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SODIUM IN MEAT PRODUCTS

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Introduction

Sodium intake exceeds the nutritional recommendations in several industrialized countries. Excessive intake of sodium has been firmly linked to hypertension (Dahl, 1972; Fries, 1976; Law, Frost & Wald, 1991a,b,c). High blood pressure may in turn increase the risk of stroke and premature death from cardiovascular diseases. Tuomilehto *et al.* (2001) found that high sodium intake correlated with mortality and risk of coronary heart disease, independent of other cardiovascular risk factors, including blood pressure. These results provide direct evidence of the harmful effects of high sodium chloride (NaCl) intake in the adult population. Sofos & Raharjo (1994) have also presented a review on the health aspects of dietary sodium chloride and other salts.

The main source of sodium in diet is sodium chloride. On a population basis, it has been established that the consumption of more than 6 g NaCl/day/person is associated with an age-increase in blood pressure. Therefore, it has been recommended that the total amount of dietary salt will be maintained at about 5-6 g/day (Aho *et al*., 1980, WHO, 1990). Such recommendations are addressed to the general public. It is, however, recognized that genetically salt susceptible individuals and hypertensives will particularly benefit from low-sodium diets, the salt content of which should range between 1 and 3g/day.

Sodium chloride is one of the most frequently used ingredients in meat processing. Sodium chloride affects flavour, texture and shelf life of meat products. Besides the perceived saltiness, the NaCl brings out the characteristics taste of the meat product enhancing the flavour (Gillette, 1985). Sodium chloride also has an important role in the texture of meat products. It improves the water and fat binding properties of meat products resulting in the formation of a desirable gel texture upon cooking (Terrell, 1983). The preservative effect of NaCl is primarily due to its ability to lower water activity (Marsh, 1983; Sofos, 1984)

Most sodium chloride in the diet comes from processed foods. The NaCl contents of processed meat products should be reduced. To control the dietary intake of sodium from these products is difficult because of the different levels of sodium found in the same type of product. For example, in 30 liver sausages from different manufacturers the sodium content varied from 0.5 to 1.0 g/100 g (Greubel, Kluthe & Zuercher, 1997). Because of the large variation in NaCl content of the same type meat products, one easy way for reducing the average sodium intake is to reduce the NaCl content particularly of those products in which NaCl content is higher than the average.

Potential sodium chloride reduction depends on aspects connected with the type of the product, its composition, the type of processing required and the preparation conditions. These factors determine the type of product that can be modified and the technological limitations of salt reduction.

This paper reviews possibilities to reduce the sodium (NaCl) content in meat products. Mainly sensory and technological aspects will be covered.

Sodium intake and recommendations

Total dietary sodium intake in Europe has been estimated to range between 3.5 and 5 g/day (9 to 12 g NaCl) (Intersalt Cooperative Research Group, 1988). Finnish men consume on average 9.9 and women 6.8 g NaCl/d, respectively. The sodium intake from meat dishes is 22% for women and 24% for men (the National FINDIET 2002 Study, 2003).

The UK Department of Health has estimated the UK intake of sodium chloride at 8.2 g/person/day. Others (e.g. Godlee, 1996) refer to 9 g/person/day, calculated from data for urinary excretion of sodium. In populations with high sodium consumption there is usually no difference in sodium intake between normotensive and hypertensive individuals (Liu *et al.*, 1979; Morgan *et al.*, 1978; Schlierf *et al.*, 1980; Swaye, Gifford & Berrettoni, 1972; Tuomilehto, Karppanen, Tanskanen, Tikkanen & Vuori, 1980).

Sources of sodium from meat products

Meat itself contains sodium but the amount is less than 100 mg Na per 100 g. The main source of sodium in meat products is sodium chloride which is added during processing. Sodium chloride contains 39.3% sodium. Sodium is a part of also many other additives added when preparing meat products, e.g. in monosodium glutamate which is a flavour enhancer, sodium phosphates, sodium citrate and sometimes also sodium lactate. The amount of sodium from other additives is, however, much lower compared to the amount of sodium from sodium chloride. Practical experience has shown that when reducing NaCl content, meat industry may start to use sodium lactate to improve the shelf life and perceived saltiness. The amount usually added is 1.2% sodium lactate containing 0.24% Na. This amount of sodium equals to 0.6% NaCl.

The sodium chloride content of Finnish cooked sausages ranges from 1.6 to 2.2%, and that of cooked hams from 1.9 to 2.7%. This is equivalent to 0.6-0.9 g Na/100 g in cooked sausages and to 0.8 – 1.2 g Na/100 g in cooked hams. In other countries, meat products contain more NaCl. The sodium chloride content of meat products has been reduced, e.g. in Finland NaCl content of cooked sausages was in 1973 on average 2.4%, and in 1995 1.7% (Karanko & Puolanne, 1996). In the USA, the sodium content of 100 studied food products was shown to have reduced by 10-15% between 1985 and 1997. (Center for Science and Public Health).

