Changes in sensory and physical parameters in chill-stored farmed Coho salmon (*Oncorhynchus kisutch*)

ABSTRACT

This work focuses on changes in sensory and physical properties of Coho salmon (*Oncorhynchus kisutch*) during chill storage (24 days). A marked change ($p<0.05$) in the results of sensory analysis was found in the flesh of raw chilled fish (fresh odour, elasticity, hardness, oxidised odour) and in the cooked flesh of the chill-stored fish (firmness, neutral flavour, oxidised flavour, oxidised odour) samples. Additionally, physical parameters (gaping, cooking loss) also showed changes ($p<0.05$) during chilled storage. According to odour and flavour descriptors (fresh odour, oxidised odour, neutral flavour), salmon fish were not acceptable after 17 days of chill storage.

Running head: Sensory and physical changes in iced Coho salmon

Keywords: Coho salmon, aquaculture, chilling, sensory descriptors, physical properties, storage period, quality.

INTRODUCTION

Marine foods have attracted a great attention from consumer as a source of high amounts of important nutritional components to human health and nutrition (Simopoulos, 1997). However, marine species deteriorate rapidly post-mortem due to the effects of autolytic degradation, microbial spoilage and lipid oxidation, that lead to a detrimental effect on the commercial value of the fish product (Whittle et al., 1990; Tantasuttikul et al., 2011). The rate of alteration has shown to depend on different kinds of factors such as the nature of the species, size, lipid content, state at the moment of capture, importance and nature of microbial load and, very importantly, storage temperature.

Technologists have developed a wide range of analytical tools for quality assessment that may be used by commercial companies, buyers and regulatory agencies (Olafsdóttir et al., 1997). Among them, sensory evaluation is recognised as the most important method for freshness and quality assessment in the marine sector; properties such as appearance, odour, taste and texture are considered the most important factors for the consumers' choice (Bredahl and Grunert, 1997; Warm et al., 2000). Similarly, measures of related physical properties such as structure, water retention and colour have been improved too (Digre et al., 2011; Nunak and Schleining, 2011). Thus, physical texture measurements can be used to determine structural changes and have shown high correlation values with texture measurement of fish by sensory analysis (Barroso et al., 1998; Jonsson et al., 2001).

Aquaculture is now an important seafood source and cultured Coho salmon (*Oncorhynchus kisutch*), also called silver salmon, has acquired a great significance because of its increasing production in countries such as Chile, Japan and Canada (FAO, 2007a), in parallel to important capture production in countries like USA,

48 Russian Federation, Canada and Japan (FAO, 2007b). However, research concerning
49 the chemical composition characteristics and changes occurring during technological
50 treatment of this species is scarce when compared to other salmonid species (Vinagre et
51 al., 2011). Sensory, chemical and microbiological changes occurring in wild Coho
52 salmon stored at refrigerated conditions have been analysed (Brown et al., 1980; Barnett
53 et al., 1991; Luong et al., 1992). For cultivated Coho salmon, high-pressure technology
54 was tested and found to enhance the shelf life during chill storage (Aubourg et al., 2013)
55 and slurry ice has been proved by Rodríguez et al. (2010) to be a pre-treatment for
56 quality preservation for Coho salmon canning.

57 This paper describes the changes in sensory and physical properties of Coho
58 salmon chill stored (2ºC) for up to 24 days. The fish used were from the same source
59 and this study followed a similar workplan than two other studies where the microbial
60 activity and development of autolysis (Aubourg et al., 2007) and the lipid hydrolysis
61 and oxidation (Aubourg et al., 2005) were analysed. In the present manuscript, the
62 change of sensory, physical, microbiological and chemical parameters during the chill
63 storage of Coho salmon is compared.

64

65 ## MATERIALS AND METHODS

66 ### Raw material, chill storage and sampling

67 Farmed Coho salmon (*Oncorhynchus kisutch*) specimens were obtained from
68 EWOS Innovation Research (Colaco, Puerto Montt, Chile). The feed employed
69 contained 40.0% protein, 28.4% fat, 16.5% carbohydrates, 1.6% crude fibre, 7.5%
70 moisture and 6.0% ash. The fatty acid composition (%) of the diet was as follows: 32.5
71 % (saturated), 27.0 % (monounsaturated) and 40.2 % (polyunsaturated).

Fish (N=40; weight range: 3.0-3.4 kg) were sacrificed by a sharp blow to the head, the gills cut, bled in a water-ice mixture, beheaded, gutted and kept in ice for 24 h until they arrived at the laboratory. The fish specimens were then stored on ice in an isothermal room at 2ºC. Samples were taken for analysis on days 0 (starting material employed for cool storage), 3, 6, 10, 12, 17, 19 and 24. Five fish (n=5) were analysed per day and studied separately to carry out the statistical analysis.

For the sensory and physical analyses, sampling was carried out according to the extraction methodology previously proposed (Einen and Thomassen, 1998; Sveinsdóttir et al., 2002). Thus, the different muscle zones employed for each kind of quality analysis are indicated in Figure 1. All chemicals used were reagent grade (E. Merck; Darmstadt, Germany).

Sensory analyses

The Quantitative Descriptive Analysis (QDA) method was applied in order to assess changes in sensory properties of Coho salmon under chilled storage (Sveinsdóttir et al., 2002; Rodríguez et al., 2010). Ten panellists (five females and five males) with experience in sensory testing were selected and trained according to international standards (Howgate, 1992; ISO 3972, 1991; Codex Alimentarius, 1999). During the training sessions, the sensory descriptors for salmon muscle in the raw state and after cooking were discussed and analysed by the panellists on samples of varying quality conditions.

A 0-10-cm unstructured lineal scale was used to evaluate the descriptors, a score of 0 corresponds to an undetected value for the descriptor, while 10 score corresponds to the highest detectable value for the descriptor. At each sampling time, 4 cm x 4 cm x 2 cm steaks (N = 20) were removed from each individual salmon according to Figure 1

97 (zone 4 in both left and right sides). Individual steaks were then placed in polyethylene
98 bags, coded with 3-digit random numbers and employed for raw (N = 10) and cooked
99 (N = 10) fish analysis. Cooking was accomplished by suspending the bags in a
100 circulating water bath heated to 100°C ± 2°C for 15 min to an internal temperature of
101 67°C ± 2°C. Each panellist was given a single raw steak and a single cooked steak of
102 each individual fish.

