Invited review

Salt in food processing; usage and reduction: a review

William Albarracín,1,* Iván C. Sánchez,1 Raúl Grau2 & José M. Barat2

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...
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).

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 isolectric 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 \( \text{M} \)) 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 (Garcia-Garrido et al., 2000), neutral lipase and acid esterase (Hernandez 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 (Hernandez 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 Mg²⁺ and Ca²⁺ 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 NaCl 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 (Luck & 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 (Vander 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 cheeses 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) makes 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 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 (Choulara et al., 2004; Goulas & Kontominas, 2007), chub mackerel (Goulas & Kontominas, 2005) and smoked salmon (Sigurgisladottir et al., 2000; Gallart-Jornet et al., 2007). The salting process involves fish preservation. First, a soft salting process provides fish products with salt concentrations below 20% (expressed in liquid-phase $z_{\text{NaCl}}$) 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.](image-url)
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, nitrates and other 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 first trend is the reduction of NaCl intake to reduce the negative effect on cardiovascular health (Morgan...
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) (Katsiaris 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; Alínó et al., 2009, 2010a,b), phosphates (Ruuusunen & Poulanne, 2005) or transglutaminase (Romero de Avila 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


Salt in food processing: usage and reduction W. Albarracín et al.


