The effects of various salt concentrations during brine curing of cod (*Gadus morhua*)

Kristin Anna Thorarinsdottir,[1] Sigurjon Arason,[1] Sigurdur G. Bogason[2] & Kristberg Kristbergsson[1]*

1 University of Iceland, Department of Food Science and Icelandic Fisheries Laboratories (IFL), Skúlagötu 4, IS-101 Reykjavík, Iceland

2 European Commission, DG Fisheries (J99-6/27) Rue de la Loi 200, B-1049 Brussels, Belgium (formerly with SIF Ltd. Fjarðargata 13-15, IS-222, Hafnarfjordur, Iceland)

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Summary The method used for salting of cod (*Gadus morhua*) is believed to influence the quality and characteristics of the final product. In recent years an initial brine salting for 1–4 days has preceded dry salting; this increases both the weight yield and quality of the final product. After removal from the brine, dry salting is followed by packaging and storage. The effect of the salt concentration in the brine has been a matter of controversy, with some indication that higher weight yield and quality may be obtained by using lower salt concentrations than by using a fully saturated brine solution. Therefore to test this hypothesis, the effect of different brine salting methods was studied; traditional brine salting, maintaining a constant brine concentration and increasing the salt concentration gradually during brining. The results indicated that the effect on weight yield, chemical composition and water holding capacity of the salted or rehydrated cod were not significant. Altering salt concentration of the brine, by adding salt during brining, did not result in any significant improvements in weight yield, either after the salting process or after the rehydration. The overall quality was increased by using a lower salt concentration of 16° Bau compared with 20 and 24° Bau.

Keywords Chemical composition, protein recovery, quality rating, rehydration, water holding capacity, weight yield.

Introduction

Salting is one of the oldest preservation methods for foods. However, despite many other processes being used today, the most common of which is freezing, salting of fish remains a very important process for Iceland where the products are, primarily, exported. In 2000, the quantity of exported salted fish was approximately 48 700 metric tons, of which salted cod was 86.5%. The traditional markets for Icelandic salted fish have been Spain, Portugal and Latin America.

In the production of salted fish, the raw fish is filleted or 'butterfly' split and then heavily salted. The curing of salted fish has traditionally been done in one of several ways, those are distinguished by variations of pickling/brining and stacking (kencing). In kench salting, split fish are piled into stacks where layers of fish and dry salt alternate. Liquid diffuses from the fish as it takes up salt and the resulting brine is allowed to drain off. In pickle salting the fish is also dry salted but the fish is kept in vats and the liquid, which diffuses from the fish, forms a strong brine solution as the salt dissolves (van Klaveren & Legrende, 1965). In recent years brine salting has gained popularity in the Icelandic fish industry. The method that is generally used is as follows: the fish is submerged for 1–4 days in a solution of salt and water (brine), normally the salt concentration is 17 ± 1% NaCl; removal from the brine; the butterfly fillets are placed with alternate thin layers of salt, into stacks, approximately 1 m high or in

*Correspondent: Fax: +354 530 8601;
e-mail: kk@rf.is/kk@hi.is

plastic tubs where the stacks are only 30–40 cm high; the fish is then kept stacked for 10–12 days for dry salting after which it is packed. Individual fish may be rotated during storage to even out the pressure exerted on each fish. The main difference between the 1 m high kench and the 30–40 cm stacks is the pressure applied to the fish in the bottom layers.

Liquid is released from the muscle during dry salting because of salt uptake and pressure and is allowed to drain off. The final salted fish product, frequently referred to by the Spanish term for cod 'bacalhau', contains 55–58% water and 18–21% salt, compared with approximately 80% water and 0.3% salt in the raw material (van Klaveren & Legrende, 1965; Bogason, 1987; Akse *et al*., 1993). Prior to consumption of the fish it is soaked in water, usually for 1–5 days, which results in an uptake of water and desalting.

Many factors are believed to affect the quality of the final product, including the condition of the raw material, the type, quality and concentration of salt as well as the salting method (Zaitsev *et al*., 1969; Beraquet *et al*., 1983). The salting method has an influence on the structural and mechanical properties of the fish muscle. When the fish is surrounded with brine the rate of salt penetration into the fish muscle is higher than that obtained by dry salting (Akse *et al*., 1993). It is also believed to render both better quality and higher weight yield (Beraquet *et al*., 1983). The concentration of salt in the brine affects the rate of salt diffusion into the muscle and the quantity of water and proteins extracted. The rates of the salt and water diffusion were positively correlated with increasing salt concentration of the brine (Poernomo *et al*., 1992; Lawrie, 1998). Protein extraction from the muscle has been shown to be a function of the salt concentration, with a maximum at 6–9% NaCl. Lower quantities were extracted by pure water or with brine of a higher salt concentration (Lawrie, 1998). This is clearly an influence of [salt/water] on the inter and intramolecular bonds of the muscle protein and will affect the structure and denaturation of the proteins and thereby the water holding capacity of the muscle. At lower salt concentrations the muscle swells but at higher salt concentration, above 9–10%, the proteins may have stronger protein–protein bonds with concomitants shrinkage of the muscle and dehydration (Borgstrom, 1968; Offer & Trinick, 1983; Hamm, 1985; Wilding *et al*., 1986; Morrissey *et al*., 1987). The amount of swelling will depend on the salt concentration. Muscle swelling has been found to be at a minimum at approximately physiological ionic strength (0.1 M) but the maximum swelling of the muscle and water holding capacity have been observed at 1 M (~5.8% salt) (Offer & Knight, 1988; Fennema, 1990). Studies on muscle from domestic animals have shown that swelling is progressively less at concentration above 1 M whilst above 4.5 M the muscle shrank. Offer & Knight (1988) observed that a gradual increase in salt concentration in the brine affected the properties of the muscle after salting. By placing meat pieces in a series of solutions with increasing salt concentration from 1–5 M they found that the muscle kept swelling up to 5 M, but when placed directly in a 5 M solution the muscle lost water. Based on these results the muscle should be assumed to swell more and have a better water holding capacity if processed at an initially lower salt concentration than when the fish is salted directly in brine with salt concentration at or above 5 M. This might indicate that the distance between the myofibrils is too long for a protein-protein binding to occur, resulting in less shrinkage of the muscle (Akse *et al*., 1993).

