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Water uptake, drip losses and retention of free amino acids and minerals in cod (*Gadus morhua*) fillet immersed in NaCl or KCl

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Abstract

The aim of this work was to study differences in water uptake, drip losses and retention of low molecular components of cod fillets immersed in relatively weak NaCl or KCl solutions. Fillet pieces were excised from post rigor cod, immersed 12 h and stored 5 days at 4 °C, and further analysed for contents of chloride, minerals and free amino acids. A markedly increased water uptake was registered when concentration of immersion solution was raised from 342 to 513 mM. At chloride concentrations above 800 mg/100 g in cod fillet, both water uptake and drip losses reached a threshold in which increased swelling and reduction of drip loss were minimal. No significant difference was found between NaCl and KCl solutions with equal molar concentration with regard to water uptake, but fillet pieces immersed in 171 mM KCl had a significantly lower drip loss. Losses of free amino acids were up to 50%, but no difference was found among any of the immersion solutions.

Keywords: Potassium chloride; Cod; Muscle; Water uptake; Drip loss; Retention; Free amino acids

1. Introduction

Dietary sodium intake is higher than recommended in developed countries. Elevated levels in blood may lead to hypertension, which is a prominent risk factor for cardiovascular diseases (Chobanian et al., 2003; Whitworth, World Health Organization, & International Society of Hypertension Writing Group, 2003). Common dietary modifications that lower blood pressure are reduced salt intake and increased potassium intake (Appel et al., 2006). Although data on the effect of potassium have been inconsistent, some studies show that potassium has a direct beneficial effect on blood pressure (Brancati, Appel, Seidler, & Whelton, 1996; Naismith & Braschi, 2003). Hyperkalemia rarely occurs solely on the basis of increased potassium intake since kidneys have a high capacity to excrete K^+ (Oh & Uribarri, 2006). However, increased potassium intake may be harmful to individuals with impaired potassium excretion, e.g. diabetics and some with renal diseases (Appel et al., 2006). Nevertheless, US Dietary Guidelines recommend a reduction of sodium consumption and an increased potassium intake (United States. Dept. of Health and Human Services, United States. Dept. of Agriculture, & United States. Dietary Guidelines Advisory Committee, 2005).

In food processing the use of salt is frequent, and approximately 75% of sodium intake is derived from salt added by manufacturers (United States. Dept. of Health and Human Services et al., 2005). The growing awareness of diet related diseases has initiated an interest in producing foods with beneficial health effects. As the consumption of sodium generally is too high, the industry are looking for ways to reduce sodium content of foods, without having an adverse effect on sensory and technological properties. One of the approaches to reduce sodium content in processed foods is the use of salt substitutes, in particular KCl (Desmond, 2006). However, bitter and metallic tastes have been associated with KCl based salt substitutes (Gillette, 1985). Some KCl mixtures have given satisfactory or equivalent sensory properties when used in sausages and hams (Guar-

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dia, Guerrero, Gelabert, Gou, & Arnau, 2006), but perceived bitterness is reported when substitution is above 30–40% (Gelabert, Gou, Guerrero, & Arnau, 2003; Hand, Terrell, & Smith, 1982).

The effects of salt on water uptake and water holding capacity (WHC) of meat, and its interaction with muscles and myofibrils are complex. The water in muscles is primarily held within myofibrils by capillary-like forces, and gains and losses of water are primarily explained by volume changes of myofibrils (Offer & Knight, 1988a). Chloride binds more strongly to proteins than sodium, raising the electrostatic repulsion between myofilaments, thus causing expansion of the filament lattice (Hamm, 1972). Increasing salt concentrations causes myosin depolymerization which leads to an entropically driven swelling (Offer & Trinick, 1983). Further swelling occurs as salt weakens or breaks structural linkages between the filaments, such as m-lines, z-disks and cross-bridges in the actomyosin complex (Offer & Knight, 1988a).