Sodium reduction in meat products

Based on the scientific information, meat industry and consumers have become more aware of the relationship between sodium and hypertension and, therefore, in many countries, the demand for a variety of low salt meat products has increased. Food processors are developing numerous low-salt products to meet the demands of consumers. Developing low-salt meat products is, however, not straightforward. Sodium chloride plays such an important role in meat products. A particular problem with low-salt meat products is that not only the perceived saltiness, but also the intensity of the characteristic flavour decreases, when salt is reduced.

Meat product manufacturers have marketed low-salt alternatives, or have progressively reduced salt content over the years, where technological and microbiological considerations have made this possible. In most cases, when low-salt meat products are developed, the benchmark for the low-salt meat product is the normal-salt product. Consequently, the same quality characteristics must apply to low-salt meat products as to the correspondent normal-salt meat products. This causes problems because the properties of low-salt products are almost always different. The most important difference is the weaker characteristic flavour.

Before a satisfactory seasoning substitute to sodium chloride is found, the best way to reduce the intake of sodium would be for the food industry to gradually reduce the sodium chloride content in products. This demands that the formulations and the manufacture procedures of low-salt meat products must also be modified. Olson (1982) reported that a 25% reduction in NaCl is probably the most that can be achieved without detrimentally affecting product characteristics (flavour, texture, shelf-life). Of course it is easier to reduce the higher salt contents than the lower salt contents without any detrimental effect. According to Ruusunen, Särkkä-Tirkkonen and Puolanne (1999), the NaCl content of cooked bologna sausages made with added phosphates may be reduced to 1.4% added NaCl without loss of flavour pleasantness. In cooked hams, based on saltiness evaluations it is possible to reduce the salt content of cooked ham to 1.7% NaCl (Ruusunen, Särkkä-Tirkkonen & Puolanne, 2001). The level of NaCl in the diet of a population determines the acceptable level to which NaCl content in meat products can be reduced. Consequently, same NaCl levels do not necessarily apply to every population.

There are several approaches for reducing the sodium content in processed meats: 1) lowering the level of sodium chloride (NaCl) added; 2) replacing all or part of the NaCl with other chloride salts (KCl, $CaCl_2$, and $MgCl_2$); 3) replacing part of the NaCl with non-chloride salts, such as phosphates, or with new processing techniques or process modifications; and 4) combinations of any of the above approaches (Terrell 1983; Sofos 1984, 1986, 1989).

Terrell and Olson (1981), Hand, Terrell and Smith (1982a,b) as well as Puolanne, Saarela and Ruusunen (1988) have studied meat products where NaCl has been substituted with other salts (KCl, $MgCl_2$). Replacement of sodium chloride by potassium chloride or magnesium chloride can lead to bitterness (Terrell and Olson, 1981), though some success has been achieved with a blend of sodium and potassium chloride.

The use of mineral salt mixtures is, however, a good way to reduce the sodium content in meat products. The same perceived saltiness can be achieved with salt mixtures at a lower sodium content (Puolanne *et al.*, 1988; Wettasinghe and Shahidi, 1997). In Finland, there are cooked sausages made with salt mixtures on the market where the salt content based on sodium chloride content is 1.2% or lower. These sausages are allowed to be labelled as low-sodium sausages.

There is, however, a disadvantage when using salt mixtures: the consumers will not get used to weaker perceived saltiness of low-salt meat products when salt mixtures are used, because of characteristic flavour still remains strong.

Perceived saltiness and flavour intensity

The perceived saltiness of NaCl in meat products is mainly due to the Na^+ cation with Cl^- anion modifying the perception (Miller & Barthoshuk 1991). Sodium chloride is also a flavour enhancer increasing the characteristic flavour of meat products (Gillette, 1985; Matulis, McKeith & Brewer, 1994; Ruusunen, Simolin & Puolanne, 2001; Ruusunen, Särkkä-Tirkkonen & Puolanne, 1999). Both the perceived saltiness and the flavour intensity depend on salt content in meat products (Matulis, McKeith, Sutherland & Brewer, 1995, Ruusunen *et al.*, 1999, Crehan, Troy & Buckley, 2000). The authors of this review stress that a certain amount of salt has to be added to food products before it can even be discerned. A small amount of sodium chloride might taste sweet (Beauchamp, Bertino & Moran, 1982) which is not appropriate in meat products. The sweet taste is probably due to stimulation of the receptors that mediate sweet perception rather than to stimulation of receptors mediating sodium chloride perception (Barthoshuk, Murphy & Cleveland, 1978).

