Partial replacement of sodium in meat and fish products by using magnesium salts. A review

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ABSTRACT

Sodium intake exceeds the nutritional recommendations in most industrialized countries becoming one concern for public health. This elimination or reduction it is not simple due to its role in final food sensory, quality and safety. The aim of this work is to review the possibilities of magnesium ion, due to its healthy properties, to become a partial substitute of sodium in the production of fish and meat products, and a particular case for Spanish dry-cured ham and loin.

Magnesium diffusion into different muscle based foods such as ham or loin, and its effect in the most important characteristics of the final product (microbiology, physico-chemical and sensory properties) has been analyzed.

Results show that magnesium has more difficulty to penetrate inside the muscle and slightly modifies the water-holding capacity of proteins, their solubility and the enzymatic activity. Salty taste, bitterness and off-flavor are the most affected characteristics. However, these effects could be compensated by using longer post-salting periods and by employing masking agents.

It is possible to reduce the sodium content in fish and meat products using magnesium as one of the ingredients, allowing to obtain new products with similar physicochemical characteristics and safety conditions.

KEY WORDS

Sodium Replacement, Magnesium, Dry-cured ham, Animal origin foods, Low salt, fish products

Introduction

Sodium is one of the most problematic nutrients in developed countries despite being an essential element for all animals and some plants, due to its role on blood volume, blood pressure, osmotic equilibrium, pH and its role in transmission of nerve impulses. Since 1972 it is known that an excessive intake of sodium is linked to hypertension (Dahl 1972; Fries 1976), and high blood pressure, which may in turn increase the risk of stroke and premature death from cardiovascular diseases. This is the reason why sodium has become one nutrient element of concern for human beings.

The main source of sodium in diet is sodium chloride, which contains a 39% of sodium ion. Mean daily sodium intakes of populations in Europe ranges from about 3 to 5 g (8 to 11 g NaCl) (EFSA 2005). On a popular 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, limitation of dietary sodium intake should be achieved by restricting daily salt (sodium chloride) intake to less than 5 g per day (WHO/FAO 2003). Such recommendations are addressed to the general public. It is however generally recognized that those individuals which are genetically salt-susceptible or hypertensive suffering will particularly benefit from low-sodium diets. In such cases, the salt content should range between 1 and 3 g/day (Ruusunen and Puolanne, 2005).

Despite raw food contains sodium, the main source of sodium in fish and meat products is sodium chloride added during food processing. Therefore, most sodium chloride in the diet comes from processed foods, where sodium affects flavor, texture, color and shelf life (Barat and Toldrá 2011). So, processed fish and meat products represent a relatively relevant part of the dietary sodium intake (Aliño et al. 2010a).

Of all the processed animal origin products, dry-cured meat products, such as dry-cured ham or loin, or dry-cured fish, such as cod, bottarga (dry cured fish roe) or mojama (dry cured tuna loin) constitute some of the most important sources of sodium. These are representative traditional foods in several cultures and in different areas around the world. Of these areas, countries around Mediterranean Sea, have possibly the most rich dry-cured products gastronomic heritage. It is explained because consumption of dry-cured products was possible in countries surrounded by Mediterranean Sea, due to its particular climate that allowed natural drying and ripening (Toldrá 2004) and have a natural source for obtaining salt. So, in Mediterranean countries like Spain, Italy and France, dry-cured products have a very important economic impact.

Production of this kind of products involves several steps, through which it is intended to obtain a dehydrated product in which electrolytes belonging to intra and extracellular liquids are concentrated, and also new salts, concretely sodium chloride, are added. After dehydration, salting is one of the fundamental operations in cured food, due to its role not only of the final flavor, but also to the contribution to the preservation of the product throughout its processing and storage (Andrés et al. 2007).

Despite the importance of dry-cured foods, they are not the only processed food that provides an extra source of sodium to the diet. Bakery product, sausages, cooked hams, surimi based products, soya sauce,… are also important sources of sodium.

Consequently, this kind of food is non-recommended for some collectives, such as hypertensive consumers. However, a total elimination of this kind of products from diet of some populations is very difficult due to cultural roots and the strength of the sector. For instance, more than 40 million pieces of Spanish dry-cured ham are produced per year (Blesa et al. 2008), representing a very important market.

