International Journal of Food Science & Technology

International Journal of Food Science and Technology 2011, 46, 1329–1336

Invited review

Salt in food processing; usage and reduction: a review

William Albarracín,[1]* Iván C. Sánchez,[1] Raúl Grau[2] & José M. Barat[2]

1 Institute of Food Science and Technology ICTA, Universidad Nacional de Colombia, Carrera 30 No. 45-03 Ed. 500C, Bogotá, Colombia
2 Department of Food Technology, Universidad Politécnica de Valencia, Camino de Vera s/n, Valencia, Spain

(Received 28 April 2010; Accepted in revised form 8 October 2010)

Summary Salt is one of the most widely used additives in food industries because of its low cost and varied properties. It has a preservative and antimicrobial effect as a direct consequence of the capacity of sodium chloride to reduce water activity values. In addition, sodium chloride is a flavour enhancer as a consequence of its effect on different biochemical mechanisms. It also has flavour enhancing effects from reducing or enhancing the enzymatic activity of some enzymes responsible for the development of different organoleptic parameters. Trends in sodium chloride use in food industries point to salt replacement or reduction by means of the use of sodium chloride substitutes such as KCl or phosphates; flavour enhancers and the optimisation of the physical form of salt. This trend has arisen as a result of the greater awareness of the negative effects of excess dietary intake of sodium, which has been linked to hypertension and consequently an increased risk of cardiovascular disease. The average total daily sodium intake per individual in developed countries is 4–5 g of Na, which is up to 25 times greater than the minimum adult requirement.

Keywords Protein behaviour, salt effect, salt in foods, salting, water-holding capacity.

Introduction

Salt played an important role throughout history. The location of salt deposits was particularly relevant in ancient Rome and ancient Egyptian and Middle Eastern towns and villages because of its food preservation properties (Netolitzky, 1913; Forbes, 1965). History says that the Egyptians called it ‘natron’, which means divine salt; in Rome, a city whose origins stem from a route designated for the transportation of salt, the Latin term ‘salarium’ derives from salt and refers to the amount of salt that was given to a worker or Roman legionary as payment for his job.

The most important techniques commonly used in food preservation involve inhibiting the growth of microorganisms. These include the following: (i) reduction of water activity (curing, drying, evaporation); (ii) temperature (high or low); (iii) acidity or pH reduction by fermentation or the addition of organic or inorganic acids; (iv) redox potential, chemical preservatives (nitrate, nitrite, sulphites); (v) competitive microorganisms (lactic acid bacteria); (vi) modified atmosphere packing – MAP (vacuum, nitrogen, carbon dioxide, oxygen).

Because 75% of the dietary salt comes from processed foods (Appel & Anderson, 2010), the aim of food industry should be focused in the salt content reduction of processed foods if public health concerns are to be addressed. In May 2009, the UK’s Food Standards Agency revised its salt reduction targets for food processors to make them even more challenging than the previous targets for 2010. These targets require reductions across a wide range of processed foods but take into account reductions already achieved such as reductions of about 44% in branded breakfast cereals, 13% reduction in standard crisps, 32% in ‘extruded snacks’ and 27% in ‘pelleted snacks’ and a range of soft white cheeses with 50% less salt for the UK market, a 32% reduction in some retail standard cheese slices and 21% in the equivalent reduced-fat cheese slices.

In the USA, the FDA is urgently considering more effective ways to work with the US food industry to increase salt reduction measures in foods (Food & Drugs Administration Press Release, 2010). Hypertension affects 75 million US adults. An additional 50 million adults suffer from prehypertension. US consumers eat 7 g of salt daily, which is more than twice the amount required. The US Institute of Medicine believes that the issue requires new federal standards for the amount of salt that food manufacturers, restaurants and food service companies can add to their products (Institute of Medicine Consensus Report, 2010).

In the light of this current concern, the purposes of this review are to discuss the main ways that salt is used

*Correspondent: E-mail: walbarracinh@unal.edu.co

doi:10.1111/j.1365-2621.2010.02492.x

in processed foods and to briefly outline some of the challenges encountered in reducing salt levels without compromising quality or shelf life.

Salt as a preservative in foods

Salt is one of the most widely used food additives as a preservative, enhancing the flavour (Silva *et al.*, 2003) and to improve water adsorption (Lawrence *et al.*, 2003). Common salt does not display antimicrobial action, but its capacity to reduce water activity values (a_w) in foods slows down or even interrupts vital microbial processes. A high salt concentration generates changes in cellular metabolism because of its osmotic effect, which, influences microorganisms in different concentrations, but can reduce the nutritional value of preserved foods because water-soluble components such as vitamins and minerals can be eliminated (Lück & Pager, 2000). Moreover, the salting process alone is inadequate as a sole preservation method in ready-to-eat products, necessitating its combination with other preservation processes (drying, osmotic dehydration, etc.).

Effect of salt on taste perception

Anions have an effect on the taste properties of different types of salt. Sodium chloride, bromide and iodide should taste almost the same, but they are perceptually different (Murphy *et al.*, 1981). Furthermore, a reduction in saltiness depends on the type of anion present in the sample (Ye *et al.*, 1991, Ye *et al.*, 1993). Sodium chloride has an influence on the perception of the salt taste, which can be explained by the presence of the Cl^- anion and its effect on receptor cells (Murphy *et al.*, 1981). The diffusion of larger anions across tight junctions and into basolateral areas of taste receptor cell channels is limited. Therefore, salts with larger anions are less effective stimuli (Delwiche *et al.*, 1999).

