Effects of Brining Conditions on Weight Gain in Herring (*Clupea harengus*) Fillets

SVEINUNG BIRKELAND, MORTEN SIVERTSVIK, HENRIK H. NIELSEN, TORSTEIN SKÅRA

ABSTRACT: Salted herring is an important product category in many European countries. Reduced need for salt as a preserving agent and the increased emphasis on less salt in the human diet has changed the basis for the traditional processing of these products. This has led to significant changes in the processing conditions and in the characteristics of the salted products. In this perspective, the effects of different brine concentrations (10.0%, 16.5%, and 25.5%), brining temperatures (3.5 °C and 17.5 °C), the presence of skin or not on the fillets, and brining time (1, 2, 3, 4, and 7 d) were investigated on the weight gain (%) and final salt content (%) of herring (*Clupea harengus*). A significant ($P < 0.001$) higher weight gain of the fillets were observed at the lowest brining temperature (3.5 °C) compared with at the higher temperature (17.5 °C), independently of brine concentration and brining time. Increased brine concentration and skinning of the fillets caused the weight gain to significantly decrease ($P < 0.001$) and increase ($P < 0.001$), respectively. After 1 d of brining, the weight gain was in the range of 10% to 12% for both brining temperatures, and at the lowest temperature, the weight gain increased significantly ($P < 0.001$) as a function of brining time. At the higher temperature, no further significant increase in weight was observed from 1 to 7 d of brining. It is concluded that the weight gain in herring fillets brined according to the present commercial practice is significantly affected by temperature, brine concentration, brining time, and the presence or not of skin on the fillets and that the weight gain may be of high magnitude.

Keywords: herring, processing, weight gain, yield, brine salting

Introduction

Salting of herring is a very old process that has played an important role in the diet of Northern Europeans, with respect to preserving the herring and thus making it available for consumption most of the year. Although herring consumption is showing decreasing trends in many western countries, herring is still an important product in northern Europe and increasingly so in the northeastern parts, especially Russia. Whereas salting in former days was carried out on fresh material to avoid spoilage, today frozen herring is increasingly used as raw material for further processed and salted products. Norway is a major supplier of herring to the European market, and approximately 85% of the Norwegian export of herring is as frozen raw material (EFF 2004).

Among a number of important factors, the reduced need for salt as a preserving agent due to the development of sophisticated refrigeration and packaging technologies, as well as the increased emphasis on less salt in the diet, has changed the basis for the traditional processing of salted herring and the product itself. This has led to a significant reduction in processing time. The main salted herring products these days are marinated or maatjes-type products that in addition to salt also rely on pH-regulating and in some cases preserving agents, as well as packaging solutions and refrigerated storage temperature for their shelf life. The use of brining as an intermediate step in marinating (Rodger and others 1984), smoking (Aitken and Baines 1969), and canning (Slabyj and others 1987) of herring has been investigated. Common to these studies is the short-term processing involved (<1 h) and the lack of information on fillet water uptake and the subsequent weight gain (that is, product yield). The effect of brining on salt content and product yield has been thoroughly investigated for cod (*Gadus morhua*). However, salted cod is a different product from salted herring both in preparation and dewatering procedures and the raw materials differs in muscle structure and fat content. Thus, it is unlikely that the results of these studies can be directly transferred to herring.

The weight changes and yield aspects of herring are important criteria for value chain considerations and are of great importance for estimating where the major value addition takes place. The yield is a key factor for profitable industrial production, and investigation and documentation of the effects of processing conditions of salted herring is lacking. Although it is obvious that these relationships have been known to, and used by, the herring industry since industrial production began. At present, most textbooks refer to Bramsnæs (1946) for the description of weight changes in herring fillets during salting in brines of different concentrations. However, this work refers to "Reports of the Food Investigation Board, London 1934 and 1935," which are currently not available, and thus cannot be studied in more detail.

In this perspective, it has been of interest to study the effect of different brine strengths, brining time, and brining temperature, not only to provide documentation for the scientific and industrial community, but also to develop a modeling tool to predict the effects of key parameters on salt uptake and yield for general herring-salting practices.

Materials and Methods

Raw material and experimental design

Packaged and frozen (–20 °C, 6 mo) blocks (3 × 20 kg) of fillets cut

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from Norwegian spring spawning herring (*Clupea harengus*) caught in mid January 2004, were obtained from Sir-Fish AS (Sirevåg, Norway). The blocks were transported frozen to Norconserv AS and subsequently thawed for approximately 20 h in a container (50 L) with constantly running water (12 ± 1 °C). The thawed herring fillets were divided into 2 batches (approximately 30 kg) and the skin removed from the fillets in one of the batches. The skin-on and skin-off fillets were subsequently exposed to different brine concentration and temperature treatments.