In consequence, scientists and food industry have been looking in recent decades for strategies to reduce sodium intake from foods. One of the developed strategies is the partial replacement of sodium chloride from other salts containing other cations, such as Magnesium.

Sodium reduction in animal origin food through Magnesium: A double health benefit

Based on the scientific information and health recommendations, consumers and food industry, increasingly aware of relationship between sodium and hypertension, are demanding and trying to offer, new low-salt products (He and MacGregor 2003). One possibility is the direct reduction of added salt to the product, while the other alternative, that can be applied in combination with the former strategy is the partial replacement of NaCl with other salts, such as magnesium chloride (Toldrá and Barat 2009).

In contrast to sodium, magnesium plays an important role in physiologic processes. Magnesium is an essential element in humans (Fox et al. 2001). This divalent metallic ion is the fourth most abundant cation in the body, and one of the most abundant intracellular ions in animals, and also in plants. Regarding to its functions, it can be stated that there is almost no biochemical process in which magnesium doesn’t play an important role. For instance, magnesium acts as a cofactor in several enzymes that convert adenosine triphosphate (ATP) to adenosine pyrophosphoric acid (ADP). As a constituent of these enzymes, magnesium is essential to reactions involving the synthesis and metabolism of carbohydrates, lipids, proteins, and nucleic acids, and in consequence, in life. Magnesium also plays a vital role in the reversible association of intracellular particles and in the binding of macromolecules to subcellular organelles: for example, the binding of RNA to ribosomes is magnesium dependent.

Brewer's yeast, chocolate, nuts, legumes, cereals, fruits, vegetables and some seafood are the main sources of magnesium in human diet. The present RDA for magnesium is 420 mg/day for men and 320 mg/day for women (Institute of medicine 1997). However, the mean intake is 323 mg/day in men and 228 mg/day in women (Rude and Gruber, 2004). In consequence, despite being widely distributed among foods, dietary Mg deficits are present from adolescence to old age. It is estimated that 10% of elderly women consume less than 136 mg/day. This is important in as much as the gastrointestinal and renal mechanisms for Mg conservation that may not be as efficient as in a younger population (Martin 1990).

Not surprisingly knowing its organic roles, an inadequate intake of magnesium has been linked to various adverse health outcomes, including the development of cardiovascular disease, hypertension, diabetes mellitus and headaches. Furthermore, magnesium is important in bone growth and may play a role in athletic performance. Studies of magnesium supplementation have been conducted in patients with cardiovascular disease, hypertension, diabetes mellitus, asthma, migraines and pregnant women. Furthermore, magnesium is used to treat cardiac arrhythmias, myocardial infarction, asthma, preeclampsia and eclampsia (Ford and Makdad 2003).

So, apparently, the replacement of sodium by magnesium in salt formulations for fish and meat looks like a good healthy alternative; it reduces sodium intake and derived adverse health effects and moreover diet is supplemented with magnesium, which harmful effects of excess are rarely described. Nevertheless, the possibility of harmful effects must be considered and studied to avoid possible side effects on consumers.

Sodium reduction in foods of animal origin through Magnesium: Technological implications

Despite all potential benefits of sodium replacement through magnesium, the 100% sodium replacement in cured meat and fish products is not possible by the moment. Sodium chloride (NaCl) is an ingredient that contributes not only to the final salty flavor, but also to the color, the texture and the shelf life (Albarracin et al. 2011).

It is well known that salt has a positive influence on salty taste. However, only sodium chloride and lithium chloride are primarily salty (Murphy et al. 1981). Other mono and divalent salts stimulate multiple taste qualities as bitter, salty, sour, and astringent sensation... at the same time. Lawless et al. (2003) studied with a Duncan test the contribution of magnesium salts (chloride and sulfate) to the salinity and bitterness, and demonstrated that saltiness and bitterness of both salts increased with concentration. Lawless et al. (2003) also studied the contribution of magnesium salts to sweetness, umami, sour and metallic taste, but not many differences between NaCl and the Mg salts were found. They also found that the substitution of NaCl by $MgCl_2$ may generate off-flavors. Nevertheless, the presence of NaCl together with other cations could suppress these unpleasant tastes, especially bitterness (Lawless et al. 2003).