Influence of salt on water-holding capacity

Water-holding capacity is defined as the ability of a food matrix to prevent water release from the three-dimensional structure (Chantrapornchai & McClements, 2002). This property is affected by pore and capillary size, the charges of the protein matrix (hydrophobic interactions, hydrogen bonds, S–S bonds), van der Waals forces (Chou & Morr, 1979; Chantrapornchai & McClements, 2002), protein ionic strength, ion species, pH, temperature, equilibrium between protein and water (Choi *et al.*, 2000) and the presence of low molecular weight substances (Correia & Mittal, 2000; Sawyer *et al.*, 2008). The increase in the water-binding capacity of meat proteins upon the addition of salt may be attributed to preferential anion binding (Cl^-) by protein molecules (Fig. 1; adapted from Girard, 1991).

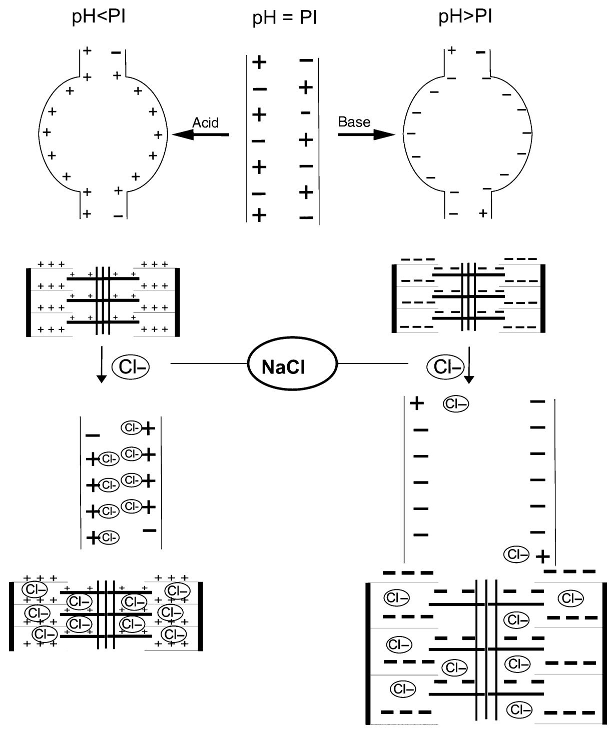

Figure 1 Chloride interaction in protein structure (adapted from Girard, 1991).

Such preferential binding for chloride ions by protein molecule at pHs above the isoelectric point increases its net negative charge and results in repulsive forces, thus permitting additional water absorption within the protein network. In contrast, at pHs below the isoelectric point, the positive charge of protein is neutralised by chloride ions, thereby reducing net positive charge and water-holding capacity. Finally, protein dehydration will occur at high salt concentrations (0.6 M) because of the competition between solutes and proteins for the available water (Chou & Morr, 1979; Wismer, 1994).

Influence of salt on the behaviour of proteins

Protein solubility in water depends on the distribution of polar and nonpolar groups in the amino acid lateral chain (Cheftel *et al.*, 1989) and the ionic species present in solutions (Curtis & Lue, 2006). At low salt concentrations, increased protein solubility results from a reduction in electrostatic interactions or binding between the hydrophilic domains within the protein. This allows resolubilisation by increased protein charge, resulting in a large protein–protein electrostatic repulsion term (Vieira *et al.*, 2006; Machado *et al.*, 2007) called the 'salting-in' process.

In contrast, at higher salt concentrations, above 1 M (Cheftel *et al.*, 1989; Machado *et al.*, 2007), increased protein solubility is because of the 'salting-out' effect of hydrophobic interactions. Salt affects hydrophobic interactions by increasing the surface tension, which is found to correlate satisfactorily with the lyotropic series (Chou & Morr, 1979), where the binding of the positive cations to the negatively charged side chains in the hydrophilic domain of proteins minimises the protein charge and therefore the protein–protein electrostatic repulsion term (Curtis & Lue, 2006).

The addition of NaCl to prerigor ground beef decelerates the rate of metmyoglobin formation (Bekhit & Faustman, 2005). Additionally, sodium chloride exerts an influence on the activity of different proteases and proteins such as Ca-dependent protease; Cathepsin D and Cathepsin L. For example, when the NaCl content increases, protease activities decrease and this prevents meat spoilage (Armenteros *et al.*, 2009) and decreasing the heat stability of both myosin and actin, using less energy input for denaturalisation (Thorarinsdottir *et al.*, 2002).

Some muscular enzymes are influenced by salt content, reducing their activity especially in the case of cathepsins and calpains (García-Garrido *et al.*, 2000), neutral lipase and acid esterase (Hernández *et al.*, 1999); in some cases, textural problems are generated by lower salt contents and higher cathepsin B activity (Sturaro *et al.*, 2008). Certain enzymes and their activity are enhanced by the presence of salt as in the case of transglutaminase F-XIIIa, whereby the hardness, cohesion and elasticity in the meat are improved (Nielsen *et al.*, 1995), the amino peptidase B enzyme (Bogra *et al.*, 2009), acid lipase (Hernández *et al.*, 1999) and m-calpain (Li *et al.*, 2004).

It has been demonstrated that monovalent cations, such as Na^+ and K^+, inhibit protease activity, while divalent ions like Mg^{2+} and Ca^{2+} activate protease activity. It has also been established that monovalent ions reduce the effect of divalent ions (Orlowski, 1990); chymotrypsin, trypsin, collagenase and elastase appear to be activated during salt curing, except when the proteins are denatured by the NaC1 concentration (Stoknes *et al.*, 2005). The haemoglobin-hydrolysing activities are reduced when NaCl concentration increases (Stoknes & Rustad, 1995; Stoknes *et al.*, 2005).

Influence of salt on lipid oxidation

Sodium chloride has been reported as a pro-oxidant (Sakai *et al.*, 2004; Honikel, 2009) or as an antioxidant (Mozuraityte *et al.*, 2006; Honikel, 2009). Ellis *et al.* (1968) postulated that salt may activate a component in lean meat, which results in a change in the oxidation characteristics of adipose tissue.