103 At each sampling time, sensory evaluation began by the analysis of the salmon
104 muscle in the raw state and was followed by the muscle analysis in the cooked state.
105 Both kinds of samples were analysed at a single sitting, according to the previous
106 training received by the panellists. At each sitting, samples were submitted
107 independently and in a randomised order to the panellists; once each score sheet was
108 filled in, the following sample to be analysed was received. Diluted tea without sugar
109 was served to panellists to clean the mouth.

110 In relation to appearance assessment, the descriptors used for the raw-state
111 samples were translucent, opaque, dehydrated, crystalline, and moist. The descriptors
112 for cooked fish samples were typical, homogeneous and compact appearance.

113 As to colour determination, the descriptor for raw and cooked samples was
114 original (colour assessed in starting fish employed in cool storage). In addition, the
115 colour attribute was evaluated by the Roche SalmoFan™ Lineal card; for it, panellists
116 matched the salmon muscle colour with a 20-34-score card system previously
117 established for salmonids pigmented with astaxanthin. In this card, 20-score and 34-
118 score represent the lightest and most intense salmon colour, respectively.

119 For texture attributes analysis, descriptors applied for raw-state salmon were
120 firmness, hardness, elasticity and cohesiveness. Hardness is the resistance of the muscle
121 fibres against compression when an external force is applied; elasticity corresponds to

122 the recovery capacity after pressure application; firmness is the maximal resistance of
123 muscle fibres against shearing; and cohesiveness corresponds to the binding degree of
124 myotomes in salmon muscle. On the other hand, descriptors applied for cooked salmon
125 analysis were soft, firm, pasty, gelatinous, and dry.

126 In relation to odour, descriptors employed for raw and cooked salmon were fresh
127 (typical marine), sour (odour sensation generally due to the presence of organic acids),
128 oxidised (associated with rancid oil), putrid (presence of off-odours related to amine
129 formation and decayed meat). As to flavour, the descriptors for cooked salmon were
130 sweet, creamy, fresh oil, neutral, sour, putrid, oxidised, and bitter.

131 For odour and flavour descriptors, score 5.0 was considered the borderline of
132 acceptability; scores from the remaining descriptors are discussed without considering a
133 borderline of acceptability. Descriptors showing significant differences ($p<0.05$) among
134 panellists were not taken into account.

135

136 **Physical analyses**

137 Gaping in salmon muscle was analysed visually within the first five minutes
138 after filleting on the right-side fillet (Figure 1). The number of incisions or slits in the
139 myotomes of the salmon muscle was recorded to obtain the gaping score. Evaluation of
140 gaping evolution in chilled Coho salmon was performed according to previous research
141 (Andersen et al., 1994; Einen and Thomassen, 1998). Thus, scores were established as
142 follows: 0 (no gaping, 0 slits), 1 (minor gaping, 1-5 slits), 2 (moderate gaping, 6-10
143 slits), 3 (intense gaping, 11-15 slits), 4 (severe gaping, 16-20 slits), and 5 (extreme
144 gaping, > 20 slits).

145 To assess the water-holding capacity (WHC), 2 g of salmon muscle (zone 1, left-
146 side fillet; Figure 1) were placed in a dried cylindrical polyester membrane and

147 centrifuged at 3600 g for 5 min at 10°C. The removed fluid drained through the
148 membrane and was collected at the bottom of the centrifuge tube. Samples were
149 weighed before and after centrifugation and the loss of weight was determined. After
150 centrifugation, the WHC was expressed as g water g^{-1} fat free dry matter (Eide et al.,
151 1982). Each analysis was conducted in duplicate for each salmon individual.

152 The expressible moisture (EM) content was measured as the amount of fluid
153 extracted from fillets subjected to compression (Jonsson et al., 2001). An Universal
154 Testing Machine (LR-5K; Lloyd Instruments Limited, Hampshire, England, UK) was
155 used with a load cell of 100 N connected to a computer and a Dapmat 40-0465 software
156 for data analyses (version 3.05, Lloyd Instruments Limited, Hampshire, England, UK).
157 Cylindrical samples (diameter = 20 mm, length = 20 mm) were extracted according to
158 Figure 1 (zone 2 in left-side fillet) and tempered at 4°C for 4 h prior to analysis.
159 Samples were compressed into 14 mm at a constant speed of 12.7 mm min^{-1}. The fluid
160 exudate was received in a Whatman No. 4 filter paper. The EM was calculated as the
161 weight difference of the filter paper before and after compression. Results were
162 expressed as a percentage of exudate in rapport to the initial sample weight. Each
163 analysis was conducted in quadruplicate for each fish individual.

164 Cooking loss in salmon muscle was determined according to Fletcher et al.
165 (2002). At each sampling time, 4 cm x 4 cm x 2 cm steaks were removed according to
166 the extraction distribution expressed in Figure 1. Individual steaks were then placed in
167 double bags and heated; the inner bag was previously perforated to allow the fish
168 exudate to drain during cooking. The samples were cooked in a circulating water bath
169 heated to 76ºC ± 2°C. When the temperature in the geometric centre of the samples
170 reached 70°C ± 2°C, samples were kept for 15 min at that temperature. Samples were
171 weighed before and after cooking, being considered the weight difference as cooking

172 loss, and expressed as percentage. The trial was conducted in quadruplicate for each fish
173 individual.