Brine salting of cod may offer a better control over the rate of changes of salt and water content in the muscle than other salting methods and thereby increase the weight yield and the overall quality of the salted fish. Quality graders of commercial salted fish have indicated that the appearance of the fish may be related to the salting method with adverse effects on appearance and colour if the initial salt concentration has been too high.

In traditional brine salting the brine has a specific initial concentration which decreases during the brining process, because of the salt and water exchange between the fish muscle and the surrounding brine. The aim of this study was to compare the effects of traditional brine salting methods with a process with increased control of the salt, either by gradually increasing the salt concentration in the brine or by keeping the concentration of the brine constant by compensating for the reduction in salt during processing. The hypothesis was that the latter method would improve weight yield and quality.

Materials and methods

Materials

Cod (*Gadus morhua*) was caught by line at the South West of Iceland by a commercial fishing boat. The fish used in the preliminary experiment, which was done to compare different salt concentrations, was caught at the end of July. In the main experiment, the fish was caught at the end of January. The cod was placed in bins, containing ample ice, immediately after gutting and stored for 2 days in ice before filleting and brining. The bins were transported to the SIF Ltd. Development Centre where the experiments were done.

Industrial grade salt (Saltkaup, Hafnarfjordur, Iceland) taken from the same sack was used throughout each experiment. The salt used for the preliminary experiment was imported from Torrevieja, Spain, but the salt used for the main experiment was imported from Almeria, Spain. Although the salt was not analysed for this study, typical chemical composition for the two types of salt is shown in Table 1 (SIF, 1990). All materials used for chemical analysis were of analytical grade (Merck, Darmstadt, Germany).

Salting, storage and rehydration

The fish was removed from the ice after 2 days of storage, after onset of rigor mortis and filleted by hand using standard industrial procedures. Each fillet was marked with a numbered plastic mark. The fillets were then divided into groups, which were brine salted by three different brine salting methods; traditional brine salting, maintaining a constant concentration and increasing the salt concentration gradually during brining. The fillets were submerged in brine for 42 h, with the fish to brine ratio at 1:1.6. After removal from the brine, the fillets were placed in plastic tubs, stacked with alternating thin layers of salt into stacks, and kept for 12–14 days for dry salting at 7 ± 1 °C. After dry salting the fillets were packed into waxed cardboard boxes and kept at 3 ± 1 °C for approximately 3 weeks, then the salted fish was desalted and rehydrated at 3 ± 1 °C.

Table 1 Chemical composition of salt from Torrevieja and Almeria, Spain (SIF, 1990)

Factor analysed	Torrevieja	Almeria
Water (%)	2.5–1.8	3.0
NaCl (%)	97.3–97.7	95.7
$CaSO_4$ (%)	0.15–0.32	0.44
$MgSO_4$ (%)	0.00–0.10	0.31
$MgCl_2$ (%)	0.00–0.12	0.31
$NaSO_4$ (%)	0	0
Matter insoluble in water (%)	0.10	0.01
Iron (mg/kg)	12–15	4.8
Copper (mg/kg)	<0.01	0.02

Preliminary experiment (I)

The effects of different brine concentrations were tested by using brine with a starting concentration of NaCl in water of 16 (17.5%), 20 (22.5%) and 24° Bau (25.6%). Final concentrations were 12.3, 15 and 18° Bau, respectively. For rehydration thick and thin pieces were cut from the fillets and submerged in water, with a fish to water ratio of 1:18, and the fish was allowed to rehydrate for 72 h. Then the water was replaced with fresh water and rehydration continued for 11 h in a 1:5 ratio water bath.

Main experiment (II)

The effects of traditional brine salting methods were compared with processes which had increased control of the salt concentration in the brine by using the following methods:

1. 5–18°: The cod fillets were salted in brine with a starting concentration of 5° Bau (7%), salt was then added gradually during the brine salting step to reach a salt concentration of approximately 18° Bau (19.7%). The salt was added after 8, 18 and 27 h to increase the salt concentrations to 6.1, 13.5 and 19.7%, respectively after the salt addition. The final concentration of the brine was 16° Bau (16.9%).
2. Constant 16°: The cod fillets were salted in brine with an initial concentration at 16° Bau (17.5%), which was maintained at 16° Bau by adding salt during the brining step. The salt was added after 8, 18 and 27 h to increase the salt concentrations to 17.9, 17.0 and 17.4% respectively. The final concentration of the brine was 15° Bau (15.8%).
3. Control 16°: The brine used for the control group had a starting concentration of 16° Bau.

The changes in the brine concentration were only from water and salt exchange between the fish and brine, as was true for the 16° Bau group in the preliminary experiment. The final concentration of the brine was 12° Bau (13.2%).

The initial salt concentration of the brine was measured with a hydrometer before and after salt addition. Samples were also collected for titration of salt using the Volhard method (AOAC, 1990).