Sensitivity may be defined as the ability to detect or recognize gustatory stimuli. Detection and recognition thresholds are extensively used measures of this taste attribute. All thresholds, however, are forms of discrimination relative to a background medium. Thus, the conditions under which a threshold is determined can greatly influence the resulting value. In addition, the sensitivity of individuals varies due to the influence of numerous endogenous and exogenous variables. With respect to the salty taste, one of the most important of these factors is the salivary sodium concentration. The taste receptors are bathed in saliva, and adapt to the sodium level of this fluid. To elicit a salty sensation, this level must be exceeded by a given amount in an individual. The perception of many flavour characteristics depends greatly on the nature of the food matrix. The food matrix plays an important role in controlling flavour release at each step of food product preparation and consumption. (Mattes, 1984, 1997).

Sensitivity to sodium chloride has been the most extensively studied parameter with respect to hypertension. Fallis, Lasagna and Tetreault (1962) were the first group to assess the NaCl detection and recognition thresholds of normotensives and hypertensives (diastolic blood pressure (DBP) >100 mmHg). While no differences in NaCl detection thresholds were observed, the hypertensives displayed elevated recognition thresholds.

Although many people add sodium chloride to enhance the taste of foods, their preference may change because of the pleasantness of NaCl is influenced by customary dietary levels. When someone follows a low-salt diet from a few weeks to a few months, they get used to the mild taste of low-salt products (Bertino, Beauchamp & Engelman, K., 1982; Blais *et al.*, 1986). There are various existing hypothesis about why diets with different salt contents changes one's preference to salt, for instance by changing the sodium content in saliva. An individual's partiality to salt can therefore be changed, but it is not necessarily easy, as a lower salt content in food does not initially meet one's expectations, customs and preferences. People get used to the taste of salty products faster than they do that of low-salt products (Bertino, Beauchamp & Engelman, 1986).

The manner in which sodium chloride is added effects how strong is the perceived saltiness. Sodium chloride has a more concentrated taste if it is sprinkled on a cooked meat instead of on raw meat before cooking. If sodium chloride is sprinkled on a cooked steak, only half as much NaCl to achieve the same level of perceived saltiness will be needed (Ruusunen, 1985).

The effect of fat and lean meat content on perceived saltiness

Fat and sodium chloride together contribute to many of the sensory properties that are characteristic of cooked sausage. When NaCl level rises it is more noticeable in fatty products than in lean ones (Hammer, 1981; Matulis *et al.*, 1994) However, Ruusunen *et al.* (2001) have shown that fat content of cooked sausages affects the perceived saltiness in different ways depending on the composition of the formulation. By replacing lean pork with pork fat, thus increasing the fat content and simultaneously reducing the meat protein content, perceived saltiness of sausages increases, but by replacing water with fat on an equal weight basis, the perceived saltiness of the sausage does not change. Therefore, the increase of meat protein content was supposed to reduce perceived saltiness. This result was confirmed with meat patties. More salt was needed in meat patties with high lean meat content to achieve the same perceived saltiness than in products with lower meat content (Ruusunen *et al.*, 2003, 2004). In meat patties, fat content had a smaller effect on perceived saltiness than lean meat content and their effects on perceived saltiness were opposite. It is also well-known that perceived saltiness is high in products with high amounts of loose water.

The theory of water-binding

Hamm (1972) and Offer and Knight (1988) have published comprehensive reviews about the technological effects of salts in meat. The above mentioned reviews concentrate on sodium chloride and phosphates, but other chloride salts and salts of weak acids are discussed, mainly to further elucidate the theories behind the effects of sodium chloride and phosphates. The reviews deal mostly with uncooked meat, and not so much with cooked meat or cooked meat products. Tornberg (2004) has recently presented a review on heat-treated meat products. The present chapter deals with effects of the lowering of the sodium content on the technological properties of meat products. Whiting (1988) also presented a review on solute-protein interactions in meat batter.

