International Journal of
Food Science & Technology
www.ifst.org
International Journal of Food Science and Technology 2010, **45**, 295–304

Original article

Effect of chill storage under different icing conditions on sensory and physical properties of canned farmed salmon (*Oncorhynchus kisutch*)

Alicia Rodríguez,[1] Nicolás Carriles[1] & Santiago P. Aubourg[2]*

1 Department of Food Science and Chemical Technology, Facultad de Ciencias Químicas y Farmacéuticas, Universidad de Chile, c/Vicuña MacKenna, 20, Santiago, Chile
2 Department of Food Technology, Instituto de Investigaciones Marinas (CSIC), c/E. Cebello, 6, 36208-Vigo, Spain

(Received 27 July 2009; Accepted in revised form 2 November 2009)

Summary This work focuses the sensory and physical properties of canned farmed coho salmon (*Oncorhynchus kisutch*); the effect of flake ice and slurry ice as previous slaughter and chilling conditions was studied. Hydrolytic chemical changes related to sensory and physical properties were also evaluated in canned salmon. Thermal treatment led to a canned muscle showing higher firmness, lower cohesivity and colour changes (higher L^* and b^* values; lower a^* values); filling oils showed higher turbidity scores and lower L^*, a^* and b^* values than starting oil. Additionally, oxidised and putrid odour development in canned muscle and filling oil was low. However, previous icing condition and time (up to 9 days) provided no changes in canned muscle and filling oil, except for an increasing oxidised odour and turbidity in filling oil with chilling time. Meantime, free fatty acid formation and K value were markedly affected by previous icing system and time.

Keywords Canning, coho salmon, constituent hydrolysis, farming, flake ice, physical properties, sensory acceptance, slurry ice.

Introduction

Canning is one of the most important means of fish preservation (Horner, 1997). This is done by two thermal steps – cooking and sterilisation – so that both enzymes and bacteria should be permanently inactivated by heat and, provided reinfection does not occur and no negative interaction with the container is produced, heat-processed fish is preserved for a very long time. However, owing to the thermal sensitivity of a large number of fish chemical constituents, different breakdown and hydrolytic events have been reported on canned fish, thus showing an important detrimental effect on sensory and physical properties related to fish colour and odour, water leaching and muscle texture (toughening, drying, etc.) (Aitken & Connell, 1979; Aubourg, 2001).

Since most species used for canning occur in glut quantities, canneries require to store the raw material before it is canned. As a result, the quality of canned fish will also depend to a large extent on the adequacy of the methods used to hold the raw material, whose quality may continuously change during storage prior to processing (Slabyj & True, 1978; Aubourg & Medina, 1997). In order to slowdown the mechanisms involved in quality loss after capture, fish refrigeration can be considered one of the most employed strategies. Therefore, various preservative methods such as traditional flake ice (FI) (Whittle *et al.*, 1990), refrigerated seawater (Kraus, 1992), and addition of chemical preservation agents (Hwang & Regenstein, 1995) have been applied.

Recently, slurry ice (SI) has been reported to be a promising technique for the preservation of aquatic fresh food products (Yamada *et al.*, 2002; Piñeiro *et al.*, 2004). Two relevant characteristics of SI when compared to FI are: (i) its faster chilling rate, which is a consequence of its higher heat-exchange capacity, and (ii) the reduced physical damage caused to food products by its microscopic spherical particles. The fluid nature of SI allows continuous processes to be carried out and hence the automation of the processing and distribution of fresh aquatic food products guarantees a more hygienic way of handling and processing them. Finally, SI systems is a versatile technique that can be combined with other preservative agents (antiseptics, antioxidants, antimelanosics, etc.).

In recent years the fishing sector has suffered from dwindling stocks of traditional species as a result of important decreases in their availability. This has prompted the fish trade to pay an increasing attention to aquaculture techniques as a source of fish and other seafood products. Among cultivated fish, coho salmon

*Correspondent: E-mail: saubourg@iim.csic.es

doi:10.1111/j.1365-2621.2009.02135.x

(*Oncorhynchus kisutch*) has received a great attention because of its increasing production in countries like Chile, Japan and Canada (FAO, 2007). Previous research related to the chilling storage of this species accounts for the development of different spoilage pathways and quality loss (Aubourg *et al*., 2005, 2007). The present study concerns the coho salmon canning. Its employment for this purpose would be greatly recommended since as a farmed species, slaughtering and previous storage conditions could be conveniently mastered, this leading to great advantages for canning manufacturers. The work focuses the sensory and physical properties of canned coho salmon, taking into account the effect of replacing traditional FI by SI as previous slaughter and chilling storage conditions. The hydrolysis formation of some chemical metabolites related to sensory and physical properties changes is also analysed.

Materials and methods

Icing systems

Two different icing systems (traditional FI and SI) were employed for the fish slaughter and chilling storage.

Flake ice (FI) was prepared from fresh water with an Icematic F100 Compact device (Castelmac SPA, Castelfranco, Italy). The temperature of the FI was −0.5 °C, being the temperature of the chilled fish in the range of 0 °C to −0.5 °C.