From a technological point of view, the replacement of some of the NaCl by other salts can influence very important aspects. One is the form of application of the salt, another is the rate of diffusion of salt inside muscle foods and finally, the potential influence on water activity and microbial control in the product.

All those aspects must be considered if a safe and controlled product must be obtained. The use of mixtures of salts with low sodium content may imply significant changes in the different steps that constitute the whole process. A summary of published results obtained in the manufacturing of Dry-cured loins and hams is shown in table 1.

Application of the mixture of salts

The application of a mixture of salts including Mg has technological problems to be solved, which depend on the type of product to be salted or the type of salting process.

As regards the type of product to be salted, the easiest way of adding a mixture of salt is to mix directly the salt with the formulation of the product. This enables the addition of an exact amount of salt and the proper distribution throughout the entire product (Barat et al. 2006). Obviously, this type of application is possible when the initial structure of the raw material is not important and all or some of the components of the food are added to the mixture.

The main problem comes when the initial structure of the product must be preserved, as in the case of dry-cured hams, salted cod or dry-cured pork loins, among others. Then, the salt must be added to the surface of the product (solid or forming a brine), or in some cases can be injected in the product. In all cases, the salts must diffuse from the point of entrance to the whole product, which means that transport by diffusion plays a vital role in the process.

As has been stated, the salting process can be mainly done by using solid salt or brines. In addition to that, the salt can be applied to a whole batch of product (pile salting or brining in big containers), or can be applied separately to every product by rubbing or by injection (Barat et al. 2006).

It is very important to pay attention to the solubility of salts in case of using solid salt mixtures. Aliño et al. (2009a) studied cation penetration throughout pork-loin pile-salting with mixtures of NaCl, KCl, $CaCl_2$ and $MgCl_2$ and found that higher Ca^{2+} and Mg^{2+} concentrations were observed in the brine with regard to their concentration in the solid salt due to the higher solubility of $CaCl_2$ and $MgCl_2$ compared with NaCl and KCl. In addition to that, these divalent cations penetrated less than monovalent cations in the muscle.

Another aspect that must be considered is different pH of the formed brine when other salts than NaCl are used. It is known the strong influence of the pH on the water holding capacity of proteic products (Thomsen and Zeuthen, 1988). Aliño et al. (2010d) determined the pH of brines containing 100% NaCl and a mixture of salts (NaCl, KCl, $CaCl_2$ and $MgCl_2$), and the experimental values ranged from 5.4 for 100% NaCl up to 7.11 for one of the mixtures.

Diffusion of magnesium in muscle foods

Some studies have been done for manufacturing Spanish dry-cured hams by using partial replacement of NaCl with $MgCl_2$ (Blesa et al. 2008). It was observed that for the same amount of total added salt to the product, the water activity values inside the product were higher when using $MgCl_2$ mixtures, which could be explained by a higher difficulty of Mg for penetrating inside the hams. This could be explained by the higher charge density (0.082 and 0.044 units of charge/molecular weight for Mg and Na, respectively) that would increase its difficulty to penetrate inside the muscle. Simultaneously, it would imply a lower entrance of anion Cl^- because of the accomplishment of electro-neutrality principle (Wesselingh and Krishna 1990). In addition to that, Ca^{2+} and Mg^{2+} cations, could bind strongly to the protein polar groups, strengthening protein interactions (Xiong and Brekke 1991) and thus hindering the penetration of salt.

These results imply that an increase in post-salting time is needed when working with $MgCl_2$ as compared with NaCl, to allow the salt to distribute homogeneously inside the food (Blesa et al. 2008; Aliño et al. 2010a).

Aliño et al. (2010a) studied the influence of a mixture of salt containing $MgCl_2$ on the physicochemical properties of ham as compared with the use of NaCl, and found that the observed differences were not dependant on the type of salt, but from the salt concentration and moisture of the samples.

Microbial activity

As was previously stated, one of the main objectives when adding NaCl to food is to improve its preservation, mainly due to the reduction of water activity (a_w) and the consequent microbial growth inhibition or reduction.