The effect of sodium chloride on meat proteins is most probable caused by the fact that chloride ion is more strongly bound to the proteins than sodium ion. This causes an increase in negative charges of proteins. Hamm (1972) concludes that this causes repulsion between the myofibrillar proteins (myofilaments), which results in a swelling of myofibrils or even a partial solubilisation of filaments, the latter is due to the repulsions of individual molecules. The cross-bridges between the filaments prohibit the unlimited swelling of the myofbrils. Polar groups of the side chains of the amino acids (ca. 76-80%) of the proteins bind water molecules on their surfaces by van der Waals' forces. The water molecules, being polar, then orient themselves so that in a case of a negative ionic group there will be the positive part towards ionic group and the negative part pointing at the solution, and vice versa with positive groups. Additional water molecule layers will be formed on this so-called monomolecular layer with similar orientations. Thus, all the water molecules are more or less influenced by the pulling forces caused by the polar groups of the proteins. On the contrary, non-polar side chains of the amino acids push the polar water molecules causing arched-like structure around the non-polar group. The combined effect is that water molecules are pulled (polar groups) and pushed (non-polar groups) between the filaments creating a tension that forces the water molecules in an ice-like form in the protein network of filaments and transverse elements, like cross-bridges and Z-line. The factors inhibiting the unlimited swelling are the actomyosin cross-bridges between the filaments and Z-lines. The amount of the water bound is determined by the net charge of the proteins causing repulsion that increase the binding, and by the number and strength of cross-bridges that limit the binding.

This sounds reasonable, because the distances between the filaments surfaces are about 20 nm (actin to myosin and actin to actin) or 30 nm (myosin to myosin). This means a thickness of a layer of about 60 to 90 water molecules. The hypothesis explains the effects of salt content and pH, as well as the role of cross-bridges and consequently how water is retained in meat. However, the hypothesis does not take the effect of counter-ions, eg. the sodium ions, into account. Offer and Knight (1988) also claim that the distances between the filaments are too long to establish a repulsive force that would be strong enough to generate the water-binding.

Offer and Knight (1988) suggest an alternative hypothesis also based on the selective binding of chloride ions to the myofibrillar proteins. According to them this does not cause a marked repulsion between the filaments but between the molecules of myosin filaments breaking down the shaft of the filament. This will cause a loosening of myofibrillar lattice. If phosphate is not used, the S1 units of heavy meromyosin are still attached to actin filaments. Offer and Knight postulate that the swelling occurs by an entropic mechanism driven by the free, light meromyosin parts bound to actin filaments.

Offer and Knight (1988) also present another aspect that is close to the hypothesis of Hamm (1972). They start with the same selective binding of chloride ions as Hamm, but because the structural proteins are solid in meat and cannot move, electrical forces pull the counter-ions (sodium ions) very close to the filament surfaces thus creating an uneven distribution of ions in the water phase. This establishes an osmosis-like force within the filament lattice which in turn pulls water molecules into the system. This would cause an unlimited swelling, but the cross-bridges cause an opposite force that Offer and Knight call 'elastic pressure'. In any case, osmotic pressure created by the uneven distribution of ions and the elastic pressure are equal at any moment. This explains the effects of salt content, cross-bridges, pH and the denaturation effects and resulting shortening of myosin S1–S2 complex as well.

The effects of NaCl on different proteins in meat are very complex, and the complexity increases if different concentration combinations of added NaCl, KCl and phosphates are acting simultaneously (see reviews of Hamm 1972 and Offer and Knight 1988). Concisely, the solubility of myosin is increased as the NaCl concentration raises from 0.04 to 0.5 M. After the initial aggregation and formation of filaments the structures start to dissociate at salt contents higher than 0.25 M. The swelling of myofibrils starts at 0.5 M without added phosphates and at 0.4 M with added phosphates, where an extensive extraction of myosin also starts to take place.

The swelling depends on pH (Hamm, review 1972; Offer & Knight, review 1988). Without salt there is a maximum at pH 3.0, a minimum (the average isoelectric point of meat proteins) at pH 5.0 and from there a constant increase within the physiological pH range. Due to the selective binding of ions, salts move the isoelectric point. By 2% NaCl the isoelectric point and swelling minimum are at pH 4.0. (Hamm, review 1972). Wilding, Hedges & Lillford (1986) found that hypertonic salt solutions (KCl and KI) induce fibre shrinkage at pHs below the isoelectric point of myofibrillar proteins (pH 5.0), which actually means that the isoelectric point has moved to lower values. With NaCl there is a maximum in swelling as well as in heated gel strength at 6.0 (Hamm, review 1972; Ishioroshi, Samejima & Yasui, 1979) or at pH 6.2 (Puolanne, Ruusunen and Vainionpää, 2001). This seems to be due to the increased sodium ion binding to the negatively charged myofilaments, and the simultaneous weakening of the binding of chloride ions.