Slurry ice (SI) was prepared using a FLO-ICE prototype (Kinarca S.A.U., Vigo, Spain). The composition of the SI binary mixture was 40% ice:60% water, prepared from filtered seawater (salinity: 3.3%). The temperature of the SI mixture was −1.5 °C, being the temperature of the chilled fish in the range of −1.0 °C to −1.5 °C.

Fish material, slaughter and chilling storage

Specimens (thirty-two fish) of farmed coho salmon (*Oncorhynchus kisutch)* (weight range: 2.8–3.2 kg) were obtained (day 0) from an aquaculture facility (Comercial Xanquéi; Lousame, La Coruña, Spain) and slaughtered at the farm by immersion either in FI (sixteen fish) or SI (sixteen fish). Fish were kept under such conditions during 24 h till arrival in the laboratory. At this time (day 1), four fish belonging to each icing condition (FI or SI) were separated and studied as raw fish. The same day (day 1), four other fish of each icing condition were canned according to conditions described below. The remaining fish (eight fish of each icing condition) were placed in an isothermal room at 2 °C and were maintained in FI or SI; chilled fish were taken for the canning process on days 5 and 9 of icing treatment (at each time, four fish belonging to each icing condition). Throughout the experiment, both the FI and SI were renewed when required, in order to maintain a 1:1 fish to ice ratio. Both in raw and in canned samples, each fish specimen was studied separately from others to achieve the statistical study ($n = 4$).

Previous research concerning the chilled storage of the present species (Aubourg *et al*., 2005, 2007) has shown that after a 10-day storage period microbiological activity and lipid oxidation development increased largely. Accordingly, in the present experiment, three different chilling times (0, 5 and 9 days) below this time limit were chosen.

Canning process

Fish were steam cooked in our pilot plant in a horizontal retort during 45 min (102–103 °C) to a final backbone temperature of 65 °C, which was measured by a set of copper-constantan thermocouples, according to Pérez-Martín *et al*. (1989). The fish were then cooled at room temperature (15–18 °C) for about 2 h, headed, eviscerated and skinned.

Muscle portions (90 g) from salmon specimens were placed in small flat rectangular cans (105 mm × 60 mm × 25 mm; 150 mL). Two grams of NaCl were weighted and added to each can, that was then filled with sunflower oil as filling medium. The cans were vacuum-sealed and sterilised in our pilot plant in a horizontal retort heated by means of steam (115 °C, 45 min; $F_o = 7$ min); such lethality value was chosen according to previous research (Banga *et al*., 1993). When the heating time was completed, steam was cut off and air was used to flush away the remaining steam. Cans cooling was carried out at reduced pressure.

After 3 months of storage at room temperature (15–18 °C), the cans were opened and the liquid part was carefully drained off gravimetrically, filtered by means of a filter paper and collected. Then, the resulting liquid phase was centrifuged, the oil phase separated and dried with anhydrous Na_2SO_4. Salmon white muscle was separated and then wrapped in filter paper. Fish white muscle and the filling oil medium were used for analyses. Initial (starting) oil and oil that was placed in cans and sterilised in the absence of salmon muscle (heated oil) were also analysed.

Canning manufacturers recommend not to open cans before 2–3 months have elapsed. This time is considered necessary for an adequate homogenisation of components inside the can. Accordingly, a 3-month storage period was employed in the present study.

Sensory analyses

The following descriptors were analysed in salmon muscle (raw and canned) and in oil (starting, heated and filling): firmness (resistance of salmon muscle to be

deformed), cohesivity (binding degree of myotomes in salmon muscle), oxidised odour (presence of off-odours related to rancidity development), putrid odour (presence of off-odours related to amine formation and decayed meat) and oil turbidity (loss of natural transparency and presence of small particles). The sensory analysis was conducted according to the Quality Descriptive Analysis (QDA) method by a sensory panel consisting of ten experienced judges (five females and five males). Panellists were selected and trained according to international standards in use of sensory descriptors for raw and processed fish of different quality conditions (Howgate, 1992).

At each sampling time, the fish muscle and oil portions were presented to panellists in individual trays and were scored individually. The panel members shared samples tested. The different sensory descriptors were evaluated on non-structured linear scales with numerical scores ranging 0–10. Scores among panellists were averaged. For firmness and cohesivity, score 10 corresponds to the stage where such properties are observed in their maximum value, while score 0 represents the stage where a decrease is no more noticeable. For turbidity and rancid and putrid odours, score 0 represents the stage where such attributes are not noticeable, while stage 10 corresponds to the stage where no increase is possible. For both odour descriptors, score 5.0 was considered the borderline of acceptability; scores from the remaining descriptors are comparatively discussed without considering a borderline of acceptability.

Physical analyses

A shear test was used to evaluate texture in raw and canned salmon muscle. Firmness and cohesivity were determined from a stress-distance curve obtained from a Universal Testing Machine (LR-5K; Lloyd Instruments Limited, Hampshire, UK) including a load cell of 500 N connected to a computer, this including a Dapmat 40-0465 software data analysis (version 3.05, Lloyd Instruments Limited, Hampshire, UK). A Warner-Bratzler blade (knife edge 60°), 1.2 mm thick, 150 mm width and cutting at a 1 mm s^{-1} speed was employed at 4 °C on a 4 cm × 4 cm × 2 cm sample. The firmness (N) was regarded as the resistance maximum of the muscle fibres against transversal shearing (maximum force) and was the height of the first peak; cohesivity was measured during the upward movement of the blade and was calculated as the cohesivity (mm) at maximum peak force (Sigurgisladóttir *et al.*, 1999). The average value of quadruplicate replicates was considered in each sample analysis.