174 Shear test was used to evaluate the firmness and deformation, respectively, in
175 raw salmon muscle (Sigurgisladóttir et al., 1999, Jonsson et al., 2001). The force-
176 deformation curve was obtained from an Universal Testing Machine (LR-5K; Lloyd
177 Instruments Limited, Hampshire, England, UK) with a load cell of 100 N connected to a
178 computer, this including a Dapmat 40-0465 software data analysis (version 3.05, Lloyd
179 Instruments Limited, Hampshire, England, UK). Samples of 4 cm x 4 cm x 2 cm from
180 left and right fillets (zone 3; Figure 1) were extracted in quadruplicate and kept at 4°C ±
181 1ºC for 4 h prior to analysis. The samples were sheared using a Warner-Bratzler steel
182 blade (knife-edge 60°; 1.2 mm thick, 155 mm high, and 150 mm width) at a constant
183 speed of 60 mm min^{-1}. In a force versus deformation curve, the peak of maximum force
184 (N) required for shearing the sample was recorded as the shear force and represents the
185 maximum resistance of the sample to shear (N). Deformation (mm) was measured
186 during the downward movement of the blade and was calculated as the deformation
187 (mm) at maximum peak force. Each analysis was conducted in quadruplicate for each
188 salmon individual.

189 Constant speed compression (CSC) test was used to evaluate texture of raw
190 salmon muscle (Sigurgisladóttir et al., 1999; Jonsson et al., 2001). Hardness (N) and
191 cohesiveness (mm) were determined from a stress-distance curve obtained from an
192 Universal Testing Machine (LR-5K; Lloyd Instruments Limited, Hampshire, England,
193 UK) including a load cell of 100 N connected to a computer using a software to analyse
194 the data (Dapmat 40-0465 version 3.05, Lloyd Instruments Limited, Hampshire,
195 England, UK). A flat-ended cylinder sensor of 20 mm of diameter was selected to
196 simulate the force applied with the index finger. Cylindrical samples (diameter = 20

197 mm, length = 20 mm) were extracted from location 2 (both left and right sides; Figure
198 1) and kept at 4°C for 4 h prior to analysis. The samples were compressed into 14 mm at
199 a constant speed of 12.7 mm min^{-1}. The hardness was regarded as the resistance of the
200 muscle fibres against compression (maximum compression force) and was the height of
201 the first peak. Cohesiveness was measured during the downward movement of the flat-
202 ended cylinder sensor and was calculated as the deformation (mm) at maximum
203 compression force. Each analysis was conducted in quadruplicate for each fish
204 individual.
205
206 **Statistical analyses**
207 For each chill-storage sampling time, data obtained from the sensory and
208 physical analyses were analysed using ANOVA method to explore differences due to
209 the chill duration; comparison of means was performed using the Tukey test. To
210 describe the relationship between sensory and physical variables and chill period, fitting
211 models (correlation coefficient, intercept, slope, determination coefficient and p-value)
212 were obtained by multivariate analysis.
213 All tests were analysed with a confidence level of 95%. Results were determined
214 in all cases as average ± standard deviation. The statistical tests were carried out with
215 the programs Excel and Statgraphics Plus version 5.1 (Manugistics Inc., Statistical
216 Graphics Corporation, 2001, Rockville, MA, USA).
217
218 **RESULTS AND DISCUSSION**
219 **Assessment of sensory descriptors in chilled Coho salmon**
220 Sensory evaluation was performed on chilled salmon samples in the raw state
221 and after cooking. Tables 1-2 include the results obtained on the descriptors that showed

222 a greater influence of the chill-storage duration; six of them correspond to the raw fish
223 state (Table 1), while the other six are related to samples that were cooked before being
224 analysed (Table 2).

225 Decreased intensities ($p<0.05$) of descriptors such as fresh odour, elasticity and
226 hardness could be observed with chilling for raw samples; all descriptors provided high
227 negative correlation coefficients ($r = 0.928$-0.992) and high determination coefficients
228 ($R^2 = 86$-98 %) ($p<0.05$), being fitted model values expressed in Table 3. Scores for
229 oxidised odour were progressively higher during the storage period ($p<0.05$); a
230 significant ($p<0.05$) correlation coefficient ($r = 0.951$) and determination coefficient (R^2
231 $= 90.35$ %) were also attained (Table 3). Colour exhibited a significant ($p<0.05$)
232 decrease at the end of the storage period (Table 1) but a satisfactory fitted model could
233 not be obtained (Table 3). Results for colour assessment using the Roche colour fan
234 changed but the changes were not significant (Tables 1 and 3).

235 The results for the cooked samples from the chill-stored fish indicated a slight
236 decrease ($p>0.05$) in firmness and neutral flavour (Table 2) with negative correlation
237 coefficients ($r = -0.837$ and -0.858, respectively) and high determination coefficients
238 ($R^2 = 70.00$ and 73.64 %, respectively), being fitted model values expressed in Table 3.
239 Parameters such as oxidised flavour and oxidised odour showed progressive increases
240 ($p<0.05$) with chilling duration (Table 2); fitted model values provided high correlation
241 ($r = 0.924$) and determination ($R^2 = 85.42$ %) coefficients for oxidised flavour (Table 3).
242 As for raw-state fish, the colour assessment (original colour and Roche colour) did not
243 provide significant differences ($p>0.05$) with chilling period (Table 2); consequently,
244 fitted model values obtained in both descriptors were not found significant (Table 3).

245 Changes in Coho salmon muscle during chill storage may be explained as a
246 result of autolytic degradation, microbial activity development and lipid damage

247 (oxidation and hydrolysis) progress (Whittle et al., 1990; Tantasuttikul et al., 2011). In
248 the present research, non acceptable scores were obtained at day 17 for the fresh and
249 oxidised odour assessment in raw fish, and for the neutral flavour determination in
250 cooked fish. In previous research (Brown et al., 1980), wild Coho salmon showed a
251 slime appearance when refrigerated (4.5ºC) for 7 days, so that it was considered
252 rejectable. In a further study (Barnett et al., 1991), wild Coho salmon was kept in ice up
253 to 14 days; results obtained from the sensory analysis showed that the fish remained at
254 the premium grade for about 7 days, followed by a short period of average sensory
255 quality, becoming borderline after 13 days.

256 Previous research has shown a marked decrease of sensory quality during the
257 chill storage of other salmonid species such as king salmon (*Oncorhynchus*
258 *tshawytscha*) (Fletcher et al., 2003), rainbow trout (*Oncorhynchus mykiss*) (Rodríguez et
259 al., 1999) and Atlantic salmon (*Salmo salar*) (Einen and Thomassen, 1998; Sveinsdóttir
260 et al., 2002; Sivertsvik et al., 2003). As in the present case, odour and flavour
261 assessments were found to be the limiting factors in such experiments. Thus, Atlantic
262 salmon showed to be still acceptable at day 16 (Einen and Thomassen, 1998) and at day
263 20 (Sveinsdóttir et al., 2002) when kept under chilling conditions; during refrigeration
264 at 4ºC, a shelf life duration of 7 days was reported (Sivertsvik et al., 2003).