A full factorial design with 3 replicates were set up to determine the effects of brine temperature (3.5 °C and 17.5 °C), brine concentration (10.0%, 16.5%, and 25.5%, w/w), and skin (on and off) on the weight changes of herring fillets during brining for 1, 2, 3, 4, and 7 d.

Preparation of brine

Saturated brine (26.5%) was prepared by dissolving 36.0 kg of NaCl (Akzo Nobel, Fine Refined Salt, minimum 99.8% NaCl, Dansk Salt AS, Mariager, Denmark) in 100.0 kg of water. The brine was vigorously stirred for 3 h and left overnight (4 °C) to ensure complete dissolution of the salt. The actual brine concentration (25.5%) was determined by a calibrated Salt Analyser (Dicromat 11-6, PCL Control Instrumentation Ltd., Leicester, U.K.). The saturated brine (25.5% ± 0.1%) was used as a stock solution for the production of brines with concentrations of 10.0% ± 0.1% and 16.5% ± 0.1%.

Brining of herring fillets

Skin-on or skin-off herring fillets (1500 ± 2 g) were weighed into plastic buckets (10 L) to which was added 1500 ± 2 g of brine of different concentration (10.0%, 16.5%, 25.5%); the fillets were subsequently stored at ambient air temperatures of 3.3 ± 2.0 °C or 17.7 ± 0.7 °C for 7 d. The brine temperature in the two temperature treatments were 3.5 ± 1.0 °C and 17.5 ± 0.8 °C, respectively.

Registration of weight changes and brine concentration

The total weight of the herring fillets in the containers was registered after 1, 2, 3, 4, and 7 d of brining. The brine was collected by spreading the fillets on a grid and allowing brine to drip off from the fillets (1 min) before weight registration. Subsequently, the brine and the fillets were returned to the container and stored for further weight registration. The brine concentration was determined directly in the container by a salt analyzer as described previously.

Chemical analysis

Dry matter, protein, and lipid content were determined on an individual basis ($n = 4$) in the raw herring fillets. Dry matter was determined after heating of the samples at 105 °C for 24 h or until stable sample weight was achieved. Crude protein content was analyzed as Kjeldahl - N×6.25 (ISO 1997) Kjeltech Autoanalyser (Tecator, Sweden) and lipid content by ethyl-acetate extraction (Standard Norge 1994a, 1994b). The salt content was determined conductivity, after accurately weighing mince (20 g) into a chopping beaker and adding distilled water with a graduated cylinder (200 mL). The solution was homogenized (1 min) using an electric blender and added through a strainer to a plastic beaker (250 mL). The salt content (%) was measured in the filtered solution using a salt analyzer (Dicromat 11-6, PCL Control Instrumentation Ltd., Leicester, U.K.). Duplicate samples were analyzed, and mean values used for statistical analyses of the data.

Statistical analyses

MINITAB (Statistical Software for Windows, Release 14, Minitab Inc., State College, Pa., U.S.A.) was used for the statistical treatment (analysis of variance [ANOVA] and General Linear Model [GLM]) of the data (means ranked by Tukey's pairwise comparison test, level of confidence 95%). A model of the weight gain in herring fillets was developed with MINITAB's response surface algorithm with uncoded units using multiple linear regression (MLR) on linear, interaction, and quadratic effects of experimental variables.

Table 1—Effects of initial brine concentration (%), brining temperature (°C) and skin-on/skin-off on the salt content (%) in herring fillets cured for 7 d

	Salt content (%)[a]
Brine concentration (%, n = 12)	
10.0	4.9[c]
16.5	7.0[b]
25.5	10.6[a]
Effect of concentration[b]	<0.001
Temperature (°C, n = 18)	
3.5	7.5
17.5	7.5
Effect of temperature[b]	0.889
Skin (n = 18)	
On	7.5
Off	7.4
Effect of skin[b]	0.072

[a] Means with different lowercase letters in column indicate significant differences between different treatments (means ranked by General Linear Model [GLM] and Tukey's pairwise comparison test).

[b] Level of significance for the effect of different treatments.

Results and Discussion

Raw material

The mean contents of lipid, protein, and dry matter of the herring fillets were 15.7% ± 1.8%, 18.1% ± 0.8%, and 32.2% ± 3.7%, respectively.