Added salt improves texture, enhances taste, prolongs shelf-life and increases the WHC (Ruusunen & Puolanne, 2005). Brining of fish fillets, which can improve fillet palatability and WHC, has recently received more attention (Esaiassen et al., 2004, 2005). Consumer attitudes towards ready-meals are changing, and as a result, the demand for lightly salted fish fillets may grow. These products generally have a salt content of 2–3%. However, soluble components within the fillets, such as free amino acids (FAA), vitamins and proteins, may leach out during brining. Thus, brining has both nutritional and economic implications, because it may increase both yield and palatability, but nutritional components may be lost during the process, and it introduces sodium chloride to a low salt-containing food.

The effect of salt on swelling and drip loss of meat is well documented, but research has primarily been carried out on mammalian meat or isolated myofibrils, and limited results are available on fish muscle. Differences between NaCl and KCl in fish processing have mainly been studied using brines of 18%, in the production of salt-cured fish and salt-cured and dried fish (Martinez-Alvarez, Borderias, & Gomez-Guillen, 2005; Martinez-Alvarez & Gomez-Guillen, 2005; Rodrigues, Ho, Lopez-Caballero, Bandarra, & Nunes, 2005). Thus, information on how lower levels of NaCl and KCl influences different quality parameters of fish fillets are lacking. The aim of the current work was to study the water uptake of cod fillets during immersion in relatively weak KCl and NaCl solutions and the subsequent drip loss during storage. In addition, losses of FAA and minerals during the process were investigated.

2. Materials and methods

2.1. Raw materials

Exsanguinated Atlantic cod ($n = 20$, 4527 ± 432 g round weight) were acquired in February 2004 from a local fishmonger, and the fish were caught by Danish seine the day before purchase. The fish were gutted, wrapped in plastic, and stored in ice for 4 days. After resolution of rigor, the fish were manually filleted, skinned and samples were excised from the loins. From each fillet, two pieces (ca $60 \times 40 \times 30$ mm) were cut and labelled. Adjoining muscle tissues, which served as control, were sampled from left- and right-hand fillets of each individual, pooled and frozen at −30 °C in polyethylene (PE) zip-bags until required for analysis.

2.2. Experimental design

The fillet pieces ($n = 68$, 76 ± 10 g) were randomly distributed between 11 treatment groups with 6 or 7 samples in each group. The samples were immersed in 5 l pre-cooled salt solutions for 12 h at 4 °C. After immersion, samples were gently surface dried with a paper tissue, transferred to reticular plastic plates (mesh size 10 mm), and stored inside boxes for 5 days at 4 °C. The weight of the samples was recorded before immersion, after immersion, and every 24 h during storage. The swelling of muscle samples during immersion were measured as increased weight, and drip loss was quantified as decreased weight during storage. The samples were frozen at −30 °C in PE zip-bags until required for analysis. The immersion solutions were fresh water (FW) and 171, 257, 342, 513 and 856 mM NaCl or KCl. These concentrations correspond approximately to 10, 15, 20, 30 and 50 g NaCl/l or 13, 19, 26, 38 and 64 g KCl/l, respectively. Tap water was used for all immersion solutions.

The samples were thawed at room temperature inside the zip-bags and whole samples, including thaw drip, were chopped with a Braun MR 6000 food processor (Braun, Germany) for 30 s. All samples were analysed for % dry matter, pH, muscle juice osmolality and chloride contents. A selection of treatment groups, i.e. untreated control, FW, 342 and 513 mM NaCl and KCl, was further analysed for mineral content and FAA.

2.3. Chloride

Muscle tissue was homogenised with twice its weight of milliQ-water with an Ultra Turrax T25 basic (Ika Werke GmbH, Staufen, Germany) at 19,000 rpm for 30 s. The suspension was heated at 100 °C for 5 min, and then centrifuged at 10,000*g* for 15 min. Chloride content in the supernatant was determined with a Corning 925 chloride analyser (Corning, Sheffiled, UK). Results (mg/100 g) are the mean of four repeated measurements.

2.4. Osmolality

Muscle juice osmolality was measured with an Osmomat 030 osmometer (Gonotec GmbH, Berlin, Germany), using the principle of freezing point depression. Muscle samples

were centrifuged at 30,000*g* for 15 min, and the osmolality in the expressed muscle juice was measured on 50 µl samples. Results (mOsmol/kg) are the mean of four repeated measurements.