Thus, when $MgCl_2$ is used as a replacer of NaCl, it is very important paying attention to the changes in a_w reduction and if the use of $MgCl_2$ has another effects on the microbial growth. The values of parameter "B", characteristic of every electrolyte in the equation of the Pitzer-Bromley model to predict water activity in aqueous solutions, are B= 0.1129, 0.0948, 0.0574 and 0.024, for $MgCl_2$, $CaCl_2$, NaCl and KCl, respectively (Ross 1975; DeHoff 2006), which indicates the higher potential of $MgCl_2$ for decreasing water activity as compared with other common salts.

Blesa et al. (2008) studied the influence of the salt type on the microbial load of Spanish dry-cured ham at the end of the post-salting period. One of the studied salt mixture contained 55% NaCl, 25% KCl, 15% $CaCl_2$ and 5% $MgCl_2$ (in weight). The experimental results determining the microbial counts of total mesophilic aerobic flora, salt-tolerant flora, *lactic acid* bacteria, lactose positive *Enterobacteriaceae*, *faecal coliforms*, *Bacillus cereus*, *Listeria spp.*, *Staphylococcus aureus*, *Clostridium perfringens*, sulfite-reducing *clostridium*, *Salmonella* spp. and *Shigella* spp. determined that although hams salted using a salt mixture with low sodium content needed more time of post-salting to reach similar water activity values than those achieved by hams salted with 100% NaCl, no differences in microbial counts were observed among the studied batches, although a sharp decrease in microbiota was observed when the post-salting time was prolonged for the sodium replaced hams.

Water-binding capacity (WHC) of meat proteins is very much influenced by the presence of NaCl. At pHs below the isoelectric point, the positive charges of proteins are neutralised by chloride ions. Thus, a reduction in net positive charge is achieved and water-holding capacity decrease. This reduction favors the dehydration of the muscle due to osmotic processes in the presence of high salt concentrations (Huff-Lonergan and Lonergan 2005). The presence of magnesium brines tended to hinder the general penetration of chlorides into the muscle, thus negatively affecting water-holding capacity and water-extractable protein.

Protein solubility in water depends on the distribution of polar and nonpolar groups in the amino acid lateral chain (Offer & Trinick 1983) and the ionic species present in solutions (Curtis & Lue 2006). At low salt concentrations, an increase in protein solubility results, due to a reduction in electrostatic interactions or binding between the hydrophilic domains within the protein. As in the case of WHC, this effect is reduced when the penetration of Na^+ ions is hindered in the presence of Magnesium.

Effect of magnesium salt on the muscle enzyme activity

One of the relevant roles of NaCl in meat and fish processing is due to its inhibitory action against muscle enzyme activity. It is especially relevant in the case of proteases and lipases because of their contribution to flavor development, such in case of typical dry-cured ham (Toldrá & Flores 1998; Toldrá 2006a).

Proteolysis is an important biochemical phenomenon in post-mortem meat and fish, which is the basis for tenderness but also for flavour development in processed meat and fish. For instance, proteolysis is quite extensive in fermented sausages and dry-cured ham (Toldrá 2006c). Main proteases are cathepsins, dipeptidylpeptidases and aminopeptidases. Monovalent cations, such as Na^+ and K^+, exert a strong inhibitory action on cathepsins and other proteases such as alanyl aminopeptidase (AAP) and also of neutral lipase and acid esterase (Toldrá & Flores 1998). In this way, the structure of muscle remains during more time and texture is preserved. On the other hand, the enzyme transglutaminase F-XIIIa increases its activity in the presence of NaCl, improving muscle hardness, cohesion and elasticity of the product. This influence of NaCl is not so noticeable in the case of divalent ions like Mg^{2+} and Ca^{2+}.