Final salt content in brined fillets

The salt content (%) of the herring fillets after 7 d of brining increased significantly ($P < 0.001$) with increasing brine concentration (Table 1). The salt content increased from 4.9% at low brine concentration (10.0%) to 10.6% at high brine concentration (25.5%). No effect of brining temperature (3.5 °C versus 17.5 °C) and skin (on versus off) were observed on final fillet salt content.

Weight gain in herring fillets during brining

The total weight gain of herring fillets after 7 d of brining at 3.5 ± 1.0 °C and 17.5 ± 0.8 °C ranged between 21% to 37% and 6% to 15%, respectively (Figure 1a and 1b). Generally, the highest %-unit alterations in weight gain between days of brining were observed between day 0 and day 1 for both brining temperatures, which coincided to amount to 22% to 47% and 43% to 105% of the total weight gain observed after 7 d of brining for the herring fillets cured at 3.5 °C and 17.5 °C, respectively.

The weight gain of herring fillets cured at 3.5 °C increased significantly ($P < 0.001$) throughout the investigated brining time (Figure 1a; Table 2). This indicates that equilibrium between the salting medium (brine) and the interior muscle tissue of the herring fillets has not been achieved at 3.5 °C, causing an influx of salt and water to the fillets even after 7 d of brining. On the contrary, the weight gain of the fillets cured at 17.5 °C generally stabilizes after 1 to 2 d of brining (Figure 1b), indicating that equilibrium conditions have been reached and that extended brining time above 1 to 2 d at 17.5 °C has no significant effect on the weight gain of herring fillets (Table 2).

Table 2—Effects of brine concentration (%), brining time (d), presence of skin, and brining temperature (°C) on weight gain (%) of herring fillets

	Weight gain (%)		
	3.5 °C[a]	17.5 °C[a]	Temp. effect[b]
Brine concentration (%, n = 30)			
10.0	26^{a}	15^{a}	***
16.5	24^{b}	14b	***
25.5	15^{c}	4^{c}	***
Effect of concentration[c]	<0.001	<0.001	
Brining time (d; n = 18)			
1	12^{e}	10^{b}	ns
2	18^{d}	11^{ab}	***
3	22^{c}	11^{a}	***
4	26^{b}	11^{a}	***
7	31^{a}	12^{a}	***
Effect of brining time[c]	<0.001	<0.001	
Skin (n = 45)			
On	19^{b}	10^{b}	***
Off	24^{a}	12^{a}	***
Effect of skin[c]	<0.001	<0.001	

[a] Means with different lowercase letters in each column indicate significant differences between different treatments (means ranked by GLM and Tukey's pairwise comparison test).
[b] Effect of brining temperature at different treatments (General Linear Model [GLM] and Tukey's pairwise comparison test); levels of significance $P < 0.05$ (*), $P < 0.01$ (**), $P < 0.001$ (***), and not significant (ns).
[c] Level of significance for the effect of different treatments.

Increased brine concentration significantly ($P < 0.001$) reduces the weight gain of the herring fillets after brining at both 3.5 °C and 17.5 °C (Table 2). Increasing the brine concentration from 10.0% to 25.5% reduces the weight gain by 11%-units for both brining temperatures.

A significant effect ($P < 0.001$) of the presence of skin on the weight gain of herring fillets was observed at both brining temperatures (Table 2). Skin-on herring fillets showed a lower weight gain compared with skin-off fillets for both brining temperatures. The effect of skin was most pronounced at the lowest brining temperature (3.5 °C), in which the presence of skin caused the weight gain to be reduced by 5%-units compared with herring fillets without skin. With respect to the effect of skin at the highest brining temperature (17.5 °C), the presence of skin caused the weight gain to be reduced by 2%-units compared with fillets without skin.

Brining temperature had a significant effect ($P < 0.001$) on the weight gain during all the different treatments although not after 1 d of brining (Table 2). Notwithstanding, brining at 3.5 °C generally causes the weight gain to be significantly higher than when brining at 17.5 °C.

Changes in brine concentration during brining

The initial brine concentrations of 25.5%, 16.5%, and 10.0% were significantly reduced ($P < 0.001$) to 13.3% ± 0.5%, 8.4% ± 0.1%, and 5.4% ± 0.1%, respectively, at the end of the experiment (Figure 2). The major alteration in the initial brine concentrations were observed from day 0 to day 1 for all the different brines, and decreases in brine concentration of 10.1%-units, 7.2%-units, and 3.9%-units were observed for the 25.5%, 16.5%, and 10.0% brine, respectively. Furthermore, from day 1 until day 2, a significant decrease ($P > 0.001$) in brine concentration was observed (Figure 2). Generally, the brine concentration changed little from day 2 until the end of the experiment for brines 25.5% (1.0%-units), 16.5% (0.5%-units), and 10.0% (0.3%-units), although significant differences were observed (Figure2). The mean recovery of salt (g) supplied to the brining system for the different treatments at the end of the brining time (7 d) was 95% ± 5% (data not shown).