2.5. Water content and pH

Water content was determined by drying approximately 10 g of minced fillet at 105 °C to constant weight using a Termaks laboratory drying oven (Termaks, Bergen, Norway). Measurement of pH was carried out with a Metrohm 744 pH meter (Metrohm Ltd., Herisau, Switzerland) after blending minced muscle samples with an equal weight of 0.15 M KCl.

2.6. Amino acid analysis

Levels of FAA were determined with a LKB 4151 Alpha Plus amino acid analyzer (LKB Biochrom, Cambridge, UK) with a lithium citrate equilibrated column. FAA was extracted by homogenising approximately 2 g minced fillet with 5 ml 20% trichloro acetic acid (TCA), 2.5 ml milli-Q water, and 2 ml of 20 mM norleusine with an Ultra Turrax for 30 s at 19000 rpm. Norleusine served as internal standard. The suspension was centrifuged at 10,000*g* for 15 min at 4 °C, and an aliquot of the supernatant was diluted with buffer (lithium citrate) and 20 µl applied for each analysis.

2.7. Mineral analyses

The analyses of minerals were carried out by a local research facility. Coarsely chopped fillet samples were ashed at 540 °C and the ash was dissolved in a 1:2 mixture of concentrated nitric acid and hydrochloric acid (HCl) respectively, followed by another ashing at 540 °C for 1 h. The ash was dissolved in HCl-solution and filtered through a Schleicher & Schuell 596 filter paper. The filtrate was analyzed for levels of sodium, potassium, magnesium, calcium and phosphate using a Perkin Elmer ICP-OES OPTIMA-3300 DV (Perkin Elmer Inc., Boston, MA, USA).

2.8. Data analysis

All values are presented as mean ± standard deviation (SD). Statistical analysis of the data was performed with SPSS 12.0 (SPSS inc., Chicago, IL, USA) using univariate analysis of variance (ANOVA) and post-hoc comparison was carried out using the Tukey test. The level of significance was set to $P < 0.05$. A Pearson correlation was performed to study the relationship between water uptake and drip loss. True retention (TR) of amino acids was calculated as described by Murphy, Criner, and Gray (1975). When calculating TR, three extreme values (outliers) were removed from the calculation.

3. Results

3.1. Water uptake, drip loss and total weight change

The effect of salt concentration on water uptake during immersion and the subsequent loss during storage are presented in Fig. 1. Only minor differences were observed between NaCl and KCl. To put emphasis on concentration differences, the values are pooled data for NaCl and KCl solutions of matching molar concentration. Differences between KCl and NaCl are presented in Fig. 2 and display weight changes during the processes plotted against chloride concentration of the muscle samples.

Lowest weight gain during immersion was recorded for fillet pieces immersed in 171, 257 and 342 mM solutions, which increased by 7.6 ± 0.6%, 7.5 ± 0.9% and 8.7 ± 1.2%, respectively. These solutions resulted in a significantly lower swelling compared to samples immersed in FW, which gained 11.1 ± 0.8% weight. The fillet pieces immersed in 513 and 856 mM solutions resulted in 13.2 ± 2.1% and 13.8 ± 1.6% weight gains, respectively, and were significantly higher compared to the other treatment groups.

There was a clear relationship between drip loss and solution concentration, with decreased loss as concentration was raised. Fillet pieces immersed in FW lost 10.8 ± 0.5% of their weight during storage, while drip loss for samples immersed in 171, 257 and 342 mM accounted for a weight reduction of 5.4 ± 2.1%, 4.9 ± 1.2% and 4.6 ± 1.3%, respectively. Samples immersed in 513 and 856 mM solutions had significantly lower drip losses, only