In particular, sodium chloride increases lipid peroxidation in the systems containing washed muscle residue and cytosol that contains iron ions, increasing the amount of catalytic free iron ions, which could penetrate into the lipid phase and increase lipid peroxidation (Min *et al.*, 2010), that affects the quality of muscle foods, as it can lead to the development of off-flavours (McGee *et al.*, 2003) but to date, the effect of salt on lipolysis has not been proven.

Salt uses in different kinds of food products

Salt in vegetables processing

In vegetable products, salt is mainly used as a preservative (Lück & Pager, 2000) and a softening agent (Van Buren, 2006), and also to achieve the dry-salting process (Panagou, 2006) or for the fermentation process. In some vegetable products, salt does not play a direct role as a preservative, because a low level of added salt initiates a competitive and selective microbiological growth process, favouring the development of lactic acid bacteria (Lück & Pager, 2000; Bautista-Gallego *et al.*, 2009).

Partial substitution of sodium by potassium, calcium or magnesium has an antimicrobial effect on pathogens; however, a reduction of NaCl directly affects growth of fungi and pathogens (Taorimina, 2010). A differential replacement with KCl on sauerkraut process fermentation has a similar effect on the fermentation with NaCl (Viander *et al.*, 2003).

Salt in dairy products

The most important dairy product involving the use of salt is cheese. Usually salt is added to control the growth of lactic acid bacteria and to prevent undesirable microbial growth, as well as having the secondary function of supplying additional flavour to an otherwise bland-tasting cheese (Rowney *et al.*, 2004), where the concentration and distribution of salt in cheese have a major influence on various aspects of cheese quality (Fox *et al.*, 2000) including texture (Kaya, 2002), modifying the water-binding capacity of casein within the cheese matrix (Pastorino *et al.*, 2003) and apparent viscosity (Floury *et al.*, 2009). In contrast, lower salt levels affect the amount of serum (Guinne, 2004).

NaCl replacement affects the casein micelles and the sodium and phosphorous equilibrium (Famelart *et al.*, 1999). On the other hand, reduction in NaCl concentration affects the fat droplet size and rheological properties on chesses with the presence of air bubbles, explained by a distortion between casein and water (Floury *et al.*, 2009).

Salt in meat products

Salt is involved in water holding, firmness, taste and flavour development, enhancement of the microbiological safety of cooked sausages (Puolanne *et al.*, 2001), generating ripening pigment, influencing microbiological growth, activated enzymatic activity and a nonenzymatic salting-in. Salting process has been developed in different products such as cured ham using different techniques such as smoking or cooking, Italian Parma ham (Cobe, 2002; Pastorelli *et al.*, 2003), Serrano ham (Barat *et al.*, 2005, 2006; Luna *et al.*, 2006) and Iberian dry-cured ham (Cava *et al.*, 1999; Martin *et al.*, 1999). Bresaola (Italy) or 'Viande des Grison', 'Bunderfleish' (Switzerland) (Paleari *et al.*, 2000) mades using salted cuts of beef that are reduced by hydraulic presses, during the curing process (Migaud, 1978); Tasajo (Cuba) or charqui (South America) (Chenoll *et al.*, 2007) where meat is salted and afterwards sun-dried.

A partial NaCl replacement generates changes in odour, taste and consistency of liver sausage, ground meat, cured and smoked chop, grilled sausage, Bologna-type chicken sausage and roasted turkey meat-balls (Schoene *et al.*, 2009). The use of potassium chloride (KCl) as a substitute for sodium chloride provides a bitter and less salty taste in food products, which implies the use of higher amounts of salt to obtain a similar taste. Another problem of potassium use is the rise in the potassium cation levels in humans, which could lead to renal and cardiac problems. Salt enhancer in use is monosodium glutamate, which contains high levels of glutamic acid and imparts a 'umami'-type taste to enhance the palatability and acceptability of savoury foods; it has been associated with the so-called Chinese Restaurant Syndrome that may cause headaches, swelling and weakness (Durack *et al.*, 2008).

Salt in fish products

Salt is used in a large variety of fish products such as salted cod (Thorarinsdottir *et al.*, 2002; Barat *et al.*, 2003), sea bream (Chouliara *et al.*, 2004; Goulas & Kontominas, 2007), chub mackerel (Goulas & Kontominas, 2005) and smoked salmon (Sigurgisladottir *et al.*, 2000; Gallart-Jornet *et al.*, 2007).

There are three salting levels involved in fish preservation. First, a soft salting process provides fish products with salt concentrations below 20% (expressed in liquid-phase z^{NaCl}) necessitating its storage in cold chambers to protect the product. Secondly, in moderate salting, the salt concentrations are lower than 20%, as in soft salting, but the concentration is higher than the latter method. Finally, intense salting involves salt concentrations higher than 24%, stronger salted fish is used as a raw material in subsequent food processing. To reinforce the preservation characteristics obtained in the salting process, the fish is usually dehydrated, as in the case of salted and dried cod and tuna.

The salting process

The salting process has mainly been employed in the meat and fish preservation industries. Food stabilisation through salt diffusion reduces water activity values and facilitates the development of a distinct flavour during a period of drying, and in some cases, maturation.

The traditional salting process has been developed by covering or rubbing the raw material with solid salt, which is partially dissolved and drained during the process by fluid effluent from the food product as a consequence of the osmotic and diffusional mechanisms. The aim of the salting stage is the uptake of a sufficient amount of curing ingredients (mainly NaCl) to make food preservation possible during the subsequent stages of the different processes carried out (drying, smoking, curing, cooking) and ultimately to preserve the product at ambient temperature.

The mass transfer mechanism has two principal fluxes (Fig. 2). First, water is lost in food pieces because of the osmotic phenomena. Secondly, water flows from lower salt concentration zones (inside food) to higher salt concentration zones (outside food), dissolving salt, which goes inside food pieces, penetrating the lower salt concentration contained therein.

The speed of salt uptake by food diminishes when equilibrium between the concentration in the salt medium and the food matrix is reached. Some external factors that affect the equilibrium are temperature, salt medium (solid salt or brine) and size of salt crystals; external food parameters such as pH, fat content, moisture and raw material state (fresh or frozen) may affect salt diffusion (Grau *et al.*, 2007, 2008).