After storage the fillets were cut into three pieces, which were rehydrated by submerging the fish in a 1:5, fish to water ratio, for 30 h. The water was then replaced with fresh water and rehydration continued for 80 h with samples submerged in a 1:4 ratio water bath. The rehydration process in the preliminary experiment was based on using 1:18 water to fish ratio, which would be highly unpractical in an industrial process. The rehydration process was designed to obtain a final salt concentration of approximately 1%. This was achieved by the process described above.

Sampling

Prior to sample preparation the fish were rated for commercial quality. In the preliminary experiment, two fillet samples were taken from the raw material, after each processing step, except when four fillets were used in the 16° Bau experiment, but in the main experiment three sample fillets were collected. A portion of about 6 cm was removed from the middle of the fillets for determination of water holding capacity (WHC). For further analysis (protein, salt, water and pH), two portions (approximately 6 cm each) were removed from the fillets, from the tail part and near the head, next to the part that was taken for measurements of WHC (Fig. 1). The samples for WHC were analysed immediately but samples for the analysis of chemical composition and pH were frozen and stored at −24 °C, until analysed. Prior to analysis, the fish was skinned by hand and minced in a Braun mixer (type 4262; Braun, Kronberg, Germany).

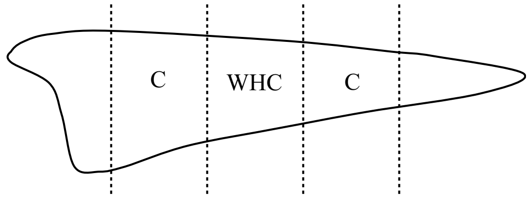

Figure 1 Location of sampling across the fillets for chemical analysis (C) and measurement of water holding capacity (WHC).

Weight and yield determination

The fillets were weighed raw and after each processing step; the weight yield was calculated with respect to the weight of the raw fillets.

Determination of pH, water, salt, protein and TCA-soluble nitrogen content

Water content (g per 100g) was calculated as the loss in weight, after drying at 105 °C for 4 h (ISO 6496, 1983). Salt content was determined by the method of Volhard (AOAC, 1990). The pH of the muscle was measured by inserting a combination glass electrode ('Red rod' C2401-7; Radiometer, Copenhagen, Denmark) directly into the cod mince. This method was a modification of the procedure by Kramers & Peters (1981), who measured pH in fillets by inserting the electrode directly in to the approximate centre of the fillets.

The total protein content of the fish muscle and brine was estimated with the Kjeldahl method (ISO 5983, 1979) with the aid of Digestion System 40, 1026 distillation unit, (Tecator AB, Hoeganaes, Sweden) and calculated using total nitrogen (N) × 6.25. Protein recovery (%) was calculated from the protein content of samples, using the content in the raw material as reference value. Trichloroacetic acid (TCA)-soluble nitrogen was also analysed by the Kjeldahl method. Approximately 20 g of fish mince were weighed accurately into a 250 mL flask and 50 mL of 10% TCA were added (Gudmundsdottir, 1995). This was followed by centrifugation at 0–5 °C for 30 min at 2300 ***g***, for precipitation of the protein fraction. The supernatant (10–12 g) was used for determination of the TCA-soluble nitrogen (Ironside & Love, 1958; Love *et al.*, 1974). The protein recovery (or yield) was estimated by comparing the calculated protein content of the raw material (in grams) to the calculated protein content after each of the processing steps.

Determination of Water holding capacity (WHC)

The salted cod samples ($n = 3$) were coarsely minced with a Braun mixer (type 4262; Braun, Kronberg, Germany) for approximately 20 s at speed 4. Approximately 10 g of the minced cod muscle was weighed accurately and immediately centrifuged at 210 ***g*** (1500 r.p.m.) for 15 min; with temperature maintained at 2–5 °C (Akse *et al.*, 1993; Ofstad *et al.*, 1993). The weight loss after centrifugation was divided by the water content of the fillet and expressed as percentage WHC.

Quality rating

Cod was rated for commercial quality by a trained grader after the dry-salting and storage period. Three quality grades were used for assessing the cod fillets: A, B and C. Some basic rules are reported here but the knowledge of the grader was gained by training and experience. In the evaluation of salted cod fillets, appearance or colour is of great importance:

Grade A: Fillets were to be light in colour, thick, without gaping and blood stains, where gaping appeared, as openings or ruptures between the myotomes, this was because of the weakening of the connective tissue.

Grade B: Fillets, which were not of 'grade A' quality because of small defects. The colour was darker and the fillets were thinner or with long gaps in the long axis of each fillet, compared with 'grade A' fillets.

Grade C: Fillets which contained defects, like gaping or other apparent mechanical defects in the fish flesh. The colour of the fillets was too dark to be graded as quality B. Slight red discoloration of the fillets (caused by the growth of halophilic bacteria) or yellow staining (caused by copper-catalysed oxidation of fat) was classified as quality C.

Statistical analysis

Samples were analysed statistically using Microsoft Excel 8.00 (Microsoft Inc, Redmond, USA). Samples were subjected to ANOVA. The Duncan's Comparison test was used to test the significance ($P = 0.05$) of differences between means (NCSS 2000, NCSS, Utah, USA). Significance level was set at $P \leq 0.05$.