Minced meat and restructured products

Minced meat products and restructured meat products are made without or with added phosphates. There is a wide variety of meat products from all meat products made of lower quality of meat, fat, carbohydrates and other polymers, added proteins and added water. There is no particular technological minimum for sodium chloride content; meat patties can be made even without added sodium chloride (Booren, Jones, Mandigo & Olsen, 1981) by pressuring frozen meat to form the patty, or freezing the product after the formulation (Demos, Forrest, Grant, Judge & Chen, 1994). In these products, sodium chloride content, if used, is mainly determined by sensory aspects. Transglutaminase has also been used to increase the gel formation in patties thus increasing the yield (Nielsen, Petersen & Møller, 1995; Tseng, Liu & Chen, 2000).

Schults, Russel and Wierbicki (1972), Schults and Wierbicki (1973) and Kenney and Hunt (1990) found, using centrifuge methods with added phosphate, a steep initial reduction of cooking loss when the salt content increased from 0 to 1%, and the best bind was at 4% NaCl. On the contrary, in sausages a marked difference between phosphate and non-phosphate systems has been found between 1.0–1.5% NaCl (e.g. Puolanne & Ruusunen, 1980; Barbut, Maurer & Lindsay, 1988). Barbut & Mittal (1989) also found that there are differences between the proteins of beef, pork and poultry meat in gelation patterns and responses to salt.

Sodium chloride is, however, important decreasing the cooking loss and improving the texture. Sodium chloride increases the cohesiveness of the batter thus improving the moisture and fat retention. Schwartz & Mandigo (1976) studied several combinations of 0–2.5% NaCl and 0–0.5% sodium tripolyphosphate in restructured pork and found that salt increased TBA values, packaging loss, improved cooked colour, aroma, flavour and eating texture. Among the variables 0.75% NaCl and 0.125% sodium tripolyphosphate were needed when producing restructured pork. Matlock, Terrell, Savell, Rhee Dutson (1984a, b) found that phosphate improved scores of saltiness, juiciness, binding, and cooking yields, but they reported decreased rancidicy due to sodium tripolyphosphate. NaCl alone increased rancidity (Matlock *et al.* (1984b). With phosphate a 15% reduction in sodium content can be achieved (Matlock *et al.* (1984a). According to Ruusunen *et al.* (2004), the increase in NaCl content causes a marked decrease in cooking loss, but the effect on increasing the firmness is less pronounced. Phosphates improve the firmness; the same firmness can be reached in meat balls by ca. 40%, using basic potassium phosphate, less sodium than without phosphates (Ruusunen *et al.*, 2004). Also other ingredients such as soy protein, caseinate, gums etc. can be used to improve the technological properties of the patties, they do not necessarily affect the meat but the entire mixture.

In conclusion, decreasing the sodium content in minced meat products is not a major technological problem. NaCl increases, however, the bind, firmness, cooked yield and taste. The sensory effects such as perceived saltiness can be affected also by other components of the meal, and spices. The NaCl content in the products varies usually from 0% to about 2%. The level for most minced meat products could, however, be below 1.0%. It is also recommendable at homes and in catering to add the salt on plate just before eating in order to obtain the same perceived saltiness by much lower amounts of salt.

Cooked sausages

Sodium chloride increases the water-binding in meat linearly between ionic strengths of 0 to 0.8–1.0 in the water phase (Hamm 1972; Offer and Knight 1988). This corresponds to less than 5% NaCl in lean meat, provided that the water content is about 75%. Part of the water is tightly bound to the monomolecular layer (4 percentage points) and multimolecular layer (4–6 percentage points), which means that this water does not have the physical characteristics of free water and consequently solves less solutes. Therefore, it can be estimated that the ionic strength of salt must be calculated for 65g water in 100g lean meat. This must be taken into account when comparing the water-binding curves; e.g Offer and Trinick (1983).

Added polyphosphates cleave the actomyosin bond thus weakening the myofibrillar structure. The amount of cross-bridges per unit volume will decrease, which according to Hamm (1972) and Offer and Knight (1988) leads to an increased water-binding capacity. With added phosphates the water-binding curve is not linear in relation to NaCl content. At low contents, up to 1.0% NaCl there is a linear relationship, but then water-binding increases considerably until levelling slowly off at 1.5% (Puolanne and Ruusunen, 1980). This means that a sausage of normal gel-forming capacity can be made with about 0.3–0.5% lower sodium chloride content when phosphates are used, compared with a sausage made without added phosphates. Offer and Trinick (1983) showed in a model study with isolated myofibrils that marked changes in myofibrillar structure take place at the ionic strengths of 0.3–0.4. This means 17.6–23.4 g NaCl/l, and in a sausage with 60% moisture (tightly bound water ca. 5 percentage points) and 20% fat a content the upper limit is 12.9 g NaCl/kg. It should be stressed, however, that although good water-binding can be obtained with this sodium chloride content in raw sausage batter, it does not necessarily form a heat stable gel. Practical experience suggests that about 15 g NaCl/kg is needed.