As the salting process is an ancient technique, the different conditions involved in the process have been established empirically. Industrialisation and research have promoted the development of new techniques for the salting process like the brine salting (Sigurgisladottir *et al.*, 2000; Barat *et al.*, 2005, 2006; Bellagha *et al.*, 2007; Gallart-Jornet *et al.*, 2007), whereby the raw material is placed in saturated brine, which reduces

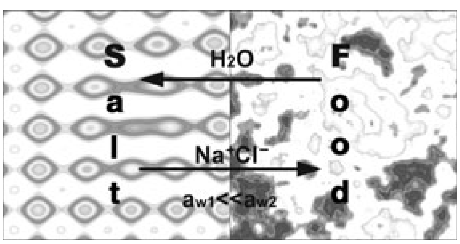

Figure 2 Mass fluxes during salting process.

salting time because of the presolubilisation of salts, while simultaneously facilitating the thawing process. The brine salting process could be improved by way of vacuum pulse application (50–100 mbar), reducing the salting time as a result of the hydrodynamic mechanism whereby the penetration of brine inside the food matrix is forced (Fito & Pastor, 1994). (Fig. 3).

Injection-salting is based on the insertion of needles into the product to spread brine and curing solutions within, ensuring a faster and more uniform distribution of sodium chloride, nitrites and other possible curing agents such as sugars, spices, polyphosphates inside food tissues (Casiraghi *et al.*, 2007). An application is on fillets of Atlantic salmon before further processing steps such as drying and smoking (Bencze Røra *et al.*, 2004; Birkeland *et al.*, 2007).

The use of high hydrostatic pressure during or after the salting process (in the range of 50–400 Mpa, over 5–10 min) has been developed to increase salt uptake and water and salt diffusion in turkey breast (Villacís *et al.*, 2008) and in Manchego cheese (Pavia *et al.*, 2000). This technique provides an additional factor of the antimicrobial effect by high pressure (Trujillo *et al.*, 2000).

Expressions of salt concentration

Some authors use different concentration bases to illustrate salt content in their works. The way in which data is expressed depends upon analysis type and research objectives. It is possible to find concentrations expressed in percentages (Martin *et al.*, 1999; Andrés *et al.*, 2005; Goulas & Kontominas, 2005; Panagou, 2006; Bellagha *et al.*, 2007) commonly used to express the salt level acquired by the different products analysed. However, it can be also be expressed on a dry basis and dry basis free of fat, where the concentration is expressed excluding water and/or fat content to make a proper comparison of the results obtained (Barat *et al.*, 2005, 2006; Ruiz-Ramirez *et al.*, 2005). On the other hand, when salt diffusion is studied, the salt concentration in the tissue liquid-phase (z^{NaCl}) is used. This is because the diffusion phenomena are carried out in the food liquid phase. Therefore, to establish clearly the level of diffusion occurring within the food matrix, the use of liquid-phase concentrations is more appropriate (Gallart-Jornet *et al.*, 2007).

However, some authors show concentrations on dry basis (Gou *et al.*, 2003, 2004). It is important to note that saltiness and salt taste in these types of products are related to the liquid salt concentration values, as a result of the receptor cells of the tongue being stimulated by the presence of Cl^- anions (Murphy *et al.*, 1981). This ion can be located in the food liquid phase by NaCl solvation.

There is a linear relationship between the liquid salt concentration and the water activity values (a_W). The role of salt in water activity reduction as a preservation method is favoured by the salt–matrix interaction. It can be witnessed in Fig. 4 that water activity values in brine at different NaCl concentrations are higher than similar NaCl concentrations in the food liquid phase. With higher z^{NaCl} values, the relationship is reduced, losing its linear behaviour (Fig. 4) and thereby illustrating that this effect is more important in foods when moisture values are lower (Fig. 4).

Trends in the salting process

The fist trend is the reduction of NaCl intake to reduce the negative effect on cardiovascular health (Morgan

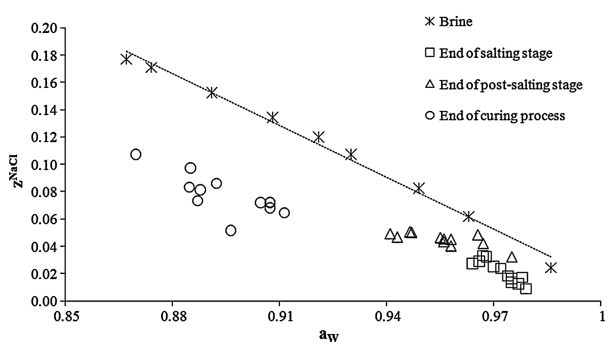

Figure 4 Relationship between liquid-phase salt concentration (z^{NaCl}) and water activity (a_W), at the inner zone (close to the bone) during dry-cured ham processing (Barat *et al.*, 2005).

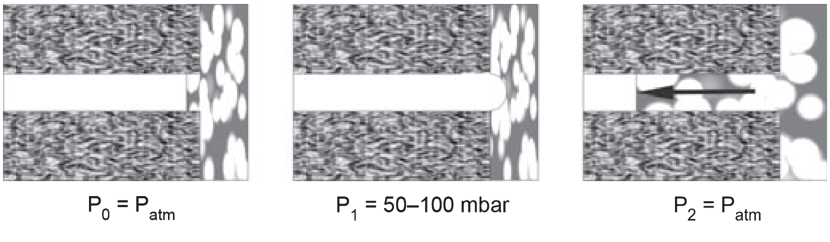

Figure 3 Effect of hydrodynamic mechanism, during vacuum pulse application in the salting process (adapted from Fito *et al.*, 1996).

et al., 2001) and blood pressure (Sacks *et al.*, 2001). The average total daily sodium intake per individual in developed countries is 4–5 g of Na (10–12 g of NaCl), which is up to 25 times greater than the minimum adult requirement (0.5 g of NaCl) (Katsiari *et al.*, 2000). Therefore, the need to reduce salt intake has serious public health implications.