Results and discussion

Preliminary experiment (I)

The weight yield of fillets salted in 24° Bau was 99.1% and lower ($P < 0.05$) than in the other groups after brining. However, the difference decreased during dry salting, and was not significant ($P > 0.05$) after dry salting, storage or rehydration (Fig. 2). During the brining step the fillets in the 16 and 20° Bau brine increased their weight compared with the weight of the raw material, having a yield of 107 and 106%, receptively. This did not happen in the 24° Bau saturated brine. Comparison of the mass, in grams of water, in the fillets before and after brine salting, showed that the fillets lost 13.6 percentage points of water. The values for the other groups, 16 and 20° Bau were 1.7 and 6.2 percentage points, respectively. The lower weight yield in the 24° Bau group may possibly be explained by a lower water content in the muscle, caused by an increased rate of water diffusion out of the muscle during brine salting because of the higher salt concentration of the brine (Table 2). Barat *et al.* (2002) observed that fillets that reached equilibrium in a 25% brine had lower weight yield than fillets brine salted in 20% brine. The fillets in their study also contained relatively less water compared with the raw material but similar concentrations of salt.

Comparison of the groups showed that the salt content after brine salting increased with increasing salt concentration of the brine. The opposite was observed for the water content. The pH decreased with increasing salt content and decreasing water

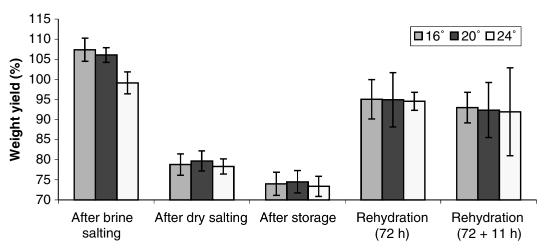

Figure 2 Weight yield (%) of salted and rehydrated cod fillets in the preliminary experiment, which were brine salted in various salt concentrations (16°: $n = 42$–50 after salting and storage, $n = 10$ after rehydration; 20 and 24°: $n = 21$–25 after salting and storage, $n = 4$–8 after rehydration of 72 h, $n = 4$–10 after rehydration of 72 + 11 h).

Table 2 Water and salt content and pH in cod fillets [$n = 2$, except 4 in 16° Bau ($n = 1$–2 after 72 h of rehydration)] after salting, storage and rehydration in the preliminary experiment (mean ± s.d.)

	Group	After brine salting	After dry salting	After storage	After rehydration of 72 h	After rehydration of 72 + 11 h
Water (%)	16°	75.1 ± 2.3	58.2 ± 0.5	56.7 ± 0.2	83.6 ± 0.2	83.9 ± 0.4
	20°	72.5 ± 0.3	58.6 ± 0.1	56.6 ± 0.6	84.1	83.9 ± 0.1
	24°	71.5 ± 1.6	58.7 ± 0.8	57.4 ± 1.0	83.9	83.8 ± 0.7
Salt (%)	16°	9.0 ± 1.7	20.2 ± 0.4	19.9 ± 0.1	1.0 ± 0.1	0.5 ± 0.0
	20°	11.4 ± 0.5	20.4 ± 0.1	20.1 ± 0.1	1.1	0.6 ± 0.0
	24°	12.4 ± 0.8	20.3 ± 0.3	20.5 ± 0.2	1.1	0.6 ± 0.1
pH	16°	6.44 ± 0.17	6.06 ± 0.10	5.99 ± 0.06	6.57 ± 0.09	6.56 ± 0.05
	20°	6.46 ± 0.06	6.08 ± 0.01	5.96 ± 0.09	6.51	6.47 ± 0.10
	24°	6.36 ± 0.02	6.10 ± 0.11	5.95 ± 0.08	6.41	6.56 ± 0.00

content. Differences between groups in water, salt and pH decreased with further salting. Changes in these parameters in the muscle were small during storage (Table 2). The water content after rehydration for 72 h was 83.6–84.1% and the salt content was 1.0–1.1%, compared with 82.0 and 0.3% in the fresh fillets, respectively. After replacement of the water and additional rehydration for 11 h, the water content changed to 83.8–83.9% and the salt content to 0.5–0.6%.

Commercial quality rating on samples after dry salting and storage of the fillets, showed no apparent relationship to the concentration of the brine (Table 3). However, the trained assessor observed that the best overall appearance was in fillets from the 16° Bau salt concentration, followed by 24° Bau and trailed by the fish from 20° Bau. These results partly support and partly contradict the theory, commonly believed in the industry, that higher quality salted fish may be produced with brine concentrations, which are lower than a fully saturated brine. The results for the 20° Bau group do not fit the theory, which might be explained by the condition of the raw material. The fish was kept in ice in plastic tubs before filleting. A large fraction of the 20° Bau group may have been collected from the bottom of the tub where the fish can be of slightly lower quality than fish from the top layers, this is because of the pressure and is not apparent during the filleting operation.

The main experiment (II)

Weight yield and composition of the muscle

The weight gain of the fillets was greatest during the first 8 h, with group 5–18° absorbing fastest, but with increased brining time, the weight decreased again resulting in a higher salt content and lower water content in the fillets (Figs 3 and 4). The weight yield in group 5–18° was believed to be

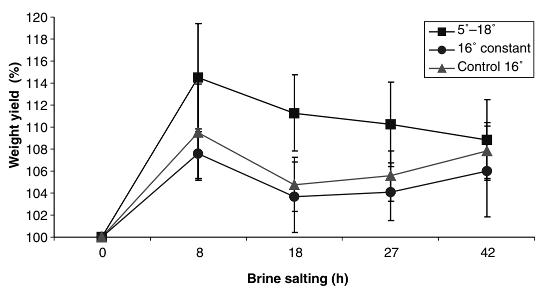

Figure 3 Weight yield (%) of cod fillets ($n = 35$–46) during brine salting, where the salt concentration of the brine was; increased gradually during brining (5–18°); simulated to constant (16° constant) or decreased with time (control 16°).