Modeling of weight gain (%) in herring fillets

Modeling of the weight gain based on the experimental variables was done by response surface regression using uncoded units. Significant linear, square, and interaction terms were observed and the regression was repeated using only significant interaction and square terms obtaining a general model (Eq. 1) with an observed $R^2_{(adj)}$ of 0.962 ($n = 180$).

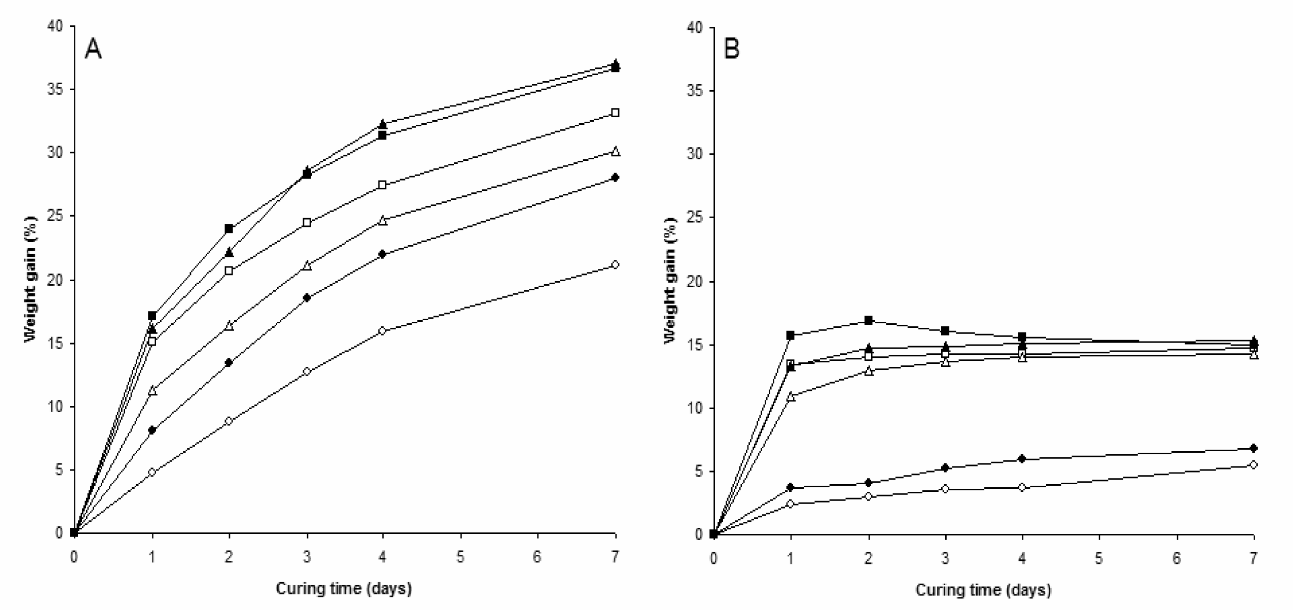

Figure 1—Weight gain (%) of herring fillets with or without skin cured for 7 d at 3.5 ± 1.0 °C (a) and 17.5 ± 0.8 °C (b) in brines of different concentration (%). —○— = 25.5% brine/skin-on; —●— = 25.5% brine/skin-off; —△— = 16.5% brine/skin-on; —▲— = 16.5% brine/skin-off; —□— = 10.0% brine/skin-on; —■— = 10.0% brine/skin-off.

$$\text{Weight gain} = \beta_0+\beta_1x_1+\beta_2x_2+\beta_3x_3+\beta_4x_4+\beta_5x_1x_3+\beta_6x_1x_4+\beta_7x_2^2+\beta_8x_3^2\pm\epsilon \quad (1)$$

where x_i, β_j, and ϵ are experimental variable level, regression coefficients, and standard error, respectively, and as given in Table 3.