This reduction can be made possible using sodium chloride substitutes such as potassium chloride (KCl) (Gou *et al.*, 1996; Guven & Karaca, 2001; Blesa *et al.*, 2008; Aliño *et al.*, 2009, 2010a,b), phosphates (Ruusunen & Poulanne, 2005) or transglutaminase (Romero de Ávila *et al.*, 2010) in proportions that do not affect salt taste, lipid oxidation, water-holding retention and yet diminish cardiovascular risk. Research and development into the salting process would point to increased salt diffusion inside products to achieve rapid and uniform food stabilisation, resulting in a faster and safer process, in addition to the consumption of products that do not pose a risk to human health.

Conclusions

Because of the different properties that sodium chloride provides in foods (a reduction in water activity values, its effect on enzymatic activity, antioxidant or pro-oxidant effect, water-holding capacity modifier, an enhancer of taste perception), salt has been linked to the evolution in food processing. The osmotic effect of salt is mainly responsible for metabolism changes in microorganisms, as well as the preservation of foods in which this compound is used. Additionally, salt is involved in the development or inhibition of some enzymatic reactions in foods, which allow the generation of reactions responsible for the development of texture, colour, taste and aroma, characteristics of many food products. Current trends in sodium chloride use in food industries indicate a substitution of, or a reduction in salt, with the use of sodium chloride substitutes and flavour enhancers, and the optimisation of the physical form of salt. Future research into sodium chloride application in food products should emphasise product stabilisation, without altering the organoleptic characteristics that such types of products traditionally display, once a reduction in sodium chloride or its substitution has been implemented. The importance of increasing food industry research into the reduction of salt levels in processed foods has become imperative. As regulatory bodies about the world take a more determined attitude with regard to urging the reduction in salt levels in the diet, including binding regulation, producers that fail to respond will find that their businesses are adversely affected and their market image is damaged.

References

Aliño, M., Grau, R., Toldrá, F., Blesa, E., Pagán, M.J. & Barat, J.M. (2009). Influence of sodium replacement on physicochemical properties of dry-cured loin. *Meat Science*, **83**, 423–430.

Aliño, M., Grau, R., Fuentes, A. & Barat, J.M. (2010a). Influence of low-sodium mixtures of salts on the post-salting stage of dry-cured ham process. *Journal of Food Engineering*, **99**, 198–205.

Aliño, M., Grau, R., Toldrá, F., Blesa, E., Pagán, M.J. & Barat, J.M. (2010b). Physicochemical properties and microbiology of dry-cured loins obtained by partial sodium replacement with potassium, calcium and magnesium. *Meat Science*, **85**, 580–588.

Andrés, A., Rodríguez-Barona, S., Barat, J.M. & Fito, P. (2005). Salted cod manufacturing: influence of salting procedure on process yield and product characteristics. *Journal of Food Engineering*, **69**, 467–471.

Appel, L.J. & Anderson, C.A.M. (2010). Compelling Evidence for Public Health Action to Reduce Salt Intake. *The New England Journal of Medicine*, **362**, 650–652.

Armenteros, M., Aristoy, M.C. & Toldrá, F. (2009). Effect of sodium, potassium, calcium and magnesium chloride salts on porcine muscle proteases. *European Food Research and Technology*, **229**, 93–98.

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

Barat, J.M., Grau, R., Ibáñez, J.B. & Fito, P. (2005). Post-salting studies in Spanish cured ham manufacturing. Time reduction by using brine thawing–salting. *Meat Science*, **69**, 201–208.

Barat, J.M., Grau, R., Ibáñez, J.B. *et al.* (2006). Accelerated processing of dry-cured ham. Part I. Viability of the use of brine thawing/salting operation. *Meat Science*, **72**, 757–765.

Bautista-Gallego, J., Arroyo-López, F.N., Durán-Quintana, M.C. & Garrido-Fernández, A. (2009). Fermentation profiles of Manzanilla-Aloreña cracked green table olives in different chloride salt mixtures. *Food Microbiology*, **27**, 403–412.

Bekhit, A.E.D. & Faustman, C. (2005). Metmyoglobin reducing activity. *Meat Science*, **71**, 407–439.

Bellagha, S., Sahli, A., Farhat, A., Kechaou, N. & Glenza, A. (2007). Studies on salting and drying of sardine *(Sardinella aurita)*: Experimental kinetics and modeling. *Journal of Food Engineering*, **78**, 947–952.

Bencze Røra, A.M., Furuhaug, R., Fjæra, S.O. & Skjervold, P.O. (2004). Salt diffusion in pre-rigor filleted Atlantic salmon. *Aquaculture*, **232**, 255–263.

Birkeland, S., Akse, L., Joensen, S., Tobiassen, T. & Skåra, T. (2007). Injection-salting of pre rigor fillets of Atlantic Salmon *(Salmo salar)*. *Journal of Food Science*, **72**, 29–35.

Blesa, E., Aliño, M., Barat, J.M., Grau, R., Toldrá, F. & Pagán, M.J. (2008). Microbiology and physico-chemical changes of dry-cured ham during the post-salting stage as affected by partial replacement of NaCl by other salts. *Meat Science*, **78**, 135–142.

Bogra, P., Singh, J. & Singh, H. (2009). Purification and characterization of aminopeptidase B from goat brain. *Process Biochemistry*, **44**, 776–780.

Casiraghi, E., Alamprese, C. & Pompei, C. (2007). Cooked ham classification on the basis of brine injection level and pork breeding country. *Lebensmittel Wissenschaft und Technologie*, **40**, 164–169.

Cava, R., Ruiz, J., Ventanas, J. & Antequera, T. (1999). Oxidative and lipolytic changes during ripening of Iberian hams as affected by feeding regime: extensive feeding and alpha-tocopheryl acetate supplementation. *Meat Science*, **52**, 165–172.