Instrumental colour analysis (CIE 1976 L^*, a^*, b^*) was performed by employing a tristimulus Hunter Labscan 2.0/45 colorimeter according to previous research (Ortiz *et al.*, 2008). Measurements were made directly on the salmon muscle and by employing a quartz cuvette in the case of oils. For each sample analysis, colour scores were obtained as mean values of four measurements obtaining by rotating the measuring head 90° between duplicate measurements per position.

Chemical analyses

NaCl content in fish muscle was determined by a modification of the Volhard method, which included boiling in HNO_3, neutralisation of NaCl meq with excess of $AgNO_3$, and final determination of the excess of $AgNO_3$ meq by reverse titration with NH_4SCN (AOAC, 1990). Results were calculated as g NaCl kg^{-1} muscle.

Trimethylamine-nitrogen (TMA-N) values were determined by means of the picrate method, this including a spectrophotometric (410 nm) assessment (Beckman Coulter DU 640, London, UK) (Tozawa *et al.*, 1971). This involves the preparation of a 5% (w/v) trichloroacetic acid extract of fish muscle. The results were expressed as mg TMA-N kg^{-1} muscle.

Free fatty acid (FFA) content was determined in the lipid extract of the salmon muscle by the Lowry & Tinsley (1976) method based on complex formation with cupric acetate-pyridine followed by spectrophotometric (715 nm) assessment. Results were expressed as g FFA kg^{-1} lipids.

Nucleotide degradation analysis was carried out starting from 6% perchloric acid extracts from the fish muscle according to previous research (Aubourg *et al.*, 2007). Analysis was performed by HPLC, using a Beckman device provided with the programmable solvent module 126 and the scanning detector module 167 connected to the System Gold software, version 8.1 (Beckman Coulter). Separations were achieved on a reverse-phase Spherisorb ODS-2 C18 250 mm × 4.60 mm column (Waters, Milford, MA, USA), with an internal particle diameter of 5 μm. Standard curves for adenosine 5′-triphosphate (ATP) and each compound involved in its degradation pathway, adenosine 5′-diphosphate (ADP), adenosine 5′-monophosphate (AMP), inosine 5′-monophosphate (IMP), inosine (INO) and hypoxanthine (Hx), were constructed in the 0–1 mm range. Results obtained for each degradation compound were calculated as mmol kg^{-1} muscle. The K value was calculated according to the following concentration ratio: K value (%) = 100 × (INO + Hx)/(ATP + ADP + AMP + IMP + INO + Hx).

Statistical analyses

Data (n = 4) obtained from the different sensory, physical and chemical analyses were subjected to the ANOVA method to explore differences by two different ways: icing condition (FI vs. SI comparison) and icing

time (Statistica, version 6.0; Statsoft Inc., 2001). Comparison of means was performed using the least-square differences (LSD) test. CI at the 95% level ($P < 0.05$) was considered in all cases.

Results and discussion

Texture changes assessment

Sensory assessment of firmness and cohesivity of the fish muscle (Table 1) indicated that the canning process has led to a product showing a higher mean firmness degree and a lower ($P < 0.05$) cohesivity value. No effect of the icing condition during the slaughtering and chilling storage could be assessed by the sensory panel. In addition, lengthening storage in both icing conditions up to 9 days was not accompanied by any additional change in both textural properties.

Texture assessment was also carried out by physical methodology (Table 2). A firmness increase ($P < 0.05$) could be observed as a result of the canning process, according to previous research on heated rainbow trout (*Oncorhynchus mykiss*) (Schubring, 2008). Further, higher values were obtained (Table 2) for fish previously kept under SI conditions than for its counterpart from FI. For both icing conditions, no differences could be outlined as a result of increasing the chilling time. Concerning the physical analysis of cohesivity (Table 2), canned muscle showed as for sensory assessment (Table 1), lower values ($P < 0.05$) than raw fish muscle. No differences could be assessed by comparison between fish samples corresponding to both icing conditions, neither as a result of lengthening the chilling time.