Several chloride salts like KCl, $MgCl_2$ and $CaCl_2$ have been assayed and their effects on muscle enzymes compared to those exerted by NaCl (Armenteros et al. 2009a). The effect exerted by divalent salts ($CaCl_2$ and $MgCl_2$) was observed at much lower amounts than for NaCl and KCl, demonstrating a strong inhibitory effect (Armenteros et al. 2009b). Aminopeptidases, enzymes involved in the generation of free amino acids through the hydrolysis of amino acids from the N-terminus of peptides and proteins, are also affected by magnesium (Armenteros et al. 2009a). However, an increase in the total amount of free amino acids in dry-cured loins salted with brines containing $MgCl_2$ was observed (Armenteros et al. 2009b). In consequence, the presence of magnesium favors the generation of more free amino acids that contribute to taste and also to the generation of new volatile compounds by Maillard reactions which contribute to flavor development in dry-cured products (Toldrá & Flores 1998).

In the case of lipolysis phenomena, lipases and phospholipases play also important roles in the breakdown of triacylglycerols and phospholipids, respectively, and the release of free fatty acids (Toldrá 2007). The flavor of Camembert cheese was reported to decrease when the NaCl content was replaced with a mixture of Mg^{2+} and Na^{+} (Lesage et al. 1993). The same effect was reported in dry-cured loins salted with brine containing a 10% of $MgCl_2$, where a significant decrease in the total amounts of free mono- and poly-unsaturated fatty acids, which are the substrate for the generation of volatile compounds, was reported (Armenteros et al. 2009b). This shows that a higher concentrations of divalent cations in the brine, like magnesium, contributed to a reduction in the lipolysis phenomena, and hence, the total amount of free fatty acids decreased.

Effects of sodium reduction through magnesium on aroma retention in foods

Meat products, especially those that are fermented and/or dry-cured, have a wide variety of aroma volatile compounds, characteristic of such products (Toldrá 2002; Toldrá and Aristoy 2010). The perception of their respective aromas may vary depending on the concentration of each volatile compound, the respective odour threshold and any potential interaction with other food components, mainly proteins (Guichard 2002). Of course, the interactions are strongly dependant on the type of salts used for processing because they may either affect the protein binding ability or exert a salting-out effect. So, KCl produced a similar salting-out effect to NaCl. For both salts, a 5–10 fold increase in the concentration of the volatile compounds in headspace was reported (Pérez-Juan et al. 2007). However, such salting out effect was not reported for $MgCl_2$ and $CaCl_2$.

Furthermore, the binding ability of sarcoplasmic proteins to volatile compounds also depends on the type of salts. In fact, the binding ability of sarcoplasmic protein extracts to branched aldehydes, hexanal and methional were significantly reduced by NaCl and KCl, while no effect was produced on octanal and 2-pentanone (Pérez-Juan et al. 2006). In the case of $MgCl_2$ and $CaCl_2$, the effects were much lower, even at high ionic strengths. There was an exception for branched aldehydes, because the presence of $MgCl_2$ at 1.0 ionic strength produced the complete release of bound volatile compounds (Pérez-Juan et al. 2006).

Effects of sodium reduction through magnesium on sensory quality

The alternative types of salts chosen for replacing NaCl must be carefully considered because they can strongly affect the product quality (Ruusunen et al. 2005; Puolanne and Halonen 2010). The NaCl roles in production of high quality dry-cured products of animal origin, in comparison to Mg or Mg-containing mixtures are summarised in Table 2.

In the case of meat batters, the replacement of sodium chloride with other salts like calcium, magnesium or potassium chloride improved the extractability and solubility of proteins, favouring also the gelation process as well as the emulsion stability (Nayak et al.

1998a, 1998b; Piggot et al. 2000), and as a consequence of that influencing the texture of the product. Other combinations with citrate, carboxymethylcellulose and carrageenan have been used in Bologina type sausages (Ruusunen et al. 2003).

The reduction of the NaCl content in dry-cured hams without adding any other replacing salts is a practice that was followed by some manufacturers but the results were quite disappointing due to the excessive softening of the hams that gave significant rejections by consumers because of the poor texture quality (Morales et al. 2007). The main reason for such softness was attributed to the muscle cathepsins B, D and L, which are partly inhibited by NaCl. As these enzymes exert a major activity into the ham during processing, due to a lower inhibitory effect, an extended protein breakdown and textural defects were reported (Toldrá 2006b; 2007). Other works tried to optimise the percentage of reduction of the total salt in dry-cured Iberian hams determining its effects on the sensory characteristics and proteolysis (Andrés et al. 2004; Martín et al. 1998) and in restructured dry-cured hams determining the salt reduction effects on physicochemical and sensory properties (Costa-Corredor et al. 2009).