Chantrapornchai, W. & McClements, D.J. (2002). Influence of NaCl on optical properties, large-strain rheology and water holding capacity of heat-induced whey protein isolate gels. *Food Hydrocolloids*, **16**, 467–476.

Cheftel, J.C., Cuq, J.L. & Lorient, D. (1989) *Proteinas Alimentarias*. p. 364. Zaragoza: Acribia S.A.

Chenoll, C., Heredia, A., Seguí, L. & Fito, P. (2007). Application of the systematic approach to food engineering systems (SAFES) methodology to the salting and drying of a meat product: Tasajo. *Journal of Food Engineering*, **83**, 258–266.

Choi, Y.J., Cho, M.S. & Park, W. (2000). Effect of hydration time and salt addition on gelation properties of major protein additives. *Journal of Food Science*, **65**, 1338–1342.

Chou, D.H. & Morr, C.V. (1979). Protein-water interactions and functional properties. *Journal of the American Oil Chemists' Society*, **56**, 53–56.

Chouliara, I., Savvaidis, I.N., Panagiotakis, N. & Kontominas, M.G. (2004). Preservation of salted, vacuum-packaged, refrigerated sea bream *(Sparus aurata)* fillets by irradiation: microbiological, chemical and sensory attributes. *Food Microbiology*, **21**, 351–359.

Cobe, P. (2002). Dry-cured ham. *Restaurant Business*, **101**, 67–71.

Correia, L.R. & Mittal, G.S. (2000). Functional properties of some meat emulsion extenders. *International Journal of Food Properties*, **3**, 353–361.

Curtis, R.A. & Lue, L. (2006). Amolecular approach to bioseparations: protein–protein and protein–salt interactions. *Chemical Engineering Science*, **61**, 907–923.

Delwiche, J.F., Halpern, B.P. & DeSimone, J.A. (1999). Anion size of sodium salts and simple taste reaction times. *Physiology and Behavior*, **66**, 27–32.

Durack, E., Alonso, M. & Wilkinson, M.G. (2008). Salt: a review of its role in food science and public health. *Current Nutrition and Food Science*, **4**, 290–297.

Ellis, R., Currie, G.T., Thornton, F.E., Bollinger, N.C. & Gaddis, A.M. (1968). Carbonyls in oxidizing fat II. The effect of the prooxidant activity of sodium chloride in pork tissue. *Journal of Food Science*, **33**, 555–561.

Famelart, M.H., Le Graet, Y. & Raulot, K. (1999). Casein micelle dispersions into water, NaCl and CaCl2: physicochemical characteristics of micelles and rennet coagulation. *International Dairy Journal*, **9**, 293–297.

Fito, P. & Pastor, R. (1994). Non-diffusional mechanisms occurring during vacuum osmotic dehydration. *Journal of Food Engineering*, **21**, 513–519.

Fito, P., Andrés, A., Chiralt, A. & Pardo, P. (1996). Coupling of Hydrodynamic Mechanism and Deformation-Relaxation Phenomena During Vacuum treatments in Solid Porous Food-Liquid Systems. *Journal of Food Engineering*, **21**, 229–240.

Floury, J., Camier, B., Rousseau, F., Lopez, C., Tissier, J.P. & Famelart, M.H. (2009). Reducing salt level in food: Part 1. Factors affecting the manufacture of model cheese systems and their structure–texture relationships. *Food Science and Technology*, **42**, 1611–1620.

Food & Drugs Administration Press Release (2010) FDA issues statement on IOM sodium report. http://www.fda.gov/NewsEvents/Newsroom/PressAnnouncements/ucm209155.htm.

Food Standards Agency (2009) Salt reduction targets downloaded from http://www.food.gov.uk/healthiereating/salt/saltreduction Press Release Monday 18 May 2009.

Forbes, R.J. (1965). *Studies in Ancient Technology*. Vol. 3. Pp. 164–181. Brill: Leiden.

Fox, P.F., Guinee, T.P., Cogan, T.M. & McSweeny, P.L.H. (2000). Starter culture. In: *Fundamentals of Cheese Science* (edited by P. Fox, P. McSweeney & T.M. Cogan). Pp. 54–97. Gaithersburg, MD: Aspen Publishers, Inc.

Gallart-Jornet, L., Barat, J.M., Rustad, T., Erikson, U., Escriche, I. & Fito, P. (2007). Influence of brine concentration on Atlantic salmon fillet salting. *Journal of Food Engineering*, **73**, 9–19.

García-Garrido, J.A., Quiles-Zafra, R., Tapiador, J. & Luque de Castro, M.D. (2000). Activity of cathepsin B, D, H and L in Spanish dry-cured ham of normal and defective texture. *Meat Science*, **56**, 1–6.

Girard, J.P. (1991). *Tecnología de la Carne y los Productos Cárnicos*. p. 295. Zaragoza: Acribia.

Gou, P., Guerrero, L., Gelabert, J. & Arnau, J. (1996). Potassium chloride, potassium lactate and glycine as sodium chloride substitutes in fermented sausages and in dry-cured pork loin. *Meat Science*, **42**, 37–48.

Gou, P., Comaposada, J. & Arnau, J. (2003). NaCl content and temperature effects on moisture diffusivity in the Gluteus medius muscle of pork ham. *Meat Science*, **63**, 29–34.

Gou, P., Comaposada, J. & Arnau, J. (2004). Moisture diffusivity in the lean tissue of dry-cured ham at different process times. *Meat Science*, **67**, 203–209.

Goulas, A.E. & Kontominas, M.G. (2005). Effect of salting and smoking-method on the keeping quality of chub mackerel (*Scomber japonicus*): biochemical and sensory attributes. *Food Chemistry*, **93**, 511–520.