According to both sensory and physical assessments of texture, a firmness increase and a cohesivity decrease have been produced as a result of the canning process, so that a more breakable fish structure and more vulnerable to mechanical damage was obtained. The texture of the fish muscle has shown to depend on numerous intrinsic biological factors related to the density of the muscle fibres, as fat and collagen content (Sigurgisladóttir *et al.*, 1999) and sexual maturity (Reid & Durance, 1992). Previous research reports that heating treatment converts the translucent, jelly-like cellular fish mass into an opaque and firmer material, as a result of protein denaturation and water removal. Additionally, the connective tissue holding the cells together is reported to be degraded by heat and blocks of cells become readily separated from one another, so that a lower cohesivity would be observed in muscle (Aitken & Connell, 1979); collagen hydrolysis to gelatine during heating would eliminate the role of connective

Table 1 Sensory analysis* of canned salmon muscle that was previously stored under different icing conditions†

	Firmness		Cohesivity		Oxidised odour		Putrid odour	
Icing time (days)	FI	SI	FI	SI	FI	SI	FI	SI
1	3.2 (1.6)	3.3 (1.7)	6.5 (1.4)	6.8 (1.3)	0.4 (0.3)	0.6 (0.4)	0.3 (0.2)	0.3 (0.1)
5	3.5 (1.5)	3.3 (1.7)	7.1 (1.4)	6.6 (0.9)	0.8 (0.6)	0.6 (0.4)	0.3 (0.2)	0.4 (0.2)
9	3.9 (1.7)	3.1 (1.4)	6.8 (1.5)	7.7 (0.7)	0.4 (0.3)	0.5 (0.3)	0.4 (0.2)	0.3 (0.2)

*Mean values of four independent determinations ($n = 4$). SD are indicated in brackets. No significant differences ($P > 0.05$) were observed as a result of the previous icing conditions (icing system and chilling time). Raw fish values (FI and SI, respectively): 2.1 ± 0.5 and 2.2 ± 0.7 (firmness), 9.1 ± 0.3 and 9.2 ± 0.4 (cohesivity), and 0.0 ± 0.0 (rancid and putrid odours in both icing conditions).
†Previous icing conditions: FI (flake ice) and SI (slurry ice).

Table 2 Texture physical assessment and NaCl content determination* in canned salmon muscle that was previously stored under different icing conditions†

	Firmness (N)		Cohesivity (mm)		NaCl (g kg^{-1} muscle)	
Icing time (days)	FI	SI	FI	SI	FI	SI
1	z 14.40 (1.16)	y 18.75 (2.10)	25.36 (2.06)	24.82 (3.17)	10.2 (0.2)	10.0 a (0.2)
5	z 12.15 (0.79)	y 20.50 (0.40)	22.96 (3.45)	25.93 (0.42)	10.5 (1.1)	10.3 a (2.7)
9	z 13.55 (0.85)	y 19.13 (2.01)	23.91 (6.25)	24.74 (0.98)	z 10.3 (0.5)	y 14.4 b (0.3)

*Mean values of four independent determinations ($n = 4$). SD are indicated in brackets. Mean values preceded by different letters (z, y) indicate significant differences ($P < 0.05$) as a result of the previous icing system. For each parameter and for each icing system, mean values followed by different letters (a, b) denote significant ($P < 0.05$) differences as a result of the icing time. Raw fish values (FI and SI, respectively): 10.17 ± 2.11 and 14.01 ± 1.52 (firmness), 45.32 ± 1.17 and 46.21 ± 1.08 (cohesivity) and 0.5 ± 0.1 and 0.5 ± 0.1 (NaCl content).
†Previous icing conditions: FI (flake ice) and SI (slurry ice).

tissue as a supporting structure so that there is no longer any link between myotomes or between the muscle and bones (Ma *et al*., 1983). Resulting toughening and firmness increase in canned fish muscle can be considered the result of increased bonding between myofibrillar proteins, the denaturation of myosin and water holding capacity decrease of proteins (Aubourg, 2001; Sankar & Ramachandran, 2005). In the case of fatty fish, the role of fat in the texture changes has also been found important due to crosslinking of peptide chains by reaction with lipid oxidation products (Rzhavskaya & Fonarev, 1988; Aubourg, 2001). Texture toughening has been reported to increase in thermally treated fish as heating processing temperature (Ma *et al*., 1983) and canned storage temperature (Paredes & Baker, 1988) increase. However, brine pre-cooking was found to result in texture improvement in canned freshwater nase (*Chondrostoma nasus*) (Lazos, 1997).

Present results on texture changes as a result of the canning process agree to previous related research on canned rainbow trout and pollock (Chia *et al*., 1983) and sardine (Losada *et al*., 2006) fish species. This latest study showed that no effect could be observed on texture properties as a result of replacing FI by SI during a previous holding time in ice (Losada *et al*., 2006), according to the present results. Contrary to the present research, texture quality changes were observed in canned sardine (*Sardinella longiceps*) and mackerel (*Rastrelliger kanagurta*) as a result of increasing the previous holding time in traditional ice (Madhavan *et al*., 1970).

An additional aspect to be considered in the muscle firmness increase as a result of canning is the NaCl content change in fish muscle. In the present research, canned muscle showed NaCl contents (Table 2) included in the 10.0–14.4 g kg^{-1} muscle range, widely higher ($P < 0.05$) than the value observed for the raw starting fish (0.5 ± 0.1 g kg^{-1} muscle). This NaCl content increase in fish muscle agrees to the enhancement effect recognised for this compound on physical properties such as firmness (Slabyj & True, 1978; Chiralt *et al*., 2001). Among the different canned samples, a marked higher ($P < 0.05$) value could be observed for canned fish previously kept under SI condition during 9 days.