The predicted fits by Eq. 1 versus the measured weight gain are shown in Figure 3. The model was able to predict the weight gain by ±1.7% within the investigated range of experimental variable level. For skin-off fillets, Eq. 1 reduces to

$$\text{Skin-off weight gain (\%)} = \beta_0+\beta_1x_1+\beta_2x_2+\beta_3x_3+\beta_5x_1x_3+\beta_7x_2^2+\beta_8x_3^2\pm\epsilon \quad (2)$$

The differences between predicted weight gain for skin-off and skin-on fillets and the influence of storage time and brine concentration at 3.5 °C are shown as response surfaces in Figure 4.

Crude composition of herring

The mean contents of lipid, protein, and dry matter of the herring fillets used in our study were 15.7% ± 1.8%, 18.1% ± 0.8%, and 32.2% ± 3.7%, respectively. Similar crude composition of herring muscle have been reported elsewhere (Aidos and others 2002; Hamre and others 2003; Nielsen and Hyldig 2004), although significant seasonal and catching-ground variations in the contents of lipid and protein in herring fillets do occur. Thus, herring fillet crude composition should be closely monitored before processing and choice of processing protocol due to the effect of lipid content on the transfer of salt and water in the muscle tissue during brining (Wang and others 2000; Collignan and others 2001) and subsequently on final salt content and product yield.

Final salt content in fillets

It is generally accepted that salt migration by diffusion plays an important role in salting of fish, and the diffusivity of salt is dependent on several factors such as species, temperature, muscle orientation, lipid content, and the presence or absence of skin (Schwartzberg and Chao 1982; Wang and others 2000) and fillet thickness and brine concentration according to Fick's s law of diffusion. In our study, a significant effect of initial brine concentration on the final salt content (%) in herring fillets was observed (Table 1). Final muscle salt content increased with increasing brine concentration, from 4.9% at 10.0% brine concentration to 10.6% at 25.5% brine concentration. An increase in the brine concentration increases the equilibrium muscle salt content and decreases the equilibrium muscle water content, thus causing a higher final muscle salt content at the higher brine concentrations. No significant effects of brining temperature or skin-on/off were observed

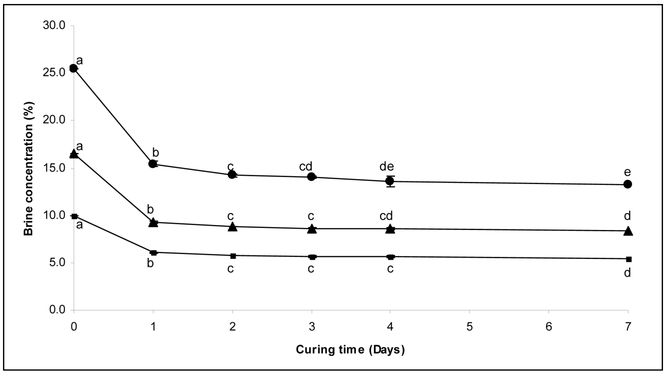

Figure 2—Changes in the concentration (%) of initial brines (10.0%, 16.5%, and 25.5%) during brining of herring fillets. —■— = 10.0%; —▲— = 16.5%; —●— = 25.5%. Values given are means (±std. dev.) for all treatments (skin-on/skin-off and temperatures 3.5 °C and 17.5 °C), and different lowercase letters indicate significant differences between different brining time for the different brine concentrations (means ranked by analysis of variance [ANOVA] and Tukey's pairwise comparison test).

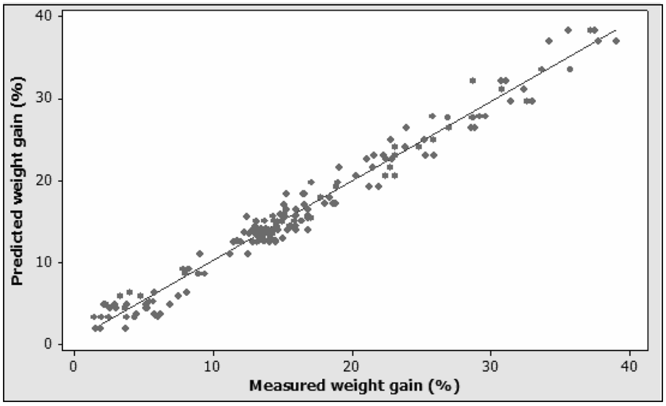

Figure 3—Predicted weight gain (%) in herring filets calculated using model (Eq. 1) versus measured weight gain (%).