Goulas, A.E. & Kontominas, M.G. (2007). Combined effect of light salting, modified atmosphere packaging and oregano essential oil on the shelf-life of sea bream (*Sparus aurata*): biochemical and sensory attributes. *Food Chemistry*, **100**, 287–296.

Grau, R., Albarracín, W., Clemente, G. & Barat, J.M. (2007). Study of the influence of product and process variables in the salting and post-salting stages of PSE thawed hams. *International Journal of Food Engineering*, **3**, 1–16.

Grau, R., Albarracín, W., Toldrá, F., Antequera, T. & Barat, J.M. (2008). Study of salting and post-salting stages of fresh and thawed Iberian hams. *Meat Science*, **79**, 677–682.

Guinne, T.P. (2004). Salting and the role of salt in cheese. *Society of Dairy Technology*, **57**, 99–109.

Guven, M. & Karaca, O.B. (2001). Proteolysis levels of white cheeses salted and ripened in brines prepared from various salts. *International Journal of Dairy Technology*, **54**, 29–33.

Hernández, P., Navarro, J.L. & Toldrá, F. (1999). Lipolytic and oxidative changes in two Spanish pork loin products: dry-cured loin and pickled-cured loin. *Meat Science*, **51**, 123–128.

Honikel, K.O. (2009). Oxidative changes and their control in meat and meat products. In: *Safety of Meat and Processed Meat* (edited by F. Toldrá). Pp. 313–340. New York: Springer.

Institute of Medicine Consensus Report (2010). Strategies to reduce sodium intake in the United States. Released: April 20, 2010.

Katsiari, M.C., Alichanidis, E., Voutsinas, L.P. & Roussis, I.G. (2000). Proteolysis in reduced sodium Feta cheese made by partial substitution of NaCl by KCl. *International Dairy Journal*, **10**, 635–646.

Kaya, S. (2002). Effect of salt on hardness and whiteness of Gaziantep cheese during short-term brining. *Journal of Food Engineering*, **52**, 155–159.

Lawrence, T.E., Dikeman, M.E., Stephens, J.W., Obuz, E. & Davis, J.R. (2003). In situ investigation of the calcium-induced proteolytic and salting-in mechanisms causing tenderization in calcium-enhanced muscle. *Meat Science*, **66**, 69–75.

Li, H., Thompson, V.F. & Goll, D.E. (2004). Effects of autolysis on properties of A- and m-calpain. *Biochimica et Biophysica Acta*, **1691**, 91–103.

Lück, E. & Pager, M. (2000). *Conservación Química de los Alimentos: Características, Usos, Efectos*. Pp. 46–98. Zaragoza: Acribia.

Luna, G., Aparicio, R. & García-González, D.L. (2006). A tentative characterization of white dry-cured hams from Teruel (Spain) by SPME-GC. *Food Chemistry*, **97**, 621–630.

Machado, F.F., Coimbra, J.S.R., Garcia Rojas, E.E., Minim, L.A., Oliveira, F.C. & Sousa, R.C.S. (2007). Solubility and density of egg white proteins: effect of pH and saline concentration. *Lebensmittel Wissenschaft und Technologie*, **40**, 1304–1307.

Martin, L., Córdoba, J.J., Ventanas, J. & Antequera, T. (1999). Changes in intramuscular lipids during ripening of Iberian dry-cured ham. *Meat Science*, **51**, 129–134.

McGee, M.R., Henry, K.L., Brooks, J.C., Ray, F.K. & Morgan, J.B. (2003). Injection of sodium chloride, sodium tripolyphosphate, and sodium lactate improves Warner–Bratzler shear and sensory characteristics of pre-cooked inside round roasts. *Meat Science*, **64**, 273–277.

Migaud, M. (1978). *La Charcuterie Crue et les Produits Saumurés*. Pp. 526–529. Orly, France: Soussana S.A.

Min, B., Cordray, J.C. & Ahn, D.U. (2010). Effect of NaCl, Myoglobin, Fe(II), and Fe(III) on lipid oxidation of raw and cooked chicken breast and beef loin. *Journal of Agriculture and Food Chemistry*, **58**, 600–605.

Morgan, T., Aubert, J.F. & Brunner, H. (2001). Interaction between sodium intake, angiotensin II, and blood pressure as a cause of cardiac hypertrophy. *American Journal of Hypertension*, **14**, 914–920.

Mozuraityte, R., Rustad, T. & Storr, I. (2006). Oxidation of cod phospholipids in liposomes: effects of salts, pH and zeta potencial. *European Journal of Lipid Science and Technology*, **108**, 944–950.

Murphy, C.L., Cardello, A.V. & Brand, J.G. (1981). Tastes of fifteen halide salts following water and NaCl: anion and cation effects. *Physiology and Behavior*, **26**, 1083–1095.

Netolitzky, F. (1913). Nahrungs- und heilmittel der urägypter. *Z Unters Nahrungs Genubm*, **26**, 425–427.

Nielsen, G.S., Petersen, B.R. & Møller, A.J. (1995). Impact of salt, phosphate and temperature on the effect of a transglutaminase (F XIIIa) on the texture of restructured meat. *Meat Science*, **41**, 293–299.

Orlowski, M. (1990). The multicatalytic proteinase complex, a major extralysosomal proteolytic system. *Biochemistry*, **29**, 10289–10297.

Paleari, M.A., Beretta, G., Colombo, F., Foschini, S., Bertolo, G. & Camisasca, S. (2000). Buffalo meat as a salted and cured product. *Meat Science*, **54**, 365–367.

Panagou, E. (2006). Greek dry-salted olives: monitoring the dry-salting process and subsequent physico-chemical and microbiological profile during storage under different packing conditions at 4 and 20 °C. *Lebensmittel Wissenschaft und Technologie*, **39**, 322–329.

Pastorelli, G., Magni, S., Rossi, R. *et al*. (2003). Influence of dietary fat, on fatty acid composition and sensory properties of dry-cured Parma ham. *Meat Science*, **65**, 571–580.