Odour development assessment

Oxidised and putrid odour development was measured by the sensory panel in the canned salmon muscle (Table 1). Incipient and very low values were attributed to both parameters in all cases, so that all kinds of muscle were scored as highly acceptable. Such results indicated that under the present experiment conditions, a low development of rancidity and microbial activity was present throughout the complete canning process including slaughtering, chilling storage, cooking and sterilisation. Both odour values did not provide significant differences as a result of the previous icing time in both icing systems. Comparison between samples corresponding to the two icing conditions did not provide significant differences. Previous research related to chilling processing has shown an enhancement of sensory quality attributes in fish kept under SI condition when compared to its counterpart fish chilled under FI (Piñeiro *et al*., 2004). However, present results have shown that after a strong heat process (cooking and sterilisation) such sensory advantages were not noticeable in the canned product. Previous related research provides contradictory results concerning the effect of the previous icing time. Thus, an off-odour development was observed in different kinds of canned products prepared from white sardine (*Kowala coval*) (Jeyasekaran & Saralaya, 1991), Maine sardine (Slabyj & True, 1978) and mackerel (*Rastrelliger kanagurta*) and sardine (*Sardinella longiceps*) (Madhavan *et al*., 1970) as a result of increasing the previous chilling time under traditional FI conditions. Contrary, a taste panel could not distinguish between canned herring (*Clupea harengus*) stored at different time in ice before canning (McLay, 1968).

The oxidised and putrid odour development was also assessed in the filling oil. Results are shown in Table 3. In spite of showing increasing values ($P < 0.05$) when

Table 3 Sensory analysis* of filling oil corresponding to canned salmon that was previously stored under different icing conditions†

	Oxidised odour		Putrid odour		Turbidity	
Icing time (days)	FI	SI	FI	SI	FI	SI
1	0.9 a (0.3)	0.9 a (0.2)	0.7 (0.8)	0.9 (0.6)	7.6 (0.9)	7.5 (1.1)
5	1.6 ab (0.8)	1.4 ab (0.7)	1.2 (1.0)	0.7 (0.4)	8.7 (0.7)	7.5 (0.9)
9	2.1 b (0.7)	1.5 b (0.1)	0.9 (0.8)	1.0 (0.7)	8.9 (0.8)	8.8 (0.8)

*Mean values of four independent determinations ($n = 4$). SD are indicated in brackets. No significant differences ($P > 0.05$) were observed as a result of the previous icing system employed. For each parameter and for each icing system, mean values followed by different letters (a, b) denote significant ($P < 0.05$) differences as a result of the icing time. Starting oil values: 0.0 ± 0.0 (oxidised odour), 0.0 ± 0.0 (putrid odour) and 2.8 ± 0.2 (turbidity). Heated oil values: 0.1 ± 0.1 (oxidised odour), 0.0 ± 0.0 (putrid odour) and 2.7 ± 0.3 (turbidity).

†Previous icing conditions: FI (flake ice) and SI (slurry ice).

compared to starting oil values, both attributes provided relatively low scores so that all kinds of canned oils were considered as largely acceptable. No effect ($P > 0.05$) of the thermal treatment on the odour development is observed by comparing the starting oil and the heated oil values (Table 3). Accordingly, presence in filling oils of molecules responsible for the oxidised and putrid odours can be explained partially by their ability to extract them from the canned muscle and partially because of the ability of oils to interact with chemical constituents present in the fish muscle. Such interaction between both phases of the can was already observed in previous research concerning nutritional and quality aspects (Aubourg & Medina, 1997; Aubourg *et al*., 1997). Oxidised odour scores (Table 3) showed an increasing pattern with icing time for filling oils corresponding to both holding conditions; in addition, higher mean values were observed in the case of filling oils related to FI condition. According to the present results, an increasing rancid odour development was already observed by Madhavan *et al*. (1970) in filling oil corresponding to canned mackerel (*Rastrelliger kanagurta*) and sardine (*Sardinella longiceps*) as a result of increasing the previous chilling time under traditional FI condition.

Colour and turbidity changes analysis

Concerning the colour assessment, the physical tristimulus method was applied to canned muscle (Table 4). According to the raw fish values, the canning process led to a very different product where higher L^* and b^* values were obtained, while a^* values reflected a substantial decrease ($P < 0.05$). Present results on L^* and a^* values agree to previous research concerning fish species thermal treatment (Choudhry, 1977; Schubring, 2008), this including a good correlation between a^* value and carotenoid pigment content (Choudhry, 1977). In addition, an a^* value loss has been reported to correlate with haemoglobin-mediated lipid oxidation and to provide an inverse relationship with secondary lipid oxidation development (Wetterskog & Undeland, 2004). On the other hand, previous research has shown that heat processed fish were always more yellow (higher b^* value) than raw fish (Choudhry, 1977), according to the present results. Additionally, an important relationship between b^* value and the formation of polymerised Schiff bases and fluorescent compounds (tertiary lipid oxidation compounds) has been observed (Undeland *et al*., 2003)

Although some differences could be observed in the present research as a result of the chilling time and the kind of ice employed, a general pattern could not be concluded concerning both effects on the colour properties of the canned fish muscle. In this sense, previous research (Ortiz *et al*., 2008) did not afford differences in L^*, a^* and b^* values in chilled rainbow trout as a result of employing different icing systems (FI and SI). Contrary, an increasing previous holding temperature and time in ice led to an increase in L^* value and a decrease in a^* value, while no effect on b^* value could be observed for canned skipjack tuna (Little, 1972).