Table 3 Commercial quality rating of cod fillets after dry salting and storage in the preliminary experiment – ratio of fillets ($n \geq 21$) in each class (A, B and C)

	After dry salting			After storage		
Group	Class A	Class B	Class C	Class A	Class B	Class C
16°	81.0	16.7	2.4	85.7	11.9	2.4
20°	44.4	55.6	0.0	44.4	55.6	0.0
24°	72.2	27.8	0.0	61.1	33.3	5.6

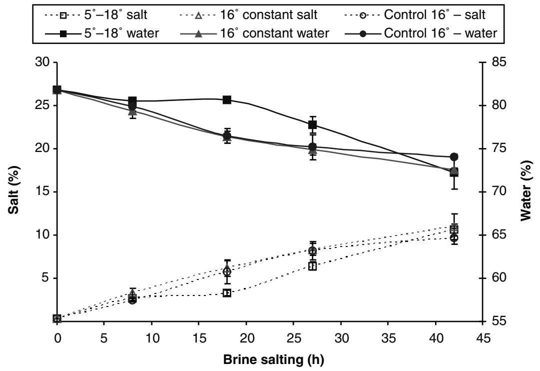

Figure 4 Mean water and salt content in cod fillets ($n = 3$), during brine salting.

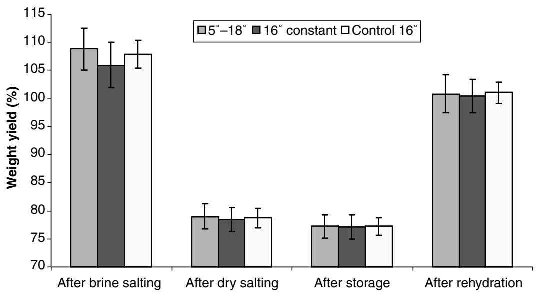

Figure 5 Weight yield (%) of salted and rehydrated cod fillets, which were brine salted with different brine salting methods ($n = 29$–37 after salting and storage, $n = 11$–13 after rehydration).

higher because of the lower salt concentration of the brine during the first part of the brining period but the difference decreased during brine salting. After brine salting the weight yield of the control 16° and 5–18° was similar but different from 16° constant ($P < 0.05$). After dry salting, storage and rehydration all groups were similar ($P > 0.05$) in weight yield (Fig. 5).

The raw fillets contained 81.8% (±0.4) water, 0.4% (±0.0) salt, and 17.5% (±0.4) proteins, respectively. During brining, the salt content of the fillets increased and the water content decreased. After brine salting the water content was similar in fillets from group 5–18° to fillets from constant 16° (Table 4) but it was slightly higher ($P > 0.05$) in the control group. The salt content of the groups after dry salting was in the range of 20.3–20.6% and the water content was 57.6–58.4%. During storage the water content decreased further but changes in salt content were smaller (Table 4). During rehydration, all groups increased their water content above the average ratio determined in the fresh fillets but the salt content in rehydrated fillets was 1.0–1.2% and higher ($P > 0.05$) than the 0.4% in fresh fillets.

The protein content was determined by the Kjeldahl method and values for protein were calculated from a measurement based on the total nitrogen content. Analysing non protein nitrogen (TCA-soluble) and subtracting this from the total nitrogen obtained by the Kjeldahl method gave indications of changes in protein nitrogen. A similar pattern was observed for recovery of total nitrogen and protein nitrogen after brine salting and dry salting but not after storage and rehydration. The recovery was 94.4–97.9% after rehydration, but the recovery of total nitrogen was in the range of 83.7–86.9% and of TCA-soluble nitrogen was 11.3–12.0% (Fig. 6). There were no

Table 4 Water, salt, protein and pH in cod fillets ($n = 3$) after brine salting, storage and rehydration in the main experiment (mean ± s.d.)

	Group	After brine salting	After dry salting	After storage	After rehydration
Water (%)	5–18°	72.2 ± 1.9	57.6 ± 0.4	56.9 ± 0.6	84.2 ± 0.1
	Constant 16°	72.6 ± 0.2	58.4 ± 0.4	56.6 ± 0.2	84,0 ± 0.6
	Control 16°	74.1 ± 0.3	58.4 ± 0.2	56.8 ± 0.4	83.9 ± 0.9
Salt (%)	5–18°	10.7 ± 1.8	20.4 ± 0.3	20.7 ± 0.2	1.0 ± 0.1
	Constant 16°	11.0 ± 0.3	20.6 ± 0.6	20.6 ± 0.1	1.2 ± 0.1
	Control 16°	9.7 ± 0.2	20.3 ± 0.2	20.9 ± 0.3	1.0 ± 0.0
Protein (%)	5–18°	17.1 ± 0.3	21.4 ± 0.5	21.5 ± 0.4	14.5 ± 0.2
	Constant 16°	16.4 ± 0.7	20.9 ± 1.1	21.9 ± 0.3	14.8 ± 0.7
	Control 16°	16.1 ± 0.3	21.0 ± 0.3	21.9 ± 0.9	14.8 ± 0.8
pH	5–18°	6.69 ± 0.09	6.23 ± 0.11	5.87 ± 0.11	6.79 ± 0.03
	Constant 16°	6.59 ± 0.02	6.22 ± 0.10	6.07 ± 0.12	6.63 ± 0.04
	Control 16°	6.60 ± 0.00	6.17 ± 0.12	6.10 ± 0.06	6.65 ± 0.02