Another aspect to be considered in cooked sausages is the fat content. If both salt content and fat content are reduced simultaneously (low fat – low sodium product), some problems may arise. If the fat content of the above mentioned sausage is reduced by 30% (from 200 to 140 g fat/kg) and replaced with water, 14.3 g NaCl/ kg is now needed for an ionic strength of 0.4; i.e. the simultaneous reductions of both constituents are not easily achieved. However, compared to the present situation worldwide, an average NaCl content of 1.6–1.8% in cooked sausages would mean a reduction.

Sofos (1983) manufactured frankfurters with 2.5%, 2%, 1.5% and 1% NaCl. A reduction in salt content more than 20% (<2.0% NaCl) resulted in frankfurters of softer and less firm texture. Sofos (1985) was able to compensate the reducing of NaCl by adding sorbate, which is usually added for antimicrobial reasons. Hand, Hollingsworth, Calkins & Mandigo (1987) reduced simultaneously fat content and salt content in frankfurters (without phosphate). Low fat frankfurters with 1.5% NaCl had softer consistency that those containing 2.0 or 2.5% NaCl. They concluded, however, that modifications of the formulation, low fat – low salt frankfurters can be manufactured. Crehan *et al.*, (2000) stated that the high hydrostatic pressure processing can be used to improve the stability of frankfurters with reduced NaCl content (from 2.5 to 1.5%), but cook yield was not affected.

Whiting (1984a) concluded that when salt content is reduced (from 2.5% to 1.5%, without phosphate), water exudates will be affected first, then gel strength, but fat release will not occur until more extreme conditions will be encountered. Whiting (1984b) compensated the reduction of water-binding and gel strength with phosphates, the effect of which was virtually independent of the pH differences the individual phosphates. Puolanne *et al.* (2001) studied the combined effects of sodium chloride, pH and use of phosphates on the water-binding (related to gel strength) of meat using model sausages. Differences in pH were reached by selecting raw meats with different pH, and no adjustments of pH were made. It was clearly seen that the same water binding can be obtained by different combinations, pH being an important variable. In some countries acid phosphates are used for better keeping quality, but this may cause problems in gel strength especially if low-salt sausages are aimed at.

Another strategy is to utilise low-sodium salt mixtures. There are many commercial mixtures, and they usually contain potassium chloride. Hand, Terrell & smith concluded that NaCl (2.8%) can be replaced with 35% KCl (by ionic basis) but not with $MgCl_2$ without detrimental effects on shrinkage. This can be expected due to the high salt levels, but technological difficulties might have been expected if the reference salt content would have been markedly lower. We have studied (Puolanne, Saarela & Ruusunen, 1988) a commercial mixture (Pan-Salt®) that contains 58% NaCl, 27% KCl, 12% $MgCl_2$ or $MgSO_4$. In our study it was shown that the sodium intake can be reduced in sausages without added phosphates by 31–37% thus obtaining the same water-binding. Mg^{2+} ions form an insoluble salt with added phosphates, and therefore this salt mixture is more suitable for sausages without added phosphates. The study showed the effects of different anions and cations as could be expected from the lyotrophic series of ionic binding as given by Hamm (1972) and Offer and Knight (1988). The use of KCl in salt mixtures also gives an additional benefit due to the fact that potassium is a counter-ion to sodium and reduces the harmful effect of sodium on blood pressure.

Finally, the water-binding and heat stability of cooked sausage can be improved by potato starch, soy protein products, gums, caseinate, added meat protein (mainly collagen), pig skin etc. gel-forming ingredients (e.g.

Whiting, 1984b). Depending on the national quality policy this also offers a way of reducing the salt content.
The use of pre-rigor curing can replace the use of phosphates. Chloride ions increase the net charge of the myofibrillar proteins preventing the formation of actomyosin bonds. Jolley, Honikel & Hamm (1981) studied the pre-rigor curing effect and found a curvilinear relationship between NaCl and water-binding in uncooked homogenates with a good binding already at 1.3% NaCl. With cooked homogenates the relationship was linear, and they found that 1.7% NaCl would give the binding similar to the normal 2% in rigor meat homogenates. Puolanne & Terrell (1983 a, b), achieved the pre-rigor effect in experimental cooked sausages with a 1.5% NaCl, but they found that the effect is curvilinear, similar to the water-binding curve in sausages with added phosphate. It should also be mentioned that the formation of an excellent raw sausage batter with 1.0% NaCl can be obtained by using pre-rigor meat, but at least 1.5% NaCl is needed for the heat stability of the gel, similar to rigor meat and added phosphate (Puolanne & Ruusunen, 1980; Puolanne & Terrell, 1983a,b). Similarly Bernthal, Booren & Gray (1981) found that 2% NaCl resulted in a good water-binding in pre-rigor meat, but 1% was not markedly better than 0 or 0.5%. The use of phosphate with pre-rigor meat does not give a marked additional benefit (Puolanne & Turkki, 1983).