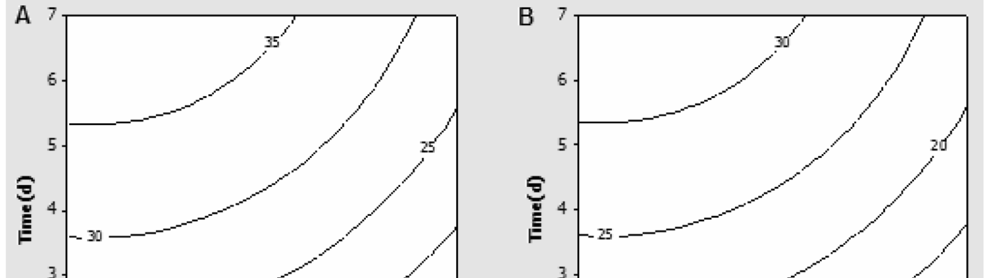

Figure 4—The effect of time and brine concentration on the predicted weight gain (%) at 3.5 °C for skin-off (a) and skin-on (b) herring fillets

Table 3—Terms and coefficient for general weight gain model, Eq. 1 and 2

Experimental variable	Uncoded coefficients (all $P < 0.001$)			
x_1 Temperature (°C)	β_0	9.19104		
x_2 Initial brine concentration (% NaCl)	β_1	–0.21473	β_5	–0.05087
x_3 Time (d)	β_2	1.12622	β_6	–0.26638
x_4 Skin (on = 1, off = 0)	β_3	5.92708	β_7	–0.19657
ϵerror = 1.708 (% weight gain)	β_4	–5.92778	β_8	0.24772

on final salt content in our study, even though temperature previously has been reported to affect salt diffusion in fish muscle. Additionally, the presence of skin-on fish fillets has been shown to provide an effective barrier against salt penetration (Sakai and Suzuki 1985; Ravesi and Krzynowek 1991).

Changes in brine concentration

The initial brine concentrations (25.5%, 16.5%, and 10.0%) were rapidly reduced after 1 d of brining to 15.4%, 9.3%, and 6.1%, respectively. Only minor changes (a total of 0.7% to 2.1%-units) in the brine concentration were observed during the following 6 d of brining. A substantial reduction of the brine concentration after 42 h of brining of cod at low brine-to-fish ratios (1.6:1) has been reported by Thorarinsdottir and others (2004). The changes in brine concentration are due to the brine concentration at low brine-to-fish ratios (1:1), when no additional salt is supplied to the brining system, being sensitive to the diffusion driven fluxes of salt and water between the brine and the herring muscle tissue. Thus, the major changes in brine concentration during salting of herring fillets in a brining system with low brine-to-fish ratios occur during the first d of brining, and relatively stable conditions with respect to brine concentration seem to be present at extended brining times (1 to 7 d). The changes in brine concentrations are similar at the two temperatures (Figure 2). At the lower temperature, the relatively stable brine concentrations from 1 to 7 d of brining indicate that the fluxes of salt and water between the brining medium and the muscle tissue probably have uniform direction and that the ratio between the amount of water and salt transferred are approximately similar to the ratio between water and salt in the brine. This is supported by the continuous weight gain of the herring fillets (Figure 1), the continuously decreased brine weight (g) with increasing brining time (data not shown), and the significant regression ($P < 0.001$, $R^2 = 0.96$) between fillet weight gain (%) and brine weight (g). In retrospect, a higher sampling resolution, especially for the first 24 h where the major change in the brine concentration occurs, could be preferred to obtain more exact information on the salt and water fluxes.

The substantial change in the initial brine concentration is important to consider when comparing and evaluating results from experiments dealing with brine salting of herring and when establishing brining protocols for industrial purposes. To avoid any reduction of brine concentrations due to the diffusion-driven processes taking place during brining, high brine-to-fish ratios (20:1) (Barat and others 2002, 2003) or continuous supply of salt to the brining system (Thorarinsdottir and others 2004) have been studied for brining of cod. With respect to herring, Deumier and others (1997) hypothesized that when using high brine-to-fish ratios (approximately 38:1), a constant brine density (concentration) would be achieved during brining. Additionally, constant marinade concentrations have been reported by Rodger and others (1984) when using large marinade to fish ratios during marinating of herring fillets. In most commercial herring brining processes, relatively low brine-to-fish ratios are applied without the addition of salt to the brining system. Thus, in the commercial production of salted herring, the fillets are cured at brine concentrations that are substantially lower than the initial brine concentration for a major part of the brining time. Thus, investigations on brining of herring at high brine-to-fish ratios may not be relevant to these commercial processes. Additionally, high brine-to-fish ratios cause handling of much brine, which is a disadvantage both for economical and practical reasons in the industry.