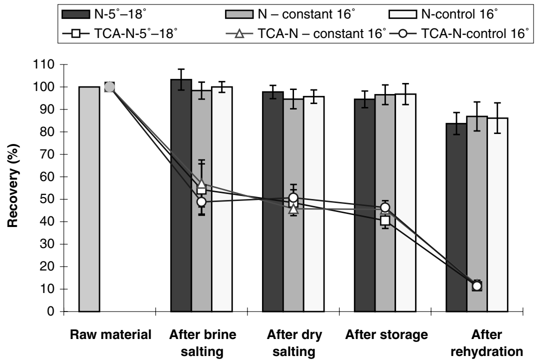

Figure 6 Recovery (%) of total nitrogen (N) and TCA-soluble nitrogen (TCA-N) of salted and rehydrated cod fillets ($n = 3$).

differences between groups ($P > 0.05$). The main changes in nitrogen content occurred during brine salting and rehydration. This indicated that nitrogenous compounds, mainly other than proteins but possibly also partly proteins, leaked out of the muscle in these two processing steps. During these steps, the fillets were surrounded by brine and water and the changes in water and salt were at their highest rate. Salt content increased from 0.4 to 9.7–11.0% during the 42 h brining step but decreased from about 20 to 1% during the 110 h rehydration step. The results were in agreement with previously reported observations (Lawrie, 1998), which indicated that the amount of protein extracted was a function of salt concentration, with the maximum extraction at 6–9% salt concentration in the brine.

It was difficult to judge the effects of the different brining methods on weight yield and composition after brine salting, considering the range of salt content (9.7–11.0%) in the fillets. This was believed to be a very critical stage with respect to the denaturation of proteins, which was thought to occur at salt levels above 9–10% (Thorarinsdottir *et al.*, 2002). Denaturation has been shown to lead to increased protein-protein bonds, shrinkage of the muscle and water loss (Duerr & Dyer, 1952; Akse *et al.*, 1993). The system becomes more stable at higher salt concentrations and a more reliable comparison of the groups was obtained after the storage period. Differences in measured parameters between groups were small ($P > 0.05$) at that stage; for example the weight yield in group 15–18° was 77.3 ± 2.1 and 77.1 ± 2.2, and 77.2 ± 1.6%) in groups 'constant 16°' and control 16°, respectively.

Studies with differential scanning calorimetry (DSC) have shown that the denaturation of the proteins was reversible to some degree after rehydration of the cod (Thorarinsdottir *et al.*, 2002). The recovery of water in the rehydrated fillets was in range of 102.0–105.6% indicating a 2–5.6% increase in weight from the raw state by absorption. This could be explained by higher salt concentration in the rehydrated fillets than in the fresh fillets and by some opening of the muscle structure because of the salting and curing process. Salting has been shown to result in increased swelling capacity of the muscle and space for water (Offer & Trinick, 1983; Honikel, 1989). According to Fennema (1990), salt concentrations above 0.1 M (0.6%) in the muscle, are believed to increase repulsive forces between filaments. However, maximum swelling should be reached at about 5–6% salt concentration.

Changes in water and salt content during the process

The relationship between the salt and water content during brining and rehydration, was highly linear with a coefficient of correlation at >0.99. This supports former studies where the rate of salt uptake was in a constant ratio to the rate of water loss, during salting (Crean, 1961). The rate of changes in salt and water content were nearly constant during brining (Fig. 4). Increasing the salt concentration gradually (5–18°) resulted in a slightly higher water content during brining than in the other groups. During rehydration the rate of salt loss and water uptake was at its highest rate in the beginning of the process (Fig. 7) and occurred at a relatively much higher rate than the changes observed in salt and water content during brining. This may have affected the proteins and thereby the weight yields. Unpublished results from our laboratory indicate that a lower weight yield was obtained by rehydration of salted fish in running water than when the fish was rehydrated in 'still' water. Among the factors that may affect the rate of change during rehydration are; time, ratio of water to fish, number of water replacements, the biological size of the fish and the treatment of the fish during processing such as filleting, skinning and size of cuts.

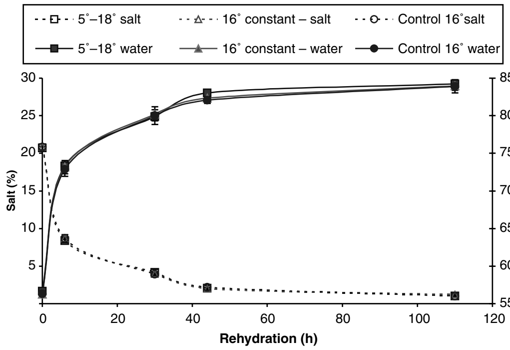

Figure 7 Mean water and salt content in cod fillets ($n = 3$), during rehydration.

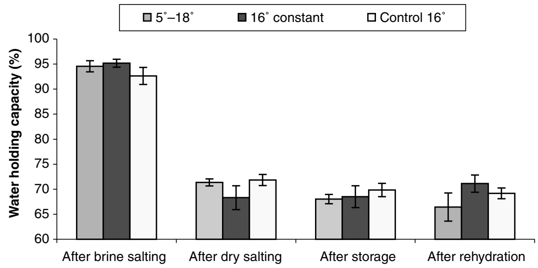

Figure 8 Water holding capacity of cod fillets ($n = 3$) during salting and rehydration.