265 The present results were compared with those previously obtained on lipid
266 hydrolysis and oxidation (Aubourg et al., 2005) and autolytic degradation and microbial
267 activity (Aubourg et al., 2007), in Coho salmon from the same source in similar storage
268 trials under the same circumstances. In the current study the elasticity of the raw flesh
269 exhibited significant decrease whereas in the previous studies free fatty acid (FFA),
270 peroxide value (PV) and K value all significantly increased. Although none of these
271 factors could singly be considered causative for decrease in elasticity they represent

changes that may affect the overall integrity of the flesh such as changes to the lipids of the membrane and dephosphorylation of nucleotides that would normally prevent aggregation of myofibrillar proteins.

Similarly, fresh odour scores decreased during storage in this study and the previous studies showed that aerobic mesophiles increased, with potential destruction of natural flavour compounds and formation of less desirable by-products, along with significant changes in the lipids by lipolysis (FFA formation) and by oxidation (significant increase in PV and thiobarbituric acid index (TBA-i)). Together, they represent a picture of continual degradation during storage in the raw flesh. These changes were noted also after the flesh was cooked where the oxidised flavour significantly increased, in keeping with the previous studies which showed significantly higher FFA, PV and TBA-i, the latter being indicative of formation of secondary oxidation products (Refsgaard et al., 1998; Aubourg et al., 2013). Further, the neutral flavour noted in the cooked fish was possibly due to oxidation of the natural volatiles as indicated by the increases in PV and TBA-i.

Assessment of physical properties in chilled Coho salmon

Evolution of gaping

Gaping is a phenomenon in which the connective tissue of fish fillets fails to hold the blocks of muscle together leading to the formation of slits across the surface of the muscle (Lavéty et al., 1988). Gaping results obtained in the present study are indicated in Table 4, where scores are expressed as slits numbers. Thus, gaping of Coho salmon was significantly affected by the chill-storage period, so that an increase ($p<0.05$) with chill duration was observed. A fitted model was obtained, this showing a significant correlation coefficient ($r = 0.849$) and determination coefficient (R^2 =

297 72.10%) (Table 5). Starting specimens employed in cool storage (day 0) were found
298 free of gaping (score 0), while minor gaping was observed in the 3-12-day period (score
299 1). However, from day 17 onwards, there was a significant gaping increase (intense
300 gaping; score 3) with undesirable separation of muscle blocks ($p<0.05$). This gaping
301 score increase can be explained as a result of the action of enzymes, mostly proteases,
302 that would act on the connective tissue (collagen) leading to its destruction. An inverse
303 relationship of gaping scores with different sensory descriptors has been found; this
304 accounts for the elasticity value ($r = - 0.874$; $R^2 = 76.36\%$), hardness ($r = - 0.775$; $R^2 =$
305 60.07%) and firmness ($r = - 0.849$; $R^2 = 72.07\%$).
306 A similar gaping development has been observed during the chill storage of
307 other salmonid species such as Atlantic salmon (Andersen et al., 1994; Einen and
308 Thomassen, 1998) and king salmon (Fletcher et al., 2003). Gaping development was
309 also observed in chilled Coho salmon (Aubourg et al., 2013); however, a partial
310 inhibition was proved to occur if an appropriate high pressure treatment (135 MPa for
311 30 s at 15 ± 2ºC) was previously applied.
312
313 *Water retention assessment*
314 The assessment of WHC and EM provided some significant differences ($p<0.05$)
315 throughout the chill storage (Table 4). However, a definite trend for both parameters
316 could not be assumed for the 0-24-day period, being values included in the ranges 2.31-
317 2.96 (g water g^{-1} fat free dry matter) and 1.38-1.55 (%), respectively. Consequently,
318 fitted model values obtained were not found significant ($p>0.05$) (Table 5).
319 A WHC decrease and an increasing EM value in fish muscle are usually related
320 to deteriorative changes in myofibrillar proteins, when their ability to retain water
321 diminishes as a result of denaturisation. This fact has been shown to be specially

322 important in frozen fish (Barroso et al., 1998; Ben-Gigirey et al., 1999). In fresh fish,
323 EM values were included in the 1.8-2.7 (%) range when different muscle locations of
324 Atlantic salmon (*Salmo salar*) without storage processing were analysed (Jonsson et al.,
325 2001); capelin (*Mallotus villosus*) and minced cod (*Gadus morhua*) showed 5.5 and 4.5
326 (g water g^{-1} fat free dry matter) scores, respectively, for WHC in fresh muscle (Eide et
327 al., 1982). It is considered that Coho salmon exhibited in the present research a low
328 water loss during a 24-day chill storage.
329 Contrary to WHC and EM results, a low but progressive cooking loss increase
330 could be observed in this study for the 0-19-day period, followed by a marked increase
331 ($p<0.05$) at the end of the experiment. A significant fitted model was obtained for the
332 evolution of the cooking loss value throughout the chilling period ($r = 0.850$; $R^2 = 72.28$
333 %; Table 5). An important dripping value (2.9 %) was also observed for king salmon
334 during a 22-day chill storage (Fletcher et al., 2003). Randell et al. (1999) considered that
335 a cooking loss value lower than 2% could be considered as acceptable, being important
336 when this score was overpassed.
337
338 *Texture assessment: Shear test and constant speed compression test*
339 Concerning the shear test, the maximum shear force applied to raw salmon using
340 the Warner-Bratzler blade should provide the firmness and deformation value. In this
341 way, information about the compression of muscle fibres, tension in adjacent fibres and
342 fibres shear would be obtained and should provide simulation of the chewing behaviour
343 during sensory analysis of texture.
344 The maximum shear force (firmness) assessment led to a 9.5-11.5 (N) values
345 range for the 0-19-day period, followed by the highest mean value (13.65 N) at the end
346 of the experiment (Table 6). A definite trend with chilling duration was not concluded

347 for this parameter and fitted model values were not found significant (Table 5). For the
348 deformation analysis, significant differences throughout the chill storage were scarce
349 (Table 6) and a significant ($p>0.05$) relationship with storage period could not be
350 obtained (Table 5).