Studies carried out with dry-cured pork loin by replacing NaCl by a mixture of KCl, $MgCl_2$ and $CaCl_2$ showed that NaCl could be reduced up to 40 to 50%, without significantly affecting sensory and/or safety characteristics of the final product (Aliño et al. 2009b; 2010c; Armenteros et al. 2009b; 2009c). Similar studies for sodium reduction in Spanish dry-cured ham have also been reported (Aliño et al. 2010a; Armenteros et al. 2012; Ripollés et al. 2010). The results also showed that an approximate 40% Na^+ reduction could be achieved without negatively affecting sensory properties. However, reductions above 40-50% gave relevant negative effects on sensory quality, especially taste, where some bitter and metallic after tastes were perceived (Armenteros et al. 2012).

Masking of unpleasant tastes through magnesium salts

Formulations replacing part of sodium chloride by potassium chloride may contribute to some unpleasant tastes (bitter taste) or even metallic aftertaste especially when magnesium or calcium chlorides are also added. These tastes may be partly reduced through the use of masking agents (Lahtinen 1986) like pepper, onion, garlic, tomato, sweet pepper, basil, parsley, thyme, celery, lime, chilli, nettle, rosemary, smoke flavoring, curry, coriander and lemon (Toldrá & Barat 2012). Another alternative to mask the bitter taste is the use of flavour enhancers to enhance the saltiness of meat products. Such enhancers can be simply magnesium glutamate (Imada et al. 2010) or naringin (Yamada 2009) but also can be a combination of substances. A large number of more or less complex mixtures have been described like that based on a combination of carboxymethyl cellulose and carrageenan with sodium citrate (Ruusunen et al. 2003) or a combination of one edible nucleotide monophosphate salt and another substance (low organic acid, low organic acid salt, phosphoric acid, phosphate salt, a magnesium salt, sugar and burnt sugar) (Zolotov et al. 1997), or a cereal flour such as rice flour and a food grade acidulant like citric acid (Chigurupagui 2007), or an organic acid with potassium, calcium and magnesium salts, or potassium bicarbonate containing magnesium, potassium or calcium carbonate, lactate, citrate, tartrate, succinate, glutamate or orthophosphate (Burckel et al. 2003) or minor amounts of magnesium sulphate and calcium carbonate, with trace amounts of folic acid and zinc oxide (Ryberg 2008).

A low sodium salt substitute of table salt, with 50% reduction of sodium but equivalent level of salty taste, was based on sodium chloride replacement by potassium chloride and either magnesium sulfate or magnesium chloride (Rood & Tilkian 1985). Authors claimed that bitterness associated to potassium was masked by the presence of magnesium. Another low sodium table salt with less than 50% NaCl, which was replaced by KCl, contained a mononucleotide monophosphate salt and another substance like organic acid, organic salt, phosphoric acid, phosphoric salt, magnesium salt, sugar and burnt sugar, to mask the bitterness of potassium (Zolotov et al. 1997).

Conclusions

The use of magnesium as a partial replacer of sodium in foods of animal origin has been extensively assayed with divergent results. In general, it seems that low amounts are efficient for reducing sodium and thus considered positive because they do not affect the sensory quality. Even the use of certain types of magnesium salts in combinations with other substances, appear to mask the bitterness associated to potassium when it is used in excess.

Special attention is needed as regards the penetration of magnesium into the muscle tissue (which is lower than in case of sodium), the influence of magnesium salts on pH and its solubility when used with a solid salt mixture.

Controlled salting process in needed to avoid a significant increase in the production cost, and to adjust the magnesium concentration to the recommended value to avoid significant changes in the sensory properties of the product.

Further studies are needed to adapt the process to the partial replacement of NaCl by other salts; such is the case of Magnesium salts.

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Table 1. Comparison of Partial Replacement of Sodium Chloride Formulations with the original formulation (100% of NaCl) for obtaining dry-cured hams and loins.