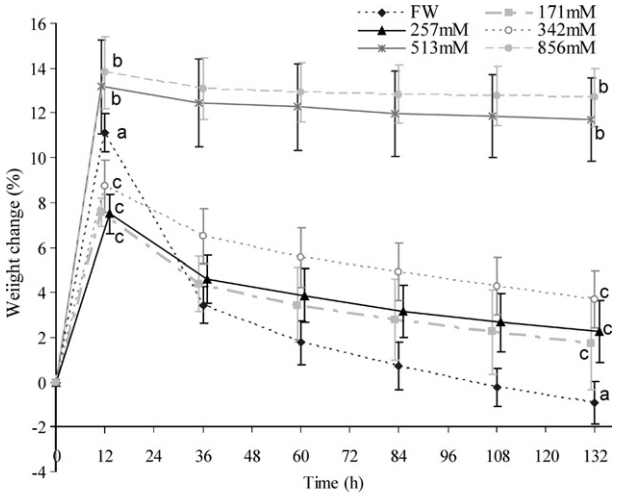

Fig. 1. Weight changes of cod fillet pieces immersed for 12 h in different solutions followed by storage at 4 °C from 12 to 132 h. The samples were immersed in fresh water (FW), and NaCl and KCl solutions of 171, 257, 342, 513 and 856 mM. Values and error bars are the pooled mean ± SD of NaCl and KCl solutions of equal concentration. Different letters at 12 h indicate significant differences on water uptake during immersion, and different letters at 132 h indicate significant differences on drip loss during storage.

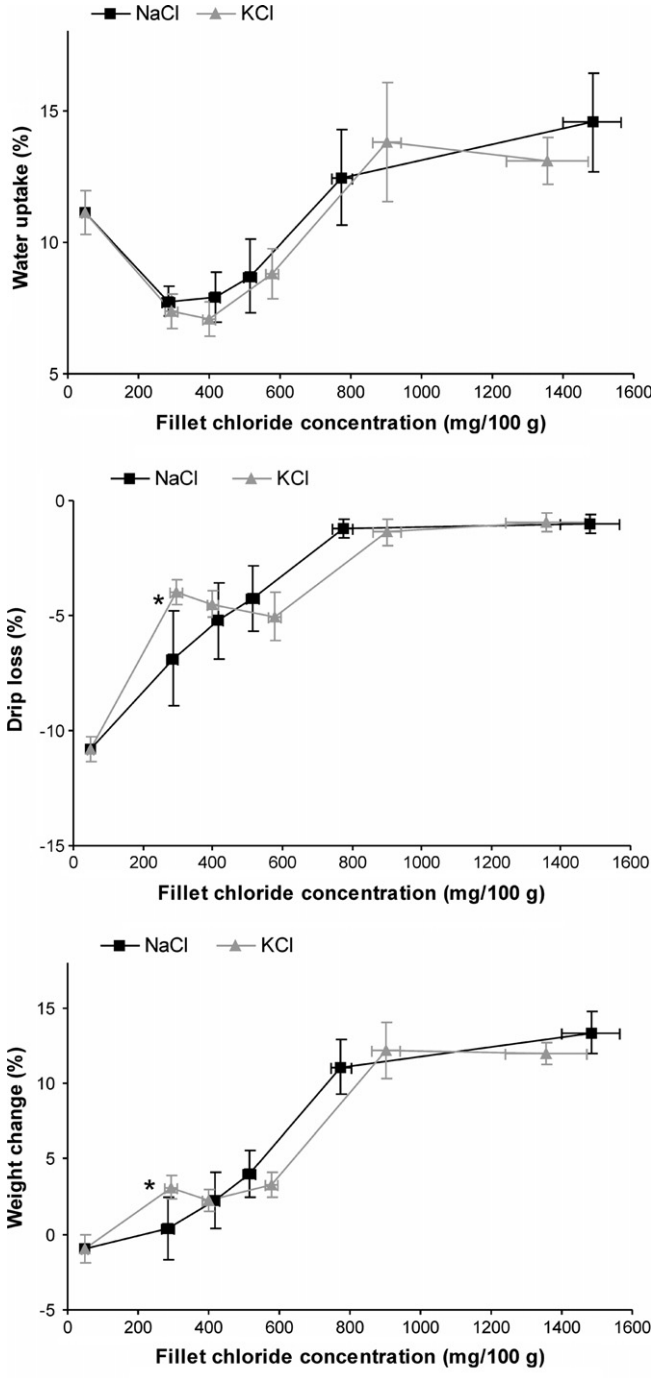

Fig. 2. Water uptake of cod fillet pieces immersed in NaCl or KCl solutions (0, 171, 217, 342, 513 and 856 mM), drip loss during storage at 4 °C for 5 days and the cumulated weight changes due to both processes. Values and error bars are mean ± SD of 6 or 7 samples. Asterisks indicate significant difference between KCl and NaCl of equal concentration.