351 The constant speed compression test was also investigated in this study. This
352 method simulates the force exerted by the human being when pressing the flesh with the
353 index finger during the sensory analysis of texture. From the obtained stress-strain
354 curve, the maximum compressive force (N) is taken as a measure of hardness, thus
355 indicating the resistance of the muscle fibres against compression (maximum
356 compression force) (Sigurgisladóttir et al., 1999).

357 A marked hardness decrease ($p<0.05$) was observed at day 3 (Table 6); after that
358 time, no differences ($p>0.05$) were found as a result of the chill storage, being all
359 hardness values included in the 18.8-31.6 range. A significant fitted model with chilling
360 duration was obtained ($r = - 0.740$; $R^2 = 54.73$ %; Table 5). According to the present
361 results, Ando et al. (1991) showed a hardness decrease in rainbow trout muscle after 3
362 days when kept under icing conditions.

363 By means of the compression test, cohesiveness value was also obtained. Its
364 measurement is related to the degree of fibre interrelation in muscle. Cohesiveness did
365 not present significant differences with storage duration ($p>0.05$) indicating that the
366 salmon fillets did not present homogeneous distortions when they were submitted to
367 pressure (Table 6). A non-significant fitted model with chilling period was obtained
368 (Table 5).

369 Texture is considered one of the most important quality attributes of seafoods,
370 which determines consumer acceptance and hence the marketability of such products.
371 The texture of the fish muscle has shown to depend on numerous intrinsic biological

372 factors related to the density of the muscle fibres, muscle zone considered, fat and
373 collagen content (Sigurgisladóttir et al., 1999) and sexual maturity (Reid and Durance,
374 1992). Collagen, the major component of the connective tissue, has a significant
375 influence on the functional and rheological properties of the flesh and is the main
376 contributor to the tensile strength in the muscles. One of the biggest problems in the
377 seafood industry, unlike other muscle foods, is the rapidity with which the flesh softens.
378 Softening of fish tissue, and accordingly firmness decrease, has been reported to be
379 directly linked to the great activity of endogenous proteases such as cathepsins,
380 calcium-dependent proteases, collagenases, alkaline proteases, and other digestive
381 enzymes (Barroso et al., 1998; Ben-Gigirey et al., 1999).

382 Previous research has shown that fish muscle softens with increasing ice-storage
383 duration, and this event is assumed to result from partial collagen destruction, changes
384 in the cytoskeleton and the myofibrils (Fletcher et al., 2003). This event has been
385 recognised in different salmonid species such as Atlantic salmon (Sveinsdóttir et al.,
386 2002), rainbow trout (Ando et al., 1991) and king salmon (Fletcher et al., 2003).
387 Furthermore, crosslinking of peptide chains by reaction with lipid oxidation products
388 has also been reported to induce important negative texture changes (Mackie, 1993;
389 Sikorski and Kolakowska, 1994). A previous study showed that a marked lipid
390 hydrolysis and oxidation was evident with chilling period (Aubourg et al., 2005);
391 additionally, the present research showed an important oxidised odour and flavour
392 development during storage (Tables 1-3). However, texture properties changes in the
393 present research have not been dependent on the icing duration. In agreement with this
394 lack of texture changes, previous related research showed that pH value did not lead to
395 significant differences with the chill-storage duration (Aubourg et al., 2007).
396

CONCLUSIONS

Marked changes in salmon muscle have been detected as a result of the chill-storage period. A progressive quality loss ($p<0.05$) could be observed in Coho salmon according to the sensory analysis carried out on raw fish (fresh odour, elasticity, hardness, and oxidised odour) and on cooked fish (firmness, neutral flavour, oxidised flavour, and oxidised odour) samples. Additionally, physical parameters such as gaping and cooking loss also showed an increasing deterioration ($p<0.05$) by means of chilling duration. On the contrary, colour assessment by sensory analysis and texture measurement by physical methodology were not found valuable tools to follow the quality losses in chilled Coho salmon.

According to odour and flavour descriptors (fresh odour, oxidised odour and neutral flavour), Coho salmon fish proved to be rejectable at day 17 of chill storage. These results are in agreement with chemical and microbiological quality parameters analysed in previous experiments that were carried out using comparable material and conditions; among such parameters, FFA content, PV, TBA-i, K value and aerobe mesophile counts can be mentioned.

It is considered that present results on sensory and physical changes observed in chill-stored farmed Coho salmon can provide valuable information related to the consumer's acceptance of such species and its commercialisation as a fresh product.

LEGENDS TO FIGURES

Figure 1. Areas from which Coho salmon were sampled for the various analyses: *Left-side fillet*: 1 (water-holding capacity), 2 (constant speed compression test and expressible moisture), 3 (shear test), 4 (sensory analysis and cooking loss). *Right-side fillet*: 1-4 (gaping), 1 (expressible moisture), 2 (constant speed compression test), 3 (shear test), 4 (sensory analysis and cooking loss).

REFERENCES

Andersen, U., Strømsnæs, A., Steinsholt, K., Thomassen, M., and Steinsholt, K. 1994. Fillet gaping in farmed Atlantic salmon (*Salmo salar*). Norwegian J. Agric. Sci. 8: 165-179.

Ando, M., Totohara, H., Shimizu, Y., and Sakaguchi, M. 1991. Post-mortem tenderisation of rainbow trout (*Oncorhynchus mykiss*) muscle caused by gradual disintegration of the extracellular matrix structure. J. Sci. Food Agric. 55: 589-597.

Aubourg, S., Quitral, V., Larraín, MªA., Rodríguez, A., Gómez, J., Maier, L., and Vinagre, J. 2007. Autolytic degradation and microbiological activity in farmed Coho salmon (*Oncorhynchus kisutch*) during chilled storage. Food Chem. 104: 369-375.