The present research accounts also for the colour analysis of the filling oil (Table 5). The canning process has led to marked decreases for all colour parameters in filling oils, a^* and b^* values attaining green and blue colour scores, respectively. Meantime, comparison between starting and heated oil showed an increase for L^* and b^* values and a decrease for a^* value as a result of the thermal treatment. Some differences as a result if the icing condition and the chilling time could be assessed in the filling oils; however, great fish-to-fish differences could be observed in some cases, so that a marked pattern could not be concluded about the effect of such factors on L^*, a^* and b^* values. Contrary to the present results, a browning development (b^* value increase) was observed in filling oil corresponding to sardine (*Sardinella longiceps*) and mackerel (*Rastrelliger kanagurta*) muscle by increasing the previous holding time in ice of chilled fish (Madhavan *et al*., 1970).

Significant increases ($P < 0.05$) in turbidity were detected in filling oils when compared to starting oil

Table 4 Comparative assessment of colour changes* in canned salmon muscle that was previously stored under different icing conditions†

	*L**		*a**		*b**	
Icing time (days)	**FI**	**SI**	**FI**	**SI**	**FI**	**SI**
1	73.70 ab (1.43)	73.28 (0.16)	2.38 (0.17)	1.71 a (0.05)	21.04 a (0.53)	21.28 (0.49)
5	z 74.09 b (0.30)	y 75.49 (0.61)	2.14 (0.87)	2.53 b (0.26)	21.32 ab (1.43)	21.70 (0.67)
9	71.48 a (1.41)	73.89 (1.67)	3.73 (1.02)	2.44 b (0.52)	y 23.01 b (0.79)	z 21.41 (0.69)

*Mean values of four independent determinations ($n = 4$). SD are indicated in brackets. For each parameter and for each icing time, mean values preceded by different letters (z, y) indicate significant differences ($P < 0.05$) as a result of the previous icing system. For each parameter and for each icing system, mean values followed by different letters (a, b) denote significant ($P < 0.05$) differences as a result of the icing time. Raw fish values (FI and SI, respectively): 55.61 ± 1.72 and 54.89 ± 1.72 (L^*), 16.01 ± 1.63 and 15.90 ± 1.34 (a^*) and 13.04 ± 2.43 and 12.91 ± 1.79 (b^*).
†Previous icing conditions: FI (flake ice) and SI (slurry ice).

Table 5 Comparative assessment of colour changes* in filling oil corresponding to canned salmon that was previously stored under different icing conditions†

	*L**		*a**		*b**	
Icing time (days)	**FI**	**SI**	**FI**	**SI**	**FI**	**SI**
1	z 7.54 a (0.07)	y 9.02 b (0.14)	−0.32 (0.03)	−0.32 (0.25)	y 0.79 b (0.23)	z − 0.32 (0.24)
5	y 9.56 c (0.03)	z 8.47 a (0.21)	y − 0.11 (0.17)	z − 0.57 (0.13)	−0.34 a (0.22)	0.01 (0.21)
9	z 8.47 b (0.19)	y 8.99 b (0.15)	−0.08 (0.23)	−0.51 (0.48)	0.14 a(0.39)	−0.03 (0.16)

*Mean values of four independent determinations ($n = 4$). SD are indicated in brackets. For each parameter and for each icing time, mean values preceded by different letters (z, y) indicate significant differences ($P < 0.05$) as a result of the previous icing system. For each parameter and for each icing system, mean values followed by different letters (a, b, c) denote significant ($P < 0.05$) differences as a result of the icing time. Starting oil values: 55.43 ± 0.12 (*L**), 0.02 ± 0.01 (*a**) and 1.41 ± 0.32 (*b**). Heated oil values: 55.98 ± 0.17 (*L**), −0.34 ± 0.05 (*a**) and 2.30 ± 0.23 (*b**).
†Previous icing conditions: FI (flake ice) and SI (slurry ice).

and heated oil (Table 3). Such increase could be mostly explained as a result of water loss of the salmon muscle inside the can. Water loss of fish muscle is considered the result of protein denaturation and accordingly, water holding capacity decrease (Aubourg, 2001; Schubring, 2008). Higher mean values were obtained for turbidity in filling oil corresponding to FI-treated fish when compared to its counterpart from SI system; additionally, an increasing pattern could be observed with storage time for both holding conditions.

Formation of hydrolysis compounds

Different hydrolysis and breakdown events concerning chemical constituents that are known to be related to sensory and physical changes in canned fish (Aitken & Connell, 1979; Aubourg, 2001) were analysed in the present research. Such analyses were carried out on the salmon muscle.