decreasing 1.3 ± 0.5% and 1.0 ± 0.4%, respectively. Drip losses were considerably higher during the first 24 h, especially for samples immersed in FW. The following days during storage there was a steady decline in the weight of samples, except for pieces immersed in 513 and 856 mM solutions, which only had minor losses. When the result from immersion in FW was excluded, a good correlation ($r = 0.899$) was found between water uptake and drip loss.

The combined weight changes during immersion and storage resulted most notably in a large difference between samples immersed in 342 and 513 mM solutions. The effect of salt on both, increased water uptake and reduced drip loss, resulted in an 8% weight difference. Also, visual differences were observed between these concentrations. Samples immersed in concentrations above 513 mM became more translucent and had a sticky surface, while the other sample groups were similar in appearance to the untreated control samples. Visually, samples immersed in KCl solutions appeared slightly whiter compared to samples immersed in NaCl.

No significant difference was found between samples immersed in NaCl and KCl solutions of equal concentration with regard to water uptake during immersion. However, KCl resulted generally in a lower water uptake. Significant differences in drip losses between NaCl and KCl were observed at a salt concentration of 171 mM. The difference was carried forward when comparing the total weight change during both processes. The most striking observation was the increased water uptake and decreased drip losses, when chloride concentration of fillets was raised from ca 600 to 800 mg/100 g. At the same time, a threshold was reached above a chloride concentration of 800 mg/100 g. Little gains were achieved in terms of both increased water uptake, and reduced drip loss above this level.

3.2. FAA and minerals

Table 1 lists the chloride content, pH, % dry matter and muscle juice osmolality of the sample groups. The % dry matter was generally lower in immersed fillet pieces compared to control samples, while pH was similar for all groups. As anticipated, both chloride content

Table 1
Mean (±SD) chloride content (mg/100 g), muscle juice osmolality (mOsmol/kg), pH and dry matter (%) of cod muscle pieces before (control) and after immersion in various salt solutions followed by storage at 4 °C for 5 days

	n[a]	Chloride	Osmolality	pH	Dry matter
Control	20	116 ± 14	450 ± 26	6.9 ± 0.2	18.6 ± 0.7
FW	6	50 ± 8	268 ± 20	6.8 ± 0.1	17.0 ± 0.7
171 NaCl	6	285 ± 17	435 ± 11	6.8 ± 0.1	17.7 ± 1.0
171 KCl	6	294 ± 18	432 ± 10	7.0 ± 0.1	18.0 ± 0.4
257 NaCl	6	416 ± 15	501 ± 9	6.9 ± 0.2	17.5 ± 0.7
257 KCl	6	401 ± 17	510 ± 10	6.9 ± 0.1	18.3 ± 1.0
342 NaCl	7	515 ± 19	580 ± 14	7.0 ± 0.1	17.3 ± 0.7
342 KCl	6	578 ± 17	626 ± 13	6.8 ± 0.1	17.6 ± 0.3
513 NaCl	6	774 ± 29	752 ± 23	6.9 ± 0.2	16.4 ± 0.4
513 KCl	7	900 ± 40	788 ± 17	7.0 ± 0.2	17.0 ± 0.3
856 NaCl	6	1483 ± 84	1124 ± 15	6.8 ± 0.2	17.8 ± 0.5
856 KCl	6	1356 ± 114	1113 ± 22	6.9 ± 0.1	18.5 ± 0.8

[a] Sample size of treatment group.

and osmolality declined in samples immersed in FW and increased when immersed in more concentrated solutions.

The sample groups with the largest differences with regard to swelling and drip loss were analysed for minerals and FAA. The mineral content of the samples is presented in Table 2. Concentrations are given in μmol/g muscle tissue for easier evaluation of differences in diffusion between sodium and potassium. After immersion in 342 mM solutions, the concentration of Na^+ and K^+ increased by 92 and 99 μmol/g, respectively. In the 513 mM solutions, the increments were 177 and 172 for Na^+ and K^+, respectively. Levels of calcium remained unchanged after immersion, and magnesium content decreased marginally. The phosphorus content in immersed samples decreased substantially compared to the control.