Aubourg, S., Rodríguez, A., Sierra, Y., Tabilo-Munizaga, G., and Pérez-Won, M. 2013. Sensory and physical changes in chilled farmed salmon (*Oncorhynchus kisutch*): Effect of previous optimised hydrostatic high-pressure treatment. Food Bioprocess Technol. 6: 1539-1549.

Aubourg, S., Vinagre, J., Rodríguez, A., Losada, V., Larraín MªA., Quitral V., Gómez, J., Maier, L., and Wittig E. 2005. Rancidity development during the chilled storage of farmed Coho salmon (*Oncorhynchus kisutch*). Eur. J. Lipid Sci. Technol. 107: 411-417.

Barnett, H., Nelson, R., and Poysky, F. 1991. A comparative study using multiple indices to measure changes in quality of pink and Coho salmon during fresh and frozen storage. http://www.nwfsc.noaa.gov/publications/techmemos/tm208/tm208.pdf). NOAA Technical Memorandum NMFS F/NWC-208. U. S. Department of Commerce.

455 Barroso, M., Careche, M., and Borderías, A.J. 1998. Quality control of frozen fish using
456 rheological techniques. Trends Food Sci. Technol. 9: 223-229.
457 Ben-Gigirey, B., Vieites Baptista de Sousa, J., Villa, T., and Barros-Velázquez, J. 1999.
458 Histamine and cadaverine production by bacteria isolated from fresh and frozen
459 albacore (*Thunnus alalunga*). J. Food Protect. 62: 933–939.
460 Bredahl, L. and Grunert, K. 1997. Determination of the consumption of fish and
461 shellfish in Denmark: Application of the theory of planed behaviour. In: Seafood
462 from producer to consumer, Integrated approach to quality. Luten, J., Børrensen,
463 T., and Oehlenschläger, J. (Eds.) Elsevier Applied Science, Amsterdam,
464 Holland. pp. 21-30.
465 Brown, D., Albright, M., Watts, D., Heyer, B., Spruce, B., and Price, R. 1980. Modified
466 atmosphere storage of rockfish (*Sebastes miniatus*) and silver salmon
467 (*Oncorynchus kisutch*). J. Food Sci. 45: 93-96.
468 Codex Alimentarius. 1999. Directrices para la Evaluación Sensorial del Pescado y los
469 Mariscos en Laboratorio. Norma Técnica CAC/GL 31-1999.
470 http://www.pes.fvet.edu.uy/cursos/mail2.pdf.
471 Digre, H., Erikson, U., Misimi, E., Standal, I., Gallart-Jornet, L., Riebroy, S., and
472 Rustad, T. 2011. Bleeding of farmed Atlantic cod: Residual blood, color, and
473 quality attributes of pre- and postrigor fillets as affected by perimortem stress
474 and different bleeding methods. J. Aquat. Food Prod. Technol. 20: 391-411.
475 Eide, O., Børrensen, T., and Strom, T. 1982. Minced fish production from capelin
476 (*Mallotus villosus*). A new method for gutting, skinning and removal of fat from
477 small fatty fish species. J. Food Sci. 47: 347-349, 354.
478 Einen, O. and Thomassen, M. 1998. Starvation prior to slaughter in Atlantic salmon
479 (*Salmo salar*). II. White muscle composition and evaluation of freshness, texture

and colour characteristics in raw and cooked fillets. Aquaculture 169: 37-53.

FAO. 2007a. Fishery statistics. Aquaculture Production. In: Food and Agriculture Organization of the United Nations. Yearbook 2005, Vol. 100/2, Rome, Italy. p. 73.

FAO. 2007b. Fishery statistics. Capture Production. In: Food and Agriculture Organization of the United Nations. Yearbook 2005, Vol. 100/1, Rome, Italy. p. 79.

Fletcher, G., Corrigan, V., Summers, G., Leonard, M., Jerrett, A., and Black, S. 2003. Spoilage of rested harvested king salmon (*Oncorhynchus tshawytscha*). J. Food Sci. 68: 2810-2816.

Fletcher, G., Summers, G., Corrigan, V., Cumarasamy, S., Dufour, J. 2002. Spoilage of of king salmon (*Oncorhynchus tshawytscha*) fillets stored under different atmospheres. J. Food Sci. 67: 2362-2374.

Howgate, P. 1992. Codex review on inspection procedures for the sensory evaluation of fish and shellfish, CX/FFP, 92/14.

ISO 3972. 1991. Sensory analysis-methodology-method of investigating sensitivity of taste. International Standardization Organization: Geneva, Switzerland.

Jonsson, A., Sigurgisladóttir, S., Hafsteinsson, H., and Kristbergsson, K. 2001. Textural properties of raw Atlantic salmon (*Salmo salar*) fillets measured by different methods in comparison to expressible moisture. Aquacult. Nutr. 7: 81-89.

Lavéty, J., Afolabi, A., and Love, R. 1988. The connective tissue of fish. IX. Gaping in farmed species. Int. J. Food Sci. Technol. 23: 23-30.

Luong, J., Male, K., Masson, C., and Nguyen, A. 1992. Hypoxanthine ratio determination in fish extract using capillary electrophoresis and immobilized enzymes. J. Food Sci. 57: 77-81.

505 Mackie, I. 1993. The effects of freezing on flesh proteins. Food Rev. Internat. 9: 575-
506 610.
507 Nunak, N. and Schleining, G. 2011. Instrumental textural changes in raw white shrimp
508 during iced storage. J. Aquat. Food Prod. Technol. 20: 350-360.
509 Olafsdóttir, G., Martinsdóttir, E., Oehlenschläger, J., Dalgaard, P., Jensen, B.,
510 Undeland, I., Mackie, I., Henehan, G., Nielsen, J., and Nilsen, H. 1997. Methods
511 to evaluate fish freshness in research and industry. Trends Food Sci. Technol. 8:
512 258-265.
513 Randell, K., Hattula, T., Skytta, E., Sivertsvik, M., Bergslein, H., and Ahvenainen, R.
514 1999. Quality of filleted salmon in various retail packages. J. Food Qual. 22:
515 483-497.
516 Refsgaard, H., Brockhoff, P., and Jensen, B. 1998. Sensory and chemical changes in
517 farmed Atlantic salmon (S*almo salar*) during frozen storage. J. Agric. Food
518 Chem. 46: 3473-3479.
519 Reid, R. and Durance, T. 1992. Textural changes of canned chum salmon related to
520 sexual maturity. J. Food Sci. 57: 1340-1342.
521 Rodríguez, A., Carriles, N., and Aubourg, S. 2010. Effect of chill storage under
522 different icing conditions on sensory and physical properties of canned farmed
523 salmon (*Oncorhynchus kisutch*). Int. J. Food Sci. Technol. 45: 295-304.
524 Rodríguez, C., Besteiro, I., and Pascual, C. 1999. Biochemical changes in freshwater
525 rainbow trout (*Oncorhynchus mykiss*) during chilled storage. J. Sci. Food Agric.
526 79: 1473-1480.
527 Sigurgisladóttir, S., Hafsteinsson, H., Jonsson, A., Nortvedt, R., Thomasses, M., and
528 Torrisen, O. 1999. Textural properties of raw salmon fillets as related to
529 sampling method. J. Food Sci. 64: 99-104.