It can be concluded that without phosphate the NaCl content can be lowered to 1.5–1.7% and with phosphate to 1.4% without jeopardising the technological quality and yield.

Hams

The connective tissue membranes and cell membrane prevent the free movements of ions in muscular tissue. The diffusion of salts is very slow in meat; it is more the question of days for salt to diffuse than hours (Vestergaard, Risum & Adler-Nissen, 2004; Ockerman *et al.*, 2004). Offer and Knight (1988) mention the “tiger stripe” -type appearance caused by uneven distribution of brine just after the injections. The diffusion is normally accelerated by brine curing and subsequent tumbling for several hours.

Hamm (1981) and Offer and Knight (1988) pointed out that whole meat and a piece of meat behave in a different manner than chopped meat. In chopped meat the connective tissue is to a large extent disrupted and fibres and myofibrils are broken. Puolanne (1999) has calculated that during the normal chopping of cooked sausage batter the cutter knife smashes on average every point of the sausage batter at least once. Hence salt, water and phosphates are able to directly attach the filaments in every part of the batter. In addition, Offer and Knight (1988) concluded that the endomysial connective tissue acts as a mechanical restraint to swelling. They also stated that if myofibrils are exposed to large excess of salt solution, especially in the presence of polyphosphates, myosin molecules formed by depolymerisation of the thick filament will tend to be extracted, and this will not result in swelling. Wilding *et al.* (1986) also claim that endomysial sheath acts as a restraint to myofibrillar swelling.

Grabowska and Hamm (1979) stated that when using 2% NaCl and a meat:water ratio 1:1.5 about 20 % of the myofibrillar proteins are dissolved, and with the addition of 0.3% diphosphate the solubility is 35%. In larger meat pieces such as hams, this brine addition is impossible in practical terms. It can be concluded that in large meat pieces there will be a swelling of the myofibrils in situ. Thus, not only the swelling itself but also the heat stability of the system is a critical factor in determining the yield and juiciness.

In addition, meat contains triphosphatase and diphosphatase, which break down polyphosphates to ortophosphates at rates depending on pH and temperature. Therefore, the effects of phosphates in larger meat pieces are subjected to variation due to the rate of phosphate diffusion and consequently the state of phosphate hydrolysis; in chopped sausages there is not such an variation, and the contact with salt, water and phosphates as added, and myofibrillar proteins is almost instant. With laboratory tests we have, however, found that also in chopped sausage batters about one hour is needed for the salt, phosphate and water to have the maximal effects on the heat stability, which can be speculated to be due to the diffusion in the myofibrillar level (Unpublished observations).

Salt mixtures can be used in hams too, although their sensory characterisitics are more sensitive than those of sausages. Frye, Hand, Calkins & Mandigo (1986) replaced 50% NaCl (2%) with KCl (by ionic basis) in hams, and concluded that hams with 2% NaCl had the best sensory scores, but a 50% replacement with KCl gave the best bind and acceptable sensory scores. Lin, Mittal & Barbut (1991) were able to obtain the best water-binding and cooked yield by replacing 15–18% NaCl (2%) with KCl in coarsely ground ham product.

As a conclusion, the recommendations given for hams should be about 0.3% higher than for cooked sausages, due to the lower fat content.

Fermented meat products

Salt, nitrite, pH and temperature control the fermentation as well as the safety and the quality of dry fermented meat products (Leistner, Herzog & Wirth, 1971). They are all inter-related, and if one of these factors is reduced it should be compensated with an increase of one or more of the other factors to keep the same safety and technological quality. Salt is such an essential constituent of dry fermented products that there are not so many studies on its reduction.

Petäjä, Kukkonen & Puolanne (1985) concluded that 2.5% NaCl is the lower limit for a good quality salami-type fermented sausage, but with 2.25% the sausages are less firm and the typical aroma is weaker and the yield lower than with higher salt contents. Also Stahnke (1995) found that a low NaCl content favours pH decrease. Cimeno, Astiasarán & Bello (1998, 1999, 2001) replaced NaCl with potassium, magnesium and calcium ascorbates and were able to reduce the NaCl content by about 50%. The only relevant difference was the lower consistency which is to be expected when the chloride ions are replaced with ascorbate ions that do not effectively react with myofilaments.