Fillet weight gain

Salting of fish is carried out using a number of different technologies, of which brining is commonly used for both herring and cod. Most available literature with respect to fillet weight gain, however, deals with brine salting (Barat and others 2002, 2003; Thorarinsdottir and others 2004) and pickling (Lauritzsen and others 2004) of cod. The observed weight changes during brining are probably not transferable between different species due to different crude muscle composition (for example, fat and water). With respect to cod and herring muscle, major differences are present in the contents of fat and water, and differences in weight gain during brining most likely exists due to the fat content affecting the diffusion of salt (Shenderyuk and Bykowsky 1990; Wang and others 2000) and the loss of water (Collignan and others 2001) in fish fillets. Our study shows a continuous weight gain (21% to 28%) of brined herring fillets (25.5% w/w, NaCl, 3.5 °C) throughout the investigated brining time (7 d), and after 2 d of brining the observed weight gain comprised 9% to 13% (Figure 1a). On the contrary, Bramsnæs (1946) reports a weight reduction (approximately 9%) following brine salting (25.4%, NaCl, 0 °C) of herring fillets for 7 d, with a maximum weight reduction (approximately 20%) after 2 d of brining. Regarding weight changes in herring fillets during brine salting, the results presented in Bramsnæs (1946) are frequently referred to in the published literature and seem generally accepted as a textbook example of brining of herring fillets. Thus, based on the results from our study and the fact that the herring-processing industry for the past decades has undergone changes with respect to processing protocols, automation and frequent use of frozen and thawed raw material indicate that salt/water diffusion during brining of herring can occur in several ways depending on the conditions of the salting process. A closer investigation of the weight changes of herring fillets, at processing conditions frequently applied by the industry at present, may contribute to avoid conflicts between the processors and the legislative authorities with respect to the balance between reported bulk weights of unprocessed and processed herring fillets.

Brine-to-fish ratio and brine concentration

The low brine-to-fish ratio (1:1) and the subsequent decrease of the initial brine concentration during brining (Figure 2) may have contributed to the continuous increase in weight gain observed in our study compared with the decrease reported by Bramsnæs (1946). A weight loss of brined herring fillets of 3% following brining for 24 h in saturated brine at high brine-to-fish ratios (38:1) have been reported by Deumier and others (1997). With respect to cod, high saturated brine-to-fish ratios (20:1) cause a substantial weight loss (10% to 15%) after approximately 7 d of brining (Barat and others 2002, 2003) and a high brine concentration (25%) compared with a low brine concentration (<20%) increase denaturation of proteins with a subsequent less sample swelling (weight gain) in brine salted cod (Barat and others 2002). Thus, brining at brine concentrations below 20% may promote solute uptake to fish fillets and thus limiting dehydration (weight loss) (Deng 1977; Collignan and others 2001) while in saturated brine (25%) fish muscle may lose water (weight) (Deng 1977). A plausible explanation to the differences in weight change observed in our study and the weight change presented in Bramsnæs (1946) could be that the experiments shown in the latter used stable brine concentration (that is, high brine-to-fish ratio) during the brining experiment. Brining systems with a low brine-to-fish ratio and thus systems with substantially reduced brine concentration (<25%) compared with the initial brine concentration are frequently used in the herring industry at present.

Prefrozen raw material

In former days, salting of herring were carried out on fresh material to avoid spoilage. Nowadays, frozen and thawed herring is increasingly used as raw material for further processed and salted products due to increasing amounts of herring being frozen at sea or shortly after landing (Stefansson and others 2000). Thus, frozen (–20 °C, 6 mo) and thawed raw material was used in our study. The initial frozen state of the raw material used may have contributed to counteract the considerable weight loss reported by Bramsnæs (1946). Freezing and thawing of fish muscle may lead to muscle fiber shrinkage, an increase in the extracellular space (Sigurgisladottir and others 2000), and alterations in the cell structures resulting in increased salt diffusivities (Wang and others 1998, 2000) and a subsequently increased weight gain during brine salting. Deng (1977) found water to migrate out of initially unfrozen mullet fillets during dipping in brine (20%), whereas water migrated into the fillets during dipping in brine after 2 mo of frozen storage. Cell wall damage occurring during freezing and thawing were assumed to cause the increased sample swelling in the initially frozen mullet fillets. Thus, the observed weight changes of unfrozen herring fillets during brining seems not transferable to initially frozen and thawed raw material.