530 Sikorski, Z. and Kolakowska, A. 1994. Changes in protein in frozen stored fish. In:
531 Seafood proteins. Sikorski, Z., Sun Pan, B., and Shahidi, F. (Eds.) Chapman and
532 Hall, New York, USA. pp. 99-112.
533 Simopoulos, A. 1997. Nutritional aspects of fish. In: Seafood from producer to
534 consumer, Integrated approach to quality. Luten, J., Börrensen, T., and
535 Oehlenschläger, J. (Eds.) Elsevier Science, London, UK. pp. 589-607.
536 Sivertsvik, M., Rosnes, J., and Kleiberg, G. 2003. Effect of modified atmosphere
537 packaging and superchilled storage on the microbial and sensory quality of
538 Atlantic salmon (*Salmo salar*) fillets. J. Food Sci. 68: 1467-1472.
539 Sveinsdóttir, K., Martinsdóttir, E., Hyldig, G., Jorgensen, B., and Kristbergsson, K.
540 2002. Application of quality index method (QIM) scheme in shelf-life study of
541 farmed Atlantic salmon (*Salmo salar*). J. Food Sci. 67: 1570-1579.
542 Tantasuttikul, A., Kijroongrojana, K., and Benjakul, S. 2011. Quality indices of squid
543 (*Photololigo duvaucelii*) and cuttlefish (*Sepia aculeata*) stored in ice. J. Aquat.
544 Food Prod. Technol. 20: 129-147.
545 Vinagre, J., Rodríguez, A., Larraín, MªA., and Aubourg, S. 2011. Chemical composition
546 and quality loss during technological treatment in Coho salmon (*Oncorhynchus*
547 *kisutch*). Food Res. Int. 44: 1-13.
548 Warm, K., Nelsen, J., Hyldig, G., and Martens, M. 2000. Sensory quality criteria for
549 five fish species. J. Food Qual. 23: 583-601.
550 Whittle, K., Hardy, R., and Hobbs, G. 1990. Chilled fish and fishery products. In:
551 Chilled foods: The state of the art. Gormley, T. (Ed.) Elsevier Applied Science,
552 New York, USA. pp. 87-116.
553
554

TABLE 1: **Sensory scores given by panel to raw fish samples taken from chill stored farmed Coho Salmon***

Chill period (days)	**Fresh odour**	**Oxidised odour**	**Elasticity**	**Hardness**	**Original colour**	**Roche colour**
0	8.13 a (1.70)	0.26 a (0.62)	6.71 a (2.09)	7.16 a (1.89)	8.57 a (1.17)	27 (2)
3	6.78 ab (2.18)	0.48 a (1.03)	6.23 a (1.93)	6.57 a (1.99)	6.36 ab (1.65)	27 (2)
6	4.50 abcd (2.45)	0.14 a (0.25)	5.64 ab (2.27)	6.03 a (2.28)	8.07 ab (1.14)	27 (1)
10	4.94 bcd (2.02)	1.62 a (1.74)	4.59 abc (2.01)	4.83 abc (2.06)	7.53 ab (1.27)	28 (2)
12	5.65 abc (2.02)	2.51 a (2.25)	4.85 abc (2.28)	5.87 ab (1.99)	7.76 ab (0.73)	28 (1)
17	3.31 cde (2.53)	5.64 b (1.75)	3.32 bc (2.14)	4.70 abc (2.12)	8.04 ab (1.39)	28 (2)
19	2.19 de (1.63)	5.30 b (2.70)	3.32 bc (2.11)	2.81 c (1.18)	8.00 ab (0.98)	28 (1)
24	1.86 e (1.97)	6.02 b (2.80)	2.13 c (1.16)	3.19 bc (1.82)	6.36 b (1.25)	28 (1)

* For each descriptor, mean values (five replicates, n=5) followed by different letters denote significant ($p<0.05$) differences as a result of the chill-storage period. No letters are provided when significant differences are not found ($p>0.05$). Standard deviations are indicated in brackets.

TABLE 2: **Sensory scores given by panel to cooked fish samples taken from chill stored farmed Coho Salmon***

Chill period (days)	**Firmness**	**Oxidised flavour**	**Neutral flavour**	**Oxidised odour**	**Original colour**	**Roche colour**
0	7.60 a (1.74)	0.70 a (1.18)	6.61 ab (1.85)	1.97 abc (1.57)	7.10 (2.13)	21 (1)
3	6.67 ab (1.91)	0.54 a (0.67)	6.90 a (2.03)	0.89 ab (1.46)	6.21 (1.64)	21 (1)
6	6.80 ab (1.80)	0.21 a (0.47)	6.80 a (1.40)	0.27 a (0.64)	7.18 (1.35)	22 (1)
10	6.26 ab (1.52)	0.82 a (1.53)	6.55 abc (1.61)	0.62 a (1.19)	7.41 (1.30)	22 (1)
12	6.00 ab (1.73)	1.53 ab (1.89)	6.89 a (1.26)	2.64 abc (3.09)	6.69 (1.81)	22 (1)
17	4.62 b (1.69)	3.50 bc (2.05)	4.50 abc (1.85)	3.47 bc (2.07)	6.57 (1.74)	22 (1)
19	5.45 ab (2.35)	3.86 cd (2.44)	4.01 c (1.90)	4.50 c (2.51)	5.70 (1.73)	22 (1)
24	5.97 ab (1.75)	6.14 d (1.84)	4.23 bc (2.51)	7.20 d (1.29)	6.49 (1.37)	22 (1)

* For each descriptor, mean values (five replicates, n=5) followed by different letters denote significant ($p<0.05$) differences as a result of the chill-storage period. No letters are provided when significant differences are not found ($p>0.05$). Standard deviations are indicated in brackets.