TR was calculated for taurine, glycine, alanine and anserine and is presented in Fig. 3. Concentrations in control samples were 431 ± 138, 144 ± 69, 160 ± 67 and 891 ± 210 mg/100 g wet weight, respectively. No significant difference was found in TR between any of the analysed sample groups. The calculated loss during immersion and storage was 28–49 for taurine, 28–42 for glycine, 20–38 for alanine and 34–51% for anserine.

Table 2
Mean (±SD) mineral content (μmol/g) in cod muscle before (control) and after immersion in various salt solutions followed by storage at 4 °C for 5 days

	n^a	K	Na	P	Ca	Mg
Control	20	90 ± 5	32 ± 6	60 ± 4	2 ± 0	12 ± 2
FW	6	55 ± 4	21 ± 4	44 ± 3	2 ± 0	10 ± 2
342 mM NaCl	7	42 ± 7	124 ± 24	36 ± 4	2 ± 0	8 ± 0
342 mM KCl	6	189 ± 14	$16 + 4$	41 ± 2	2 ± 0	8 ± 2
513 mM NaCl	6	58 ± 3	209 ± 18	42 ± 3	2 ± 0	8 ± 0
513 mM KCl	7	262 ± 11	14 ± 2	38 ± 2	2 ± 0	8 ± 0

[a] Sample size of treatment group.

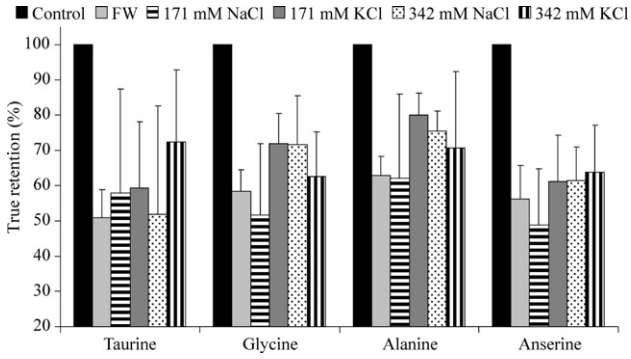

Fig. 3. True retention of taurine, glycine, alanine and anserine in cod fillets immersed for 12 h in different salt solutions followed by storage at 4 °C for 5 days. Column height and error bars are means ± SD of 6 or 7 samples.

4. Discussion

4.1. Effect of salt on water uptake and drip loss

A structural approach is often applied when describing the mechanisms of water uptake and the retention of water in meat. Most of the water within muscles is located in the myofibrils in the spaces between thin and thick filaments, and the swelling of myofibrils and the WHC is primarily determined by alterations in this interfilament spacing (Offer & Cousins, 1992; Offer & Trinick, 1983). During immersion, as salt diffuses into muscle fibres, swelling occurs due to increased electrostatic repulsion, depolymerization of thick filaments and weakening of structural linkages. At the same time, the osmolality of the solution will act to pull water out of the muscle if the osmolality is above the physiological level, and vice versa in a hyposmotic solution. Thus, salt concentration of both the solution and the concentration within the muscle are important factors on the events that occur during immersion.

Lowest swelling was recorded in solutions with concentrations of 171, 217, 342 mM, which is in agreement with the literature that water uptake is least in solutions with physiological ionic strength of ca 0.2 M (Offer & Knight, 1988a). At these concentrations, there were low osmotic differences between the immersion solutions and the fillet samples, and thus the increased chloride concentration was the major cause of swelling. A decrease in chloride concentration from 116 to 50 mg/100 g fillet was recorded for samples immersed in FW, however, immersion in water lead to water uptake due to the hyposmotic environment. In the 513 and 856 mM solutions a significantly higher water uptake was recorded. Although these solutions are hyperosmotic, the increased salt concentration within the fillets must have generated a higher swelling pressure. Maximum swelling is reported to occur at ionic strengths of ca 1.0 M NaCl, and at concentrations of ca 5.5 M there is a net loss of weight during immersion (Knight & Parsons, 1988).