Trimethylamine (TMA) is known to be produced as a result of microbial activity during the chilled storage (Whittle *et al.*, 1990; Olafsdóttir *et al.*, 1997) and as a result of thermal breakdown of trimethylamine oxide (TMAO) during cooking and sterilisation steps (Madhavan *et al.*, 1970; Gallardo *et al.*, 1990; Losada *et al.*, 2006). TMA presence has shown a great effect on off-odours development related to putridity. In the present research (Fig. 1), great differences ($P < 0.05$) were found between the raw fish TMA-N values and those from canned fish from day 1, this leading to the conclusion that thermal treatment (cooking and sterilisation) has exerted a marked effect on the TMA formation. Such result agrees to previous research where albacore tuna was canned under different sterilisation conditions (Gallardo *et al.*, 1990); in all cases, a marked TMAO content decrease was accompanied by an important TMA formation during cooking and sterilisation steps. However, no effect of the icing time or the icing system employed could be outlined in the present study, according to a previous experiment on canned

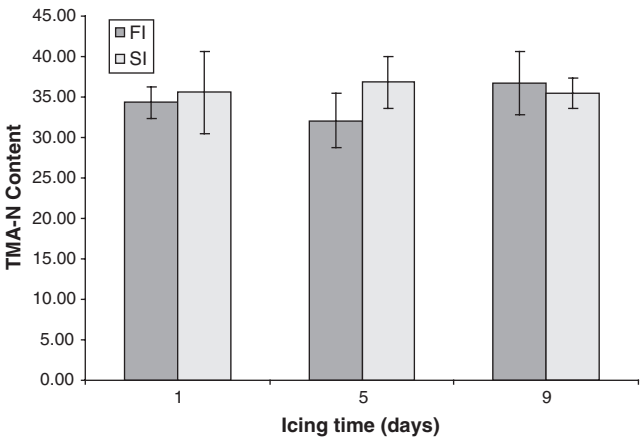

Figure 1 Trimethylamine-nitrogen (TMA-N) content (mg kg^{-1} muscle)* in canned salmon muscle that was previously stored under different icing conditions**. *Mean values of four independent determinations ($n = 4$). SD are indicated by bars. Raw fish values (FI and SI, respectively): 0.5 ± 0.2 and 0.5 ± 0.1. **Previous icing conditions: FI (flake ice) and SI (slurry ice).

sardine where both previous icing systems (FI and SI) were comparatively checked (Losada *et al.*, 2006). Contrary, previous research (Madhavan *et al.*, 1970; Slabyj & True, 1978) showed that an increasing holding time in traditional ice would lead to an increase in the TMA-N content in the canned product. Present results on TMA formation agree to putrid odour development in both muscle (Table 1) and filling oil (Table 3) in the sense that a marked increasing effect ($P < 0.05$) is observed for thermal treatment, while no effect ($P > 0.05$) can be attributed to holding conditions (icing system and time).

Free fatty acids (FFA) are known to be produced as a result of endogenous and microbial enzymes activity on large-size lipid molecules (TG and PL classes, namely) during the chilled storage (Olafsdóttir *et al.*, 1997) and as a result of large-size lipid molecules breakdown

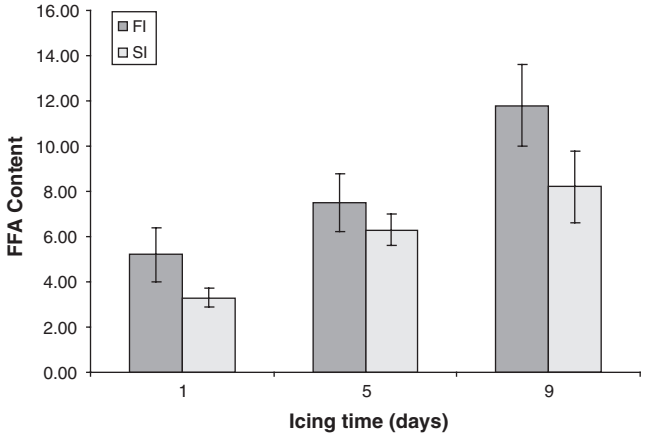

Figure 2 Free fatty acid (FFA) content (g kg^{-1} lipid)* in canned salmon muscle that was previously stored under different icing conditions**. *Mean values of four independent determinations ($n = 4$). SD are indicated by bars. Raw fish values (FI and SI, respectively): 1.7 ± 0.1 and 1.6 ± 0.7. **Previous icing conditions: FI (flake ice) and SI (slurry ice).

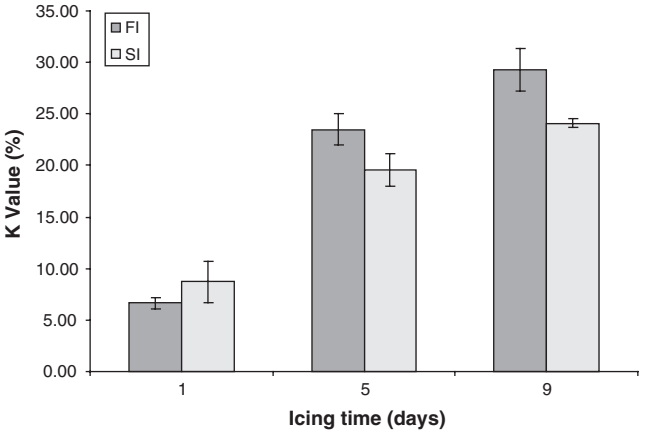

Figure 3 K value (%) assessment* in canned salmon muscle that was previously stored under different icing conditions**. *Mean values of four independent determinations ($n = 4$). SD are indicated by bars. Raw fish values (FI and SI, respectively): 6.4 ± 0.4 and 7.3 ± 0.7. **Previous icing conditions: FI (flake ice) and SI (slurry ice).