If the salt was evaluated as the ratio of salt in the water phase of the fish, it was 12.9 ± 2.2, 13.1 ± 0.3 and 11.6 ± 0.3 after brine salting, in groups 5–18°, constant 16° and control 16°, respectively. The same factor was 26.2 ± 0.1, 26.0 ± 0.5 and 25.8 ± 0.2 after dry salting, in groups 5–18°, constant 16° and control 16°, respectively and increased by 0.5–1.1% during storage, to 26.7 ± 0.1%, 26.7 ± 0.1% and 26.9 ± 0.2%, respectively. As the salt content after storage was above the level found in saturated salt solutions (26.4%), a part of the salt may have crystallized in the muscle. Barat *et al.* (2002) reported a salt concentration of 20–25% in fillets salted until equilibrium was reached between salt in the fish and in the brine when kept in 20–25% salt solutions. They also found that brining the fillets in saturated brine (25%) or salting them only by dry salting resulted in 25% salt in the water phase. The water content was relatively higher in the fish which was brine salted and therefore the weight yield was also higher (Barat *et al.*, 2003).

Water holding capacity (WHC)

The salting process influenced WHC greatly in the cod. WHC in the fresh fillets was 86.0% (±1.80) but after brine salting the range was 92.6 to 95.2% for the different groups and after dry salting the WHC had decreased to 68.3 to 71.8%. After rehydration, the highest value of WHC was obtained for group 16° constant where the salt concentration in the brine was kept constant (Fig. 8), but the differences between groups were not significant ($P > 0.05$). The increase in WHC after brine salting may have been caused by the increased salt concentration in the muscle. At higher salt concentration, proteins had probably denaturated, leading to less WHC and dehydration of the muscle. Fennema (1990) discussed the effects of salts on the WHC of the muscle in relation to studies conducted by Offer & Trinick (1983); Hamm (1986); Honikel *et al.* (1986) and Wilding *et al.* (1986). He suggested that at a relatively low salt concentration, salt anions bind to the filaments and thereby increase repulsive forces between the filaments. Salt was also believed to lessen the structural constraints to swelling. At higher salt concentration the protein denaturated, unfolded and the exposure of hydrophobic areas in the proteins increased, leading to aggregation and loss of water from the muscle. Cross-linking between proteins and shrinkage of the muscle may have resulted in less space for water and therefore, decreased WHC. According to Akse *et al.* (1993), changes in WHC during heavy salting, correlated with structural changes in the muscle observed by electron microscopy. After heavy salting, the muscle filaments had aggregated and fibre structure could not be seen. The cells had shrunk and the intracellular fluid had been pressed out to the external cellular space. The space between the cells had decreased, which resulted in less capillary forces and the fluid was more easily squeezed out of the muscle.

Commercial quality rating

After dry salting the percentage of fillets rated as class A was in the range of 75.9–80.6%, with group 5–18° having the highest percentage (Table 5). After storage of the dry salted fillets for three weeks both group 5–18° and the control group did not change significantly, however, the ratio of fillets rated as 'class A' in group 16°

Table 5 Commercial quality rating after dry salting in the main experiment – ratio (%) of fillets in each class (n = 29–31)

	After dry salting			After storage		
Group	Class A	Class B	Class C	Class A	Class B	Class C
5–18°	80.6	19.4	0.0	74.2	22.6	3.2
Constant 16°	77.4	22.6	0.0	93.5	6.5	0.0
Control 16°	75.9	20.7	3.4	75.9	20.7	3.4

constant had increased to 93.5%. The storage period may be considered as a tempering step used in many food processing operations for the even distribution of water and or flavour. The tempering step or process may affect the final quality of the salted fish differently depending on the salting method. Comparable results for quality (80–100% in class A) have been obtained by traditional brining methods and with a 16° Bau brine concentration, in former trials.

The maximum concentration of the brine, reached by salt addition, was believed to be important. It has generally been believed in the fish salt processing industry in Iceland, that there may be a relationship between brine concentration and the final quality of salted fish and that a higher quality 'bacalhau' may be produced in 16–18° Bau compared with a saturated brine at 22–24° Bau, although there has not been a recognized scientific basis for this assumption. The results from this study support this theory.

Conclusions

Increased control of the brine concentration did not show significant effects on the weight yield, water holding capacity or the composition of the salted, rehydrated cod fillets. There was an increase in the overall quality rating of the fillets when salted in brine with concentrations lower than normally found in a fully saturated salt solution. There were also indications that the yield was lower in fillets from a fully saturated brine solution, this was not observed after dry salting, storage or rehydration of the fish.

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References

Akse, L., Gundersen, B., Lauritzen, K., Ofstad, R. & Solberg, T. (1993). *Saltfisk: Saltmodning, Utproving av Analysemetoder, Misfarget Saltfisk (in Norwegian)*. Pp. 1–61. Tromsö: Fiskeriforskning.

AOAC (1990). *937.09. Sodium Chloride in Seafood. Official Methods of Analysis*, 15th edn. Arlington, Virginia: Association of Official Analytical Chemists.

Barat, J.M., Rodríguez-Barona, Andrés, A. & Fito, P. (2002). Influence of increasing brine concentration in the cod-salting process. *Journal of Food Science*, **67**, 1922–1925.

Barat, J.M., Rodríguez-Barona, S., Andrés, A. & Fito, P. (2003). Cod salting manufacturing analysis. *Food Research International*, **36**, 447–453.