The water uptake reached a threshold at chloride concentrations above 800 mg/100 g. The results on fish muscle generally agree with a study on rabbit fibres where threshold effects were observed between 0.6–1.0 M (Wilding, Hedges, & Lillford, 1986). Water uptake of samples immersed in 513 mM was significantly higher than samples immersed in 342 mM. Other studies on myofibrils and meat homogenates also describe the sudden increase in swelling as concentration is raised above a certain level (Offer & Trinick, 1983; Paterson, Parrish, & Stromer, 1988; Xiong, Lou, Harmon, Wang, & Moody, 2000). The sudden rise in swelling is primarily attributed to the break-up of structural elements which oppose swelling (Offer & Trinick, 1983; Voyle, Jolley, & Offer, 1984; Xiong et al., 2000). The results indicate that the increased swelling and the threshold level occur at a lower concentration than in the cited studies. This may be explained by differences between species, muscle type, ultimate pH of muscles, and pH of

solutions. Differences in swelling between fast-twitch and slow-twitch fibres have been documented (Parsons & Knight, 1990), and ultimate pH of cod muscles is higher than mammalian muscles (Foegeding, Lanier, & Hultin, 1996). Connective tissues may also impose a constraint on fibre swelling, and gross muscle structure of fish is unlike mammalian muscles. Thus, fish muscle may be more disposed to swelling during immersion.

Drip losses decreased as the salt concentration was raised, and reached a threshold for samples with chloride concentration above 800 mg/100 g. When excluding results from samples immersed in FW, the water uptake and drip loss were well correlated. Good correlations between WHC and swelling have also been reported by Hamm (1957). This indicates that the same mechanisms that give rise to fibre swelling are also responsible for reduced drip loss. Higher salt concentrations increased the interfilament spacing in the myofibrils. As most of the water within muscles is held by the myofibrillar structure, samples with higher salt content were more able to retain the water. Additionally, muscle samples with weakened or broken structural elements will exert less, or no force, to compress the filament lattice after the swelling pressure is released (Offer & Knight, 1988b). Samples immersed in fresh water displayed a poor WHC, and the rapid release of water during the first 24 h of storage was much higher compared to the other immersion solutions. This may be caused by the dilution of internal salt concentration, which would decrease electrostatic repulsion of filaments. The sticky surface of samples immersed in 513 and 856 mM solutions may be due to extraction of myofibrillar proteins, primarily myosin (Offer & Knight, 1988a).

The overall weight change during both processes showed that there was a large difference between samples immersed in 342 mM compared to samples immersed in 513 mM solutions. The synergies of both increased water uptake, and reduced drip loss, were clearly seen between these two concentrations. Raising fillet chloride concentration from 600 to 800 mg/100 g tissue increased yield by 8%. Thus, targeting a certain chloride level or salt level within fish fillets can be vital for achieving reduced drip losses and better yield. But, it could also be an important level to target for reducing salt levels within the fish fillet, as minimal improvement of drip loss and yield was achieved by adding more salt. As salt concentration of lightly salted fish products generally lies between 2% and 3%, there is a potential of reducing the salt content based on the technological qualities of yield and drip losses, because a threshold was reached above NaCl concentration of ca 1.2% (chloride concentration 800 mg/g muscle). Thus, a product with potential health benefits may be achieved by lowering the salt content. Yet, other aspects of a lower salt concentration must be taken into account when deciding the salt level. A homogenous NaCl concentration of 2% is regarded as most desirable in rehydrated salt-cured cod (Bjørkevoll, Olsen, & Olsen, 2004). Hence, a prime challenge would be to get consumers accustomed to lower salt levels, as higher salt levels generally are preferred from a sensory point of view.

4.2. NaCl versus KCl

No significant difference was found between NaCl and KCl with regard to swelling, but fillet pieces immersed in NaCl tended to swell a little more. This agrees with similar research on meat, and the effect of cations is in accordance to the Hofmeister series (Hamm, 1972). When comparing drip losses, deviations between KCl and NaCl were apparent at 171 mM, but not significant at the other concentrations. The authors have no obvious explanation for the significant difference found at 171 mM. However, a shift from primarily binding anions at higher concentrations to cation binding at lower concentrations (Sarkar, 1950), may have influenced the results.

