d}	17.0 ± 1.7^{a}
0	10	194.2 ± 11.3^{ab}	217.7 ± 66.0^{a}	425.7 ± 39.5^{abc}	310.2 ± 35.4^{ab}	60.1 ± 8.5^{ab}	403.6 ± 40.7^{ab}	22.0 ± 1.2^{bc}	18.4 ± 2.8^{a}
	30	219.8 ± 25.8^{a}	254.4 ± 48.8^{a}	463.9 ± 63.4^{ab}	332.6 ± 49.3^{a}	67.6 ± 12.8^{a}	439.0 ± 63.1^{a}	24.9 ± 0.2^{ab}	17.6 ± 2.4^{a}
	60	207.7 ± 14.1^{ab}	241.5 ± 94.8^{a}	439.2 ± 50.4^{ab}	317.2 ± 49.2^{ab}	63.0 ± 8.3^{ab}	415.5 ± 51.7^{a}	23.7 ± 1.3^{abc}	17.6 ± 3.2^{a}
1.5	10	173.7 ± 17.7^{bc}	207.0 ± 65.3^{a}	362.9 ± 45.2^{bc}	258.1 ± 36.8^{ab}	52.0 ± 2.6^{ab}	342.4 ± 41.4^{ab}	20.5 ± 3.8^{cd}	16.9 ± 1.1^{a}
	30	232.8 ± 17.7^{a}	285.5 ± 68.4^{a}	484.6 ± 37.5^{a}	340.2 ± 23.9^{a}	70.7 ± 9.3^{a}	457.1 ± 37.7^{a}	27.6 ± 0.2^{a}	16.6 ± 1.5^{a}
	60	219.2 ± 20.5^{a}	246.1 ± 39.7^{a}	449.0 ± 59.4^{ab}	322.1 ± 44.1^{a}	65.2 ± 12.3^{ab}	424.4 ± 59.2^{a}	24.7 ± 0.3^{ab}	17.2 ± 2.2^{a}

Different letters within a column indicate significant differences ($p < 0.05$).
[A] *Abbreviations:* FAME ID, fatty acids identified; SAT, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; DHA, docosahexaenoic acid; EPA, eicosapentaenoic acid.

mon which contains much less oil content than other tissues or other wild Pacific salmon species. Furthermore, Table 3 shows a high $n-3/n-6$ ratio in the raw and cooked fish (16.6–18.4). The $n-3/n-6$ ratio has been suggested to be the best index when comparing relative nutritional values of fish oils from different species (Pigott & Tucker, 1990) and ranged from 7.5 to 19.5 in marine fish species (Stansby, 1967). Therefore, it can be concluded that canned wild pink salmon is a valuable source of these fatty acids.

4. Conclusions

Addition of 1.5% salt reduced cook loss of canned pink salmon by 15.4% and area shrinkage 24.6%. Product with added salt was tenderer with shear force decreased by 10.8%. Salt addition also caused the product to be slightly darker. Salt did not result in significant changes in thiamin degradation, lipid oxidation and fatty acids composition. The canning process employed here did not result in a loss of $n-3$ fatty acids making canned pink salmon, even when prepared from spawning female fish, a very good source of $n-3$ PUFA, particularly with respect to DHA + EPA ($\sim$0.4 g/100 g tissue) and $n-3/n-6$ ratio ($>$16.6).

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