Pastorino, A.J., Hansen, C.L. & McMahon, D.J. (2003). Effect of salt on structure–function relationships of cheese. *Journal of Dairy Science*, **86**, 60–69.

Pavia, M., Trujillo, A.J., Guamis, B. & Ferragut, V. (2000). Effectiveness of high-pressure brining of Manchego-type cheese. *Lebensmittel Wissenschaft und Technologie*, **33**, 401–403.

Puolanne, E.J., Ruusunen, M.H. & Vainionpä, J.I. (2001). Combined effects of NaCl and raw meat pH on water-holding in cooked sausage with and without added phosphate. *Meat Science*, **58**, 1–7.

Romero de Ávila, M.D., Ordóñez, J.A., de la Hoza, L., Herrero, A.M. & Cambero, M.I. (2010). Microbial transglutaminase for cold-set binding of unsalted/salted pork models and restructured dry ham. *Meat Science*, **84**, 747–754.

Rowney, M.K., Roupas, P., Hickey, M.W. & Everett, D.W. (2004). Salt-induced structural changes in 1-day old Mozzarella cheese and the impact upon free oil formation. *International Dairy Journal*, **14**, 809–816.

Ruiz-Ramirez, J., Arnau, J., Serra, X. & Gou, P. (2005). Relationship between water content, NaCl content, pH and texture parameters in dry-cured muscles. *Meat Science*, **70**, 579–587.

Ruusunen, M. & Poulanne, E. (2005). Reducing sodium intake from meat products. *Meat Science*, **70**, 531–541.

Sacks, F.M., Stevkey, L.P., Vollmer, W.M. *et al*. (2001). Effects on blood pressure of reduced dietary sodium and the dietary approaches to stop hypertension (dash) diet. *The New England Journal of Medicine*, **344**, 1–10.

Sakai, T., Munasinghe, D.M.S., Kashimura, M., Sugamoto, K. & Kawahara, S. (2004). Effect of NaCl on lipid peroxidation-derived aldehyde, 4-hydroxy-2-nonenal formation in minced pork and beef. *Meat Science*, **66**, 789–792.

Sawyer, J.T., Apple, J.K. & Johnson, Z.B. (2008). The impact of lactic acid concentration and sodium chloride on pH, water-holding capacity, and cooked color of injection-enhanced dark-cutting beef. *Meat Science*, **79**, 317–325.

Schoene, F., Mnich, K., Jahreis, G. *et al*. (2009). Analysis of meat products produced with mineral salt constituents. *Fleischwirtschaft*, **89**, 149–152.

Sigurgisladottir, S., Sigurdardottir, M.S., Torrissen, O., Vallet, J.L. & Hafsteinsson, H. (2000). Effects of different salting and smoking processes on the microstructure, the texture and yield of Atlantic salmon (*Salmo salar*) fillets. *Food Research International*, **33**, 847–855.

Silva, J.G., Morais, H.A. & Silvestre, M.P.C. (2003). Comparative study of the functional properties of bovine globin isolates and sodium caseinate. *Food Research International*, **36**, 73–80.

Stoknes, I. & Rustad, T. (1995). Purification and characterisation of a multicatalytic proteinase from Atlantic salmon (*Salmo salar*) muscle. *Comparative Biochemistry and Physiology*, **111**, 587–596.

Stoknes, I.S., Walde, P.M. & Synnes, M. (2005). Proteolytic activity in cod (*Gadus morhua*) muscle during salt curing. *Food Research International*, **38**, 693–699.

Sturaro, E., Gallo, L., Noventa, M. & Carnier, P. (2008). The genetic relationship between enzymatic activity of cathepsin B and firmness of dry-cured hams. *Meat Science*, **79**, 375–381.

Taorimina, P. (2010). Implications of salt and sodium reduction on microbial food safety. *Critical Reviews in Food Science and Nutrition*, **50**, 209–227.

Thorarinsdottir, K.A., Arason, S., Geirsdottir, M., Bogason, S.G. & Kristbergsson, K. (2002). Changes in myofibrillar proteins during processing of salted cod (*Gadus morhua*) as determined by electrophoresis and differential scanning calorimetry. *Food Chemistry*, **77**, 377–385.

Trujillo, A.J., Guamis, B. & Carretero, C. (2000). A procedure for the manufacture of goat milk cheese with controlled-microflora by means of high hydrostatic pressure. *Food Chemistry*, **69**, 73–79.

Van Buren, J.P. (2006). Snap bean texture softening and pectin solubilization caused by the presence of salt during cooking. *Journal of Food Science*, **51**, 131–134.

Viander, B., Maki, M. & Palva, A. (2003). Impact of low salt concentration, salt quality on natural large-scale sauerkraut fermentation. *Food Microbiology*, **20**, 391–395.

Vieira, C.R., Biasutti, E., Capobiango, M., Afonso, W. & Silvestre, M. (2006). Effect of salt on the solubility and emulsifying properties of casein and its tryptic hydrolysates. *Ars Pharmaceutica*, **47**, 281–292.

Villacís, M.F., Rastogi, N.K. & Balasubramaniam, V.M. (2008). Effect of high pressure on moisture and NaCl diffusion into turkey breast. *Lebensmittel Wissenschaft und Technologie*, **41**, 836–844.

Wismer, J. (1994). Química de los tejidos animales. In: *Ciencia de la Carne y de los Productos Cárnicos* (edited by J. Price & B. Schweigert). Pp. 23–85. Zaragoza: Acribia.

Ye, Q., Heck, G.L. & DeSimone, J.A. (1991). The anion paradox in sodium taste reception: resolution by voltage-clamp studies. *Science*, **254**, 726–742.

Ye, Q., Heck, G.L. & DeSimone, J.A. (1993). Voltage dependence of the rat chorda tympani response to Na + salts: implications for the functional organization of taste receptor cells. *Journal of Neurophysiology*, **70**, 167–178.