Matching concentrations of NaCl and KCl generally resulted in similar water uptake during immersion and drip loss during storage, and thus KCl can replace NaCl on the basis of these quality parameters. As such a food will contain less sodium, it has the potential of being marketed as a functional food. The products would also follow governmental recommendations of lowering sodium consumption and increasing potassium intake, and claims of potential health benefits may be forwarded. Again, challenges are met on a sensory level, as higher concentrations of KCl are associated with an off taste (Gillette, 1985). However, as in some processed meat products, mixtures of KCl, NaCl and organic acids, could make the products sensory acceptable (Guardia et al., 2006). The favourable observation that fillets immersed in KCl appear whiter has also been reported by Rodrigues et al. (2005).

Another important issue when replacing NaCl with KCl is the possible influence on the microbiological stability of the food products. In a study of cod salted in brines of 18% of different chemical composition, the microbiological quality was not influenced by replacing KCl with NaCl (Rodrigues et al., 2005). Other studies on growth of *Listeria monocytogenes* in broth (Boziaris, Skandamis, Anastasiadi, & Nychas, 2007) and *Clostridium botulinum* in brined and smoked whitefish (Pelroy, Scherer, Peterson, Paranjpye, & Eklund, 1985), found that substitution of NaCl with KCl did not decrease the microbiological safety. Nevertheless, further investigations are required at salt levels used in current study.

4.3. Differences in pH, water content and low molecular weight components

The pH value of muscles is known to influence swelling and drip losses (Fennema, 1990; Hamm, 1986), but in the current study no differences were measured between the sample groups. All immersion solutions were neutral, and would not have influenced pH of muscles to a large degree. Also, post-rigor fish were used in this experiment, and ulti-

mate pH would have been reached before immersion. Thus, the pH of samples did not seem to be a key factor in explaining differences in water uptake and drip loss.

Physiologically, the content of K^+ is higher than Na^+ in raw samples and this explains why the percentage increase in sodium is higher than potassium. However, the concentration increase in μmol/g from for the control samples was similar for both minerals. The results also reveal that equilibrium between samples and solution was not attained within 12 h of immersion. Most of the Mg and Ca was retained during the process, but levels were close to the detection limit of the instrument, and thus these results have a degree of uncertainty. Phosphorus concentration decreased substantially after immersion and storage. Most intracellular phosphorus exists as organic compounds (Kochel, 2006), and many compounds are in free form which make them susceptible to leaching during immersion.

The calculation of TR showed that 30–50% of the FAA and anserine was lost during the process, but no significant difference in retention was found between the different solutions. It was expected that samples which had lower drip losses, would also display a higher retention of components. However, most of the components were probably lost during immersion due to the lengthy brining period, rather than as drip during storage. Other brining techniques such as vacuum tumbling or injection salting, will reduce the time of brining, and have thus a higher potential to retain water soluble components within the muscles. Mean loss of taurine after vacuum tumbling for 15 min was 17% (Larsen, Stormo, Dragnes, & Elvevoll, 2006), which was substantially less than in the current study. Thus, a different technique with a shorter brining period is more suited for retaining such components.

5. Conclusion

The concentration of chloride within cod fillets is a key factor for water uptake during immersion, and for reducing drip loss during storage. A chloride concentration of 800 mg/100 g fillet resulted in the best combination of increased yield, lower drip loss and lower salt levels. KCl was a suitable salt substitute with regard to water uptake, drip loss and retention of FAA. Thus, a reduction in salt levels from the industry standard of ca 2–3% to ca 1.2%, and replacing some of the sodium with potassium, do not significantly influence the technological parameters of yield and drip loss. Additionally, this may have health benefits as it reduces the sodium content of brined fillets, and it may be marketed as a functional food. An improvement of the procedure, both regarding the type of brining solution and brining method, is a prerequisite for minimizing drip losses when producing lightly salted fish.

However, the sensory and microbiological properties must be further investigated to fully evaluate the use of KCl industrially.

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