Peltonen (2003) studied the combined effects of sodium chloride and pH on the water-binding capacity of meat. The minimum water-binding was at pH 4.6–4.7, and the maximum ionic strength was at about 1.0 (Figure 1.). At high ionic strengths, however, there is no water-binding minimum at the range of pH 5.7–4.4. When the drying period starts, the water binding is high (pH 5.6 and ionic strength ca. 0.8-1.0 in the water phase), but starts to decrease with the decrease of pH and increase of ionic strength. This initial phase favours particle cohesion, and later on the decrease of water-binding favours the evaporation of water and thus the drying.

Recently, Olesen, Meyer & Stahnke (2004) found that NaCl (1.5 and 3.0%) had a strong effect on contents of volatile compounds in fermented sausage, and the effect was influenced by the ripening time. The relevance of the findings was not tested by sensory tests.

In dry fermented products a simple reduction cannot be made, because the low water activity has to be reached in order to control the microbial flora. Consequently the technological and microbiological as well as sensory characteristics of the supplements compared to NaCl will decide to what extent NaCl can be replaced. Bitterness seems to be the most relevant sensory trait (Gou, Guerrero, Gelabert & Arnau (1995), but effects on microbial flora should not be forgotten.

It can be concluded that the regulation of the fermentation is the decisive factor in fermented sausages. This will limit the lowering to the level >2.0% NaCl.

Concluding remarks

In most countries and in most cases, sodium contents of meat products can be lowered markedly. High fat content, non-meat ingredients, pressure treatment etc. may allow even lower NaCl values for different products than mentioned in the text above. Perceived saltiness and overall acceptability of the low-salt products may, however, weaken. Particularly important is that increased meat protein content reduces perceived saltiness. The sodium content in consumers normal diet must also be taken into account; have they used to high or low salt content in their diet. This means that the values given above must always be tested product by product, by consumer segment and by nationality. Shelf life will also be affected when lowering the salt content of meat products. By using salt mixtures the intake of sodium (NaCl) can be markedly reduced.

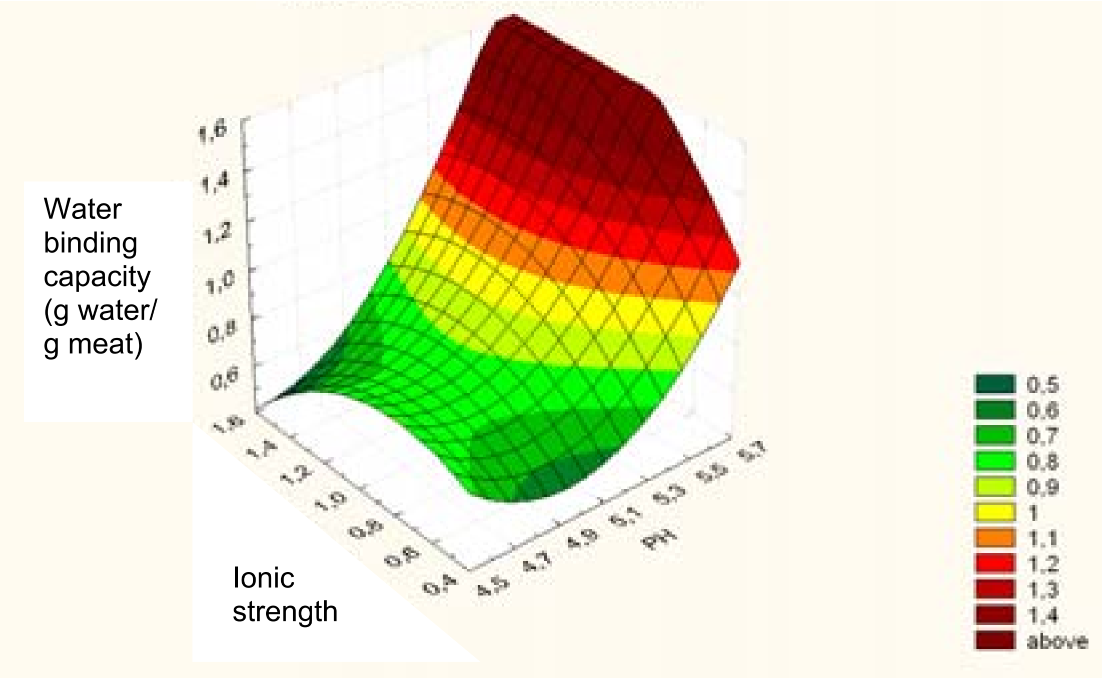

Figure 1. The effects of pH and ionic strength on the water-binding capacity of meat. (Peltonen, 2003)

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