Beraquet, N.J., Iaderoza, M., Jardim, D.C.P. & Lindo, M.K.K. (1983). Salting of mackerel (Scomber japoonicus) II. Comparison between brining and mixed salting in relation to quality and salt uptake. *Coletaneado Instituto de Tecnologia de Alimentos*, **13**, 175–198.

Bogason, S.G. (1987). Söltun orskafla (in Icelandic). *Fiskvinnslan* no.4, 39–44.

Borgstrom, G. (1968). *Principles of Food Science*. Vol. 1. Pp. 285–313. London: The Macmillan Company, Collier-Macmillan Limited.

Crean, P.B. (1961). The light pickle salting of cod. *Journal of Fisheries Research Board of Canada*, **18**, 833–844.

Duerr, J.D. & Dyer, W.J. (1952). Proteins in fish muscle. IV. Denaturation by salt. *Journal of Fisheries Research Board of Canada*, **8**, 325–331.

Fennema, O.R. (1990). Comparative water holding properties of various muscle foods. A critical review relating to definitions, methods of measurement, governing factors, comparative data and mechanistic matters. *Journal of Muscle Foods*, **1**, 363–381.

Gudmundsdottir, G. (1995). *The effect of raw material handling on salt uptake, texture, taste, chemical and biochemical changes in spice-salted herring*. MSc dissertation, University of Iceland.

Hamm, R. (1985). The effect of water on the quality of meat and meat products: problem and research needs. In: *Third Internal Sumposium of Properties of Water in relation to Food Quality and Stability* (edited by J.L. Simatos & J.L. Multon). Pp. 591–602. Dordrecht, Netherlands: M. Nijhoff Publ.

Hamm, R. (1986). Functional properties of the myofibrillar system and their measurements. In: *Muscle as Food* (edited by P.J. Bechtel). Pp. 135–199. Orlando: Academic Press.

Honikel, K.O. (1989). The meat aspects of water and food quality. In: *Water and Food Quality* (edited by T.M. Hardman). Pp. 277–304. London: Elsevier Applied Science.

Honikel, K.O., Kim, C.J. & Hamm, R. (1986). Sarcomere shortening of prerigor muscles and its influence on drip loss. *Meat Science*, **18**, 267–282.

Ironside, J.I.M. & Love, R.M. (1958). Studies of protein denaturation in frozen food. I. – Biological factors influencing the amounts of soluble and insoluble protein present in the muscle of the North Sea cod. *Journal of Science of Food and Agriculture*, **9**, 597–604.

ISO 5983 (1979). *Determination of Nitrogen Content and Calculation of Crude Protein Content – Kjeldahl Method.* Genf, Switzerland: The International Organization for Standardization.

ISO 6496 (1983). *Determination of Moisture and other Volatile Matter Content*. Genf, Switzerland: The International Organization for Standardization.

van Klaveren, F.W. & Legrende, R. (1965). Salted cod. In: *Fish as Food* (edited by G. Borgstrom), Vol III. Pp. 133–160. New York: Academic press.

Kramers D.E. & Peters M.D. (1981). Effect of pH and prefreezing treatment on the texture of yellowtail rock fish (*Sebastes flavidus*) as measured by the Ottawa Texture Measuring System. *Journal of Food Technology*, **16**, 496–504.

Lawrie, R.A. (1998). The storage and preservation of meat II. Moisture control. In: *Lawrie's Meat Science*, 6th edn. (edited by R.A. Lawrie). Pp. 191–194. Cambridge, UK: Woodhead Publishing Limited.

Love, R.M., Robertson, O., Smith, G.L., & Witthle, K.J. (1974). The texture of cod muscle. *Journal of Texture studies*, **5**, 201–212.

Morrissey, P.A., Mulvihill, D.M., & O'Neill, E.M. (1987). Functional properties of muscle proteins. In: *Developments in Food Proteins* (edited by B.J.F. Hudson). Pp. 195–225. New York: Elsevier Science.

Offer, G. & Knight, P. (1988). The structural basis of water-holding in meat. In: *Developments in Meat Science 4*. (edited by R. Lawrie). Pp. 63–171. London: Elsevier.

Offer, G. & Trinick, J. (1983). On the mechanism of water-holding in meat: the swelling and shrinking of Myofibrils. *Meat Science*, **8**, 245–381.

Ofstad, R., Grahl-Madsen, E., Gundersen, B., Lauritzsen, K., Solberg, C. & Solberg, T. (1993). Stability of Cod (*Gadus morhua* L.) surimi processed with $CaCl_2$ and $MgCl_2$ added to wash water. *Journal of Food Science and Technology*, **28**, 419–427.

Poernomo, A., Fawzya, Y.N. & Ariyani, F. (1992). Salting and drying of mackerel. *ASEAN Food Journal*, **7**, 141–146.

SIF (1990). *Saltfiskdagbókin (in Icelandic). Information to producers of salted cod*. Hafnarfjordur, Iceland: SIF, Ltd.

Thorarinsdottir K.A., Arason S., Geirsdottir M., Bogason S.G. & Kristbergsson K. (2002). Changes in myofibrilar proteins during processing of salted cod (*Gadus morhua)* determined by electrophoresis and Differential Scanning Calorimetry. *Food Chemistry*, **77**, 327–335.

Wilding, P., Hedges, N. & Lillford, P. (1986). Salt-induced swelling of meat: The effect of storage time, pH, ion-type and concentration. *Meat Science*, **18**, 55–75.

Zaitsev, V., Kizevetter, I., Lagunov, L., Makarova, T., Minder, L. & Podsevalov, V. (1969). Salting and marinating. In: *Fish curing and processing*. Pp. 198–256. Moscow: MIR Publishers.