during the thermal treatment (Aubourg *et al.*, 1997); further, FFA formation during the canning process has shown a great dependence on sterilisation temperature (Aubourg *et al.*, 1997). FFA presence has shown an important role in fish muscle texture changes (Aubourg, 2001) and by enhancing the lipid oxidation development and accordingly, the formation of rancid off-odours (Rzhavskaya & Fonarev, 1988). In the present research (Fig. 2), canned fish corresponding to day 1 showed an important FFA content increase ($P < 0.05$) when compared to raw fish (thermal breakdown effect). In addition, an important effect of icing time could be observed for both icing conditions, since increasing FFA contents could be observed by increasing the previous icing time for both FI and SI conditions, according to previous related research (Madhavan *et al.*, 1970; Aubourg & Medina, 1997). Finally, higher mean values were obtained in all cases for fish that had been previously stored under FI system when compared to its counterpart from SI condition. This result agrees to previous research on chilled material where, a lower FFA formation was obtained in fish kept under SI condition when compared to its counterpart under FI (Piñeiro *et al.*, 2004). A good correlation value ($r^2 = 0.91$ and $r^2 = 0.94$, for FI and SI conditions, respectively) was obtained in this study between FFA values in canned muscle and oxidised odour scores in filling oils, according to the above mentioned lipid hydrolysis–oxidation relationship (Rzhavskaya & Fonarev, 1988; Aubourg, 2001). Meantime, lower correlation values were obtained between the FFA formation in muscle and the oil turbidity scores ($r^2 = 0.81$ and $r^2 = 0.70$, for FI and SI conditions, respectively).

During post-mortem fish storage, muscle nucleotides are known to degrade in a series of stages as a result of endogenous biochemical changes; the level of major adenine nucleotides and their related compounds (*K* value assessment) has been utilised extensively as an index of freshness of fish muscle (Olafsdóttir *et al.*, 1997). In addition, some of the molecules included in the *K* value assessment (IMP and Hx) have been reported to exert an important effect on sensory properties of the fish muscle (Hughes & Jones, 1966; Kawai *et al.*, 2002). In the present research (Fig. 3), no effect of the thermal treatment (cooking and sterilisation) could be observed on the *K* value since, canned fish samples corresponding to day 1 did not reveal differences ($P > 0.05$) when compared to raw fish values. However, an important effect of icing time and icing condition could be outlined. Thus, an increasing *K* value could be observed with icing time and a lower autolysis behaviour could be concluded in canned fish corresponding to previous SI system storage. A good correlation value ($r^2 = 0.93$ and $r^2 = 0.95$ for FI and SI conditions, respectively) could be obtained between the *K* value in canned fish and the oxidised odour scores in filling oils; however, poor correlation values were obtained between the *K* value and the putrid odour development in fish muscle and in filling oil. In previous research (Piñeiro *et al.*, 2004), a lower *K* value has been reported for chilled fish kept under SI system when compared to its counterpart stored under FI condition. Previous research carried out on *K* value analysis in canned fish is scarce, but shows that the *K* value assessment would not be likely to be influenced by the thermal treatment (Hughes & Jones, 1966; Vázquez-Ortiz *et al.*, 1997) in agreement with present results. Accordingly, this quality index could be

considered a profitable tool in order to assess the freshness degree of the raw material employed for canning.

Final remarks

The different steps included in the canning process have led to important sensory and physical properties changes in the fish product. Most changes (texture and colour, specially) can be related to the thermal treatment (cooking and sterilisation steps), while previous holding conditions studied (icing system and time) were found to have short effects on sensory and physical properties changes (namely, oxidised odour and turbidity in filling oil) of the canned product. According to oxidised and putrid odour values (fish muscle and filling oil assessments), it could be concluded that coho salmon has provided a widely acceptable canned product under the present conditions checked (slaughter and icing storage up to 9 days).

A greater effect of icing condition and time could be observed by analysing the hydrolysis formation of some chemical metabolites. Thus, FFA formation and *K* value in canned muscle showed a marked influence of the previous icing system employed and the icing time, while TMA formation showed a similar pattern than most sensory and physical properties. A good correlation value was obtained for the oxidised odour in filling oil with FFA content and *K* value in canned muscle.

Acknowledgments

The authors thank Mr Marcos Trigo for technical assistance, Kinarca S.A.U. for providing the SI equipment, Comercial Xanquéi (Lousame, La Coruña, Spain) for providing the salmon fish and Justo López Valcarcel S.A. for lending its equipment to elaborate the canned product. The work was carried out in the Chilean University (Chile)-Consejo Superior de Investigaciones Científicas (Spain) Program (Project 2006 CL 0034) and supported by the Secretaría Xeral de I+D (Xunta de Galicia, Spain) (Project PGIDIT05TAL00701CT).

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