Effect of initial brine concentration

A significantly decreased weight gain of the herring fillets was observed with increasing initial brine concentrations for both brining temperatures, and the major differences in weight gain (9% to 10%-units) were observed between brines of initial concentrations of 16.5% and 25.5% (Table 2). Similar results have been reported for fillets of brine-salted herring (Bramsnæs 1946; Aitken and Baines 1969), cod (Barat and others 2002; Thorarinsdottir and others 2004), and mullet (Deng 1977). Increased protein denaturation at a high brine concentration compared with at low brine concentrations causes less sample swelling (weight gain) (Barat and others 2002) and may promote loss of water from the fillets (Deng 1977). Thus, a different degree of muscle protein denaturation at different brine concentrations may have caused the differences in weight gain observed in the herring fillets in our study and, if high weight gain is aimed for the initial brine concentration, should be below 25%.

Effect of brining time

The continuous weight gain in our study (Figure 1a; 3.5 °C) indicates that equilibrium between the brining medium and the muscle tissue in the investigated time interval (7 d) not was reached. Thus, an increased weight gain seems possible by further extension of the brining time. Similar results were reported for herring fillets by Bramsnæs (1946).

Effect of skin-on or skin-off

At both brining temperatures, the presence of skin on the herring fillets caused a significantly reduced weight gain compared with fillets without skin. Fish skin is an effective barrier against salt penetration (Sakai and Suzuki 1985; Ravesi and Krzynowek 1991) and water uptake. Thus, for large fillets, the skin would constitute a major hindrance for salt uptake. For herring fillets with a thickness of approximately 10 to 15 mm, this may not be a major factor; however, the skin amounts to approximately 3% of the total fillet weight (personal comm. with the industry) and it can be assumed that the weight gain of the skin during brining is negligible and subsequently for a fillet with skin-on approximately 3% of the total fillet weight will be unsusceptible to gain weight compared with a fillet with skin-off. Due to this, less of a weight gain in skin-on fillets may be expected compared with skin-off fillets. In addition, skin-on fillets have less of a fillet surface-to-volume ratio than skin-off fillets, and thus less surface area available for the salt and water fluxes to proceed in. This may reduce the weight gain, although a closer examination is needed. A reduced weight gain in skin-on fillets is supported by our results, where the difference in weight gain between skin-on and skin-off fillets is in the range of 2% to 5%-units (Table 2).

Effect of brining temperature

Brining temperature (3.5 °C versus 17.5 °C) has a significant effect on the weight gain regardless of brine concentration, brining time, and the presence of skin or not. High temperature causes the weight gain to be substantially lower than at low temperature. A plausible explanation for the differences observed in the weight gain between the lower and higher brining temperature may be related to differences in herring muscle water-holding capacity (WHC) at the different temperatures. The WHC is affected by muscle protein denaturation (Thorarinsdottir and others 2002), and the lower WHC at the higher temperature may be due to increased thermal denaturation of proteins at the higher compared with the lower temperature (Sankar and Ramachandran 2005). Sankar and Ramachandran (2005) observed that proteins from Indian carp appeared labile to denaturation at relatively low temperatures (20 °C). Additionally, the thermal stability and transition temperatures of herring proteins are decreased during salting (Schubring 1999). Thus, thermal denaturation of muscle proteins may be a possible cause of the observed lower weight gain at the higher temperature investigated in our experiments. Increased proteolytic activity at the higher temperature, by endogenous enzymes such as cathepsins, and possible differences in the pH of the brine at the two temperatures may also contribute to differences in protein denaturation and subsequently the WHC.

Modeling of the weight gain (%)

In the modeling of the weight gain removal of 8 possible outliers and/or inclusion of none significant interaction terms, did not significantly increase the $R^2_{(adj)}$ or decrease ϵ of the model. Hence, all 180 measurements were used for modeling of the weight gain. Determination of possible square effects (nonlinearity) on the weight gain by the brining temperature could not be done with only two test temperatures and linear relationship was assumed; however, lack-of-fit tests indicated a possible curvature in the brining time and brine temperature interaction. Addition of at least 1 more temperature level (for example, 10.5 °C) would reveal more information and strengthen the model. There was also observed possible lack-of-fit in effect of brine concentration and interaction with the variable. This could be due to the fact that brine concentration changes during storage time and the model will not be valid for cases in which the brine-to-fillet ratio is significantly different from the ratio investigated; however, the model could be a useful tool for the industry to predict how different brine parameters would influence the weight gain and ultimately the yield.

Conclusions

The weight gain (product yield) of the herring fillets following a commercial processing protocol is of high magnitude and is significantly affected by the applied brining conditions. Thus, in production of salted herring fillets, different brine concentrations, brining temperatures, brining times, and skinning or not of the fillets may be used by the processors to target specific yields.

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