TABLE 3: **Fitted model values* between the chill-storage period and different sensory descriptors of farmed Coho salmon muscle (raw-state and cooked fish)****

Parameter	r	Intercept	Slope	R^2 (%)	*p*-value
		Raw-state fish			
Fresh odour	- 0.939 [b]	2.78	- 0.06	88.22	0.00
Oxidised odour	0.951 [a]	- 0.56	0.29	90.35	0.00
Elasticity	- 0.992 [a]	6.76	0.19	98.36	0.00
Hardness	- 0.928 [a]	7.13	0.17	86.05	0.00
Original colour	- 0.314 [c]	8.07	0.16	9.83	0.45
Roche colour	0.725 [c]	26.99	0.21	55.56	0.14
		Cooked fish			
Firmness	- 0.837 [c]	7.60	- 0.47	70.00	0.00
Oxidised flavour	0.924 [b]	0.41	0.08	85.42	0.00
Neutral flavour	- 0.858 [d]	2.02	- 0.03	73.64	0.00
Oxidised odour	0.844 [a]	- 0.01	0.24	71.30	0.00
Original colour	-0.463 [a]	7.02	- 0.03	21.48	0.25
Roche colour	0.724 [c]	20.85	0.23	52.47	0.04

* Values expressed: Pearson correlation coefficient (r), intercept, slope, determination coefficient (R^2) and *p*-value.

** For each sensory descriptor, linear[a], square root-Y[b], square root-X[c], and exponential[d] models were studied. In each case, the model system corresponding to the best correlation coefficient is expressed.

TABLE 4: Gaping score and water retention of muscle during chill storage of farmed Coho Salmon*

Chilling time (days)	**Gaping****	**Water-holding capacity****	**Expressible moisture** (%)	**Cooking loss** (%)
0	0.00 a (0.00)	2.92 ab (0.34)	2.02 ab (0.79)	1.60 a (0.61)
3	3.60 ab (1.95)	2.75 ab (0.37)	1.97 ab (0.57)	2.37 ab (0.48)
6	5.80 abc (4.09)	2.78 ab (0.78)	1.38 a (0.27)	2.28 ab (0.59)
10	3.40 ab (2.07)	2.72 ab (0.25)	1.54 ab (0.47)	2.86 ab (1.18)
12	3.60 ab (2.61)	2.75 ab (0.31)	1.69 ab (0.68)	2.04 ab (1.23)
17	14.80 d (7.05)	2.96 b (0.22)	3.26 c (0.63)	2.81 ab (1.66)
19	10.60 bcd (5.77)	2.31 a (0.58)	3.55 c (0.67)	2.95 b (0.35)
24	12.60 cd (1.52)	2.82 ab (0.48)	2.20 b (0.71)	4.25 c (0.64)

* For each parameter, mean values of five independent determinations (n=5) followed by different letters denote significant ($p<0.05$) differences as a result of chill-storage period. Standard deviations are indicated in brackets.

** Gaping is expressed as the slits number. Water-holding capacity is expressed as g water g^{-1} fat free dry matter.

TABLE 5: **Fitted model values* between the chill-storage period and different physical parameters of farmed Coho salmon muscle****

Parameter	r	Intercept	Slope	R^2 (%)	*p*-value
Gaping	0.849 [a]	0.84	0.53	72.10	0.01
Water-holding capacity	-0.614 [a]	2.88	- 0.01	37.70	0.11
Expressible moisture	0.560 [a]	1.60	0.05	31.34	0.15
Cooking loss	0.850 [b]	1.34	0.02	72.28	0.01
Firmness	0.454 [a]	10.35	0.07	20.60	0.26
Deformation	0.300 [d]	0.025	0.00	9.16	0.47
Hardness	- 0.740 [c]	58.02	- 9.09	54.73	0.04
Cohesiveness	-0.259 [c]	18.26	- 0.11	6.71	0.54

* Values expressed: Pearson correlation coefficient (r), intercept, slope, determination coefficient (R^2) and *p*-value.

** For each index, linear[a], square root-Y^b, square root-X^c and inverse-Y^d models were studied. In each case, the model system corresponding to the best correlation coefficient is expressed.

TABLE 6: Results for physical texture parameters during chill storage of farmed Coho Salmon*

Chilling time (days)	Shear test		Constant speed compression test	
	Firmness (N)	**Deformation** (mm)	**Hardness** (N)	**Cohesiveness** (mm)
0	10.76 ab (2.01)	39.96 a (7.54)	78.85 b (64.54)	19.18 (8.42)
3	11.50 ab (5.39)	43.18 ab (8.00)	24.64 a (7.99)	16.53 (2.59)
6	9.83 a (2.67)	41.68 ab (6.35)	23.04 a (4.84)	17.98 (0.06)
10	11.35 ab (2.61)	47.78 b (2.51)	20.77 a (6.74)	17.90 (0.32)
12	10.71 ab (3.20)	44.26 ab (6.09)	23.34 a (4.44)	18.00 (0.00)
17	9.57 a (2.61)	40.44 a (6.50)	31.55 a (12.41)	17.91 (0.20)
19	11.50 ab (2.98)	32.69 a (6.01)	25.22 a (17.91)	17.91 (0.20)
24	13.65 b (2.96)	37.36 a (7.02)	18.88 a (5.88)	17.91 (0.27)

* For each parameter, mean values of five independent determinations (n=5) followed by different letters denote significant ($p<0.05$) differences as a result of chill-storage period. No letters are provided when significant differences are not found ($p>0.05$). Standard deviations are indicated in brackets.

FIGURE 1