Product	Formulation	Sensory effect	Other	References
Dry-Cured Loins	55% NaCl, 25% KCl, 15% $CaCl_2$, 5% $MgCl_2$	not significantly different		Armenteros et al. 2009b
Dry-Cured Loins	a) 55% NaCl, 25% KCl, 15% $CaCl_2$, 5% $MgCl_2$ b) 45% NaCl, 25% KCl, 20% $CaCl_2$, 10% $MgCl_2$		Mg penetrated with difficulty into the muscle remaining in the brine. Presence of Mg considerably reduced the sodium and potassium content of the salted loin. MgCl2 increased water loss.	Aliño et al. 2009b
Dry-Cured Loins	55% NaCl, 25% KCl, 15% $CaCl_2$, 5% $MgCl_2$ 45% NaCl, 25% KCl, 20% $CaCl_2$, 10% $MgCl_2$		divalent cations contributed to increase the salting time	Aliño et al. 2010d
Dry-Cured Loins	55% NaCl, 25% KCl, 15% $CaCl_2$, 5% $MgCl_2$	significantly increased hardness and	No significant differences were observed in the counts of pathogenic	Aliño et al. 2010c

	45% NaCl, 25% KCl, 20% $CaCl_2$, 10% $MgCl_2$ 30% NaCl, 50% KCl, 15% $CaCl_2$, 5% $MgCl_2$	chewiness of dry-cured loins No significant differences were observed in colour.	microorganisms in loins salted with the different mixtures.	
Dry-cured ham	55% NaCl, 25% KCl, 15% $CaCl_2$ and 5% $MgCl_2$		more time of post-salting to reach similar water activity values. no differences in microbial counts were observed	Blesa et al. 2008
Dry-cured ham	55% NaCl, 25% KCl, 15% $CaCl_2$ and 5% $MgCl_2$		slightly higher lipolysis and lower inhibition of acid lipase activity	Ripollés et al. 2011
Dry-cured ham	55% NaCl, 25% KCl, 15% $CaCl_2$ and 5% $MgCl_2$	poorer scores	No significantly affecting the final proteolytic phenomena, as measured by amino acid liberation	Armenteros et al. 2012
Dry-cured ham	55% NaCl, 25% KCl, 15% $CaCl_2$ and 5% $MgCl_2$		calcium and magnesium had more difficulty to penetrate inside the muscle	Aliño et al. 2010b

			post-salting period increases.	
Dry Fermented Sausages	44.42% NaCl, 10.44% $MgCl_2$, 24.52% KCl, 20.61% $CaCl_2$	Lower salty taste.	Greater acidification and water activity. No effects were found in the lactic acid bacteria counts but a decrease of Micrococcaceae was observed	Gimeno et al. 1998

Table 2. Comparison of sodium and magnesium roles during curing meat process.

	Sodium	Magnesium	
Influence on flavor			References
Salty taste	Saltiness increases with sodium concentration	Saltiness is not as pronounced as sodium	Gimeno et al. 1998
Metallic and bitter taste	Any contribution	Contributes to bitterness	Armenteros et al. 2009b
Off-flavour	Any contribution	Contributes to off-flavour	Ripollés et al. 2011
Salting out effect	High effect	No effect	Flores et al. 2007
Aroma compounds binding to proteins	High effect	Low effect	Pérez-Juan et al. 2008
Influence on texture			
Protein binding	Direct effect	Decreases due to hinder sodium penetration	Aliño et al. 2009b
Protein solubilization	Direct effect	Decreases due to hinder sodium penetration	Aliño et al. 2009b
Water holding capacity	Depends on the pH	Decreases due to hinder sodium penetration	Aliño et al. 2009b
Lipase activity	Inhibitory	Inhibitory but at much lower concentrations	Ripollés et al. 2011
Protease activity	Inhibitory	Inhibitory but at much	Armenteros et al.

		lower concentrations	2012
Influence on shelf-life			
a_w	Decreases water activity	Decreases water activity (a_w) with less intensity	Aliño et al. 2010b
Salt Penetration	Penetrates easily	Difficulty to penetrate inside the muscle	Aliño et al. 2010b
Salt diffusion	Diffuses easily	Difficulty to diffuse	Aliño et al. 2010b