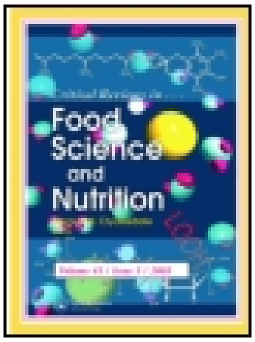

Critical Reviews in Food Science and Nutrition

ISSN: 1040-8398 (Print) 1549-7852 (Online) Journal homepage: https://www.tandfonline.com/loi/bfsn20

Challenges to reduce or replace NaCl by chloride salts in meat products made from whole pieces – a review

Vitor A. S. Vidal, Jose M. Lorenzo, Paulo E. S. Munekata & Marise A. R. Pollonio

CRITICAL REVIEWS IN FOOD SCIENCE AND NUTRITION
https://doi.org/10.1080/10408398.2020.1774495

Taylor & Francis
Taylor & Francis Group

REVIEW

Challenges to reduce or replace NaCl by chloride salts in meat products made from whole pieces – a review

Vitor A. S. Vidal[a], Jose M. Lorenzo[b], Paulo E. S. Munekata[b], and Marise A. R. Pollonio[a]

[a]Faculdade de Engenharia de Alimentos, Universidade Estadual de Campinas, Campinas, São Paulo, Brazil; [b]Centro Tecnológico de la Carne de Galicia, Parque Tecnológico de Galicia, Ourense, Spain

ABSTRACT
NaCl is fundamental for the development of the physico-chemical, sensorial and microbiological stability in meat products made from whole pieces such as dry-cured lacón, loin, ham, bacon, jerked beef, and pastirma). The substitution of NaCl by other chloride salts (KCl, $CaCl_2$ and $MgCl_2$), in order to minimize changes in the processing steps and insertion of new ingredients, is a major challenge for the elaboration of salted meat products in the context of increasing awareness among consumer about sodium consumption and health. This review aims to discuss the potential use of binary, ternary and quaternary salting mixtures in the processing of salted meat products and their effects on microbiological evolution and safety, sensory properties, oxidative reactions on proteins and lipid, and proteolysis and lipolysis reactions. More specifically, the substitution of NaCl by other chloride salts can influence the growth of microorganisms, the formation of toxic compounds, progression of enzymatic and oxidative reactions, and the sensory attributes. Scientific evidences from a food technological point of view, support the use of KCl to partially replace NaCl while major advances/more sophisticated strategies are still necessary to effectively introduce $CaCl_2$ and $MgCl_2$ as NaCl replacers. Moreover, further studies regarding the shelf-life and economic problems of the alternatively salted products are still necessary.

KEYWORDS
Salted meat products; chloride salts; enzymatic reactions; oxidative reactions; sensory attributes; shelf-life

Introduction

Meat products made from whole pieces such as dry-cured lacón (Lorenzo et al. 2003; Purriños et al. 2011), loin (Aliño, Grau, Fuentes, et al. 2010; Pateiro et al. 2015), ham (Jiménez-Colmenero, Ventanas, and Toldrá 2010), bacon (Wu et al. 2014, 2015), jerked beef (Vidal, Biachi, et al. 2019) and pastirma (Kilic 2009) are widely appreciated and consumed due to their unique sensory characteristics and long shelf-life. After a successful processing, salted meat products can be stored at room temperature for months due of their microbiological stability, making this category very important in regions where the cold chain is scarce or not used (Torres et al. 1989). Although meaningful advances have been made in order to improve the preservation of salted meat products, NaCl (by means of salting steps) still remains an important factor to achieve desirable sensory and technological characteristics of this products (Inguglia et al. 2017).

The excessive sodium intake increases the risk of developing high blood pressure, cardiovascular diseases, renal disorders, and other related diseases (Cook, Appel, and Whelton 2016; Strazzullo et al. 2009) (Figure 1). In this regard, the recommend maximum daily intake is 2 gm of sodium is recommended by health-related societies and researchers (Bibbins-Domingo et al. 2010; Whelton et al. 2012). In any case, the large amount of NaCl used in the processing of salted meat products makes this category high in sodium content and, taking into account its worldwide high consumption, it is necessary and very important the effective substitution of NaCl content to consequently decrease the amount of sodium intake by the population.

There are several strategies for reducing sodium in meat products. It is possible to reduce sodium content by others chloride salts as KCl, $CaCl_2$ (Vidal, Biachi, et al. 2019) and $MgCl_2$ (Domínguez et al. 2016), non-chloride salts as lactate and diacetate (Devlieghere et al. 2009), flavor enhancers as arginine, lysine, sodium inosinate, sodium guanylate, taurine, yeast extracts and monosodium glutamate (Vidal, Paglarini, et al. 2020; Vidal, Santana, et al. 2020) among other strategies. In this regard, Pandya et al. (2020) noticed that samples processed with 50:50 (by weight) blend of sodium chloride and disodium phosphate solution showed favorable results with 20% lower sodium in the final product. In addition, the hedonic sensory evaluation strongly favored the texture and overall acceptability of the formula with disodium phosphate replacement compared to the full salt control suggesting favorable flavor profile and texture improvements.

The most common strategy to sodium reduction is addition of chloride salts, being potassium chloride (KCl) the most used due of its similar chemical properties with NaCl

CONTACT Marise Aparecida Rodrigues Pollonio pollonio@unicamp.br Faculdade de Engenharia de Alimentos, Universidade Estadual de Campinas, 13083-862, Campinas, São Paulo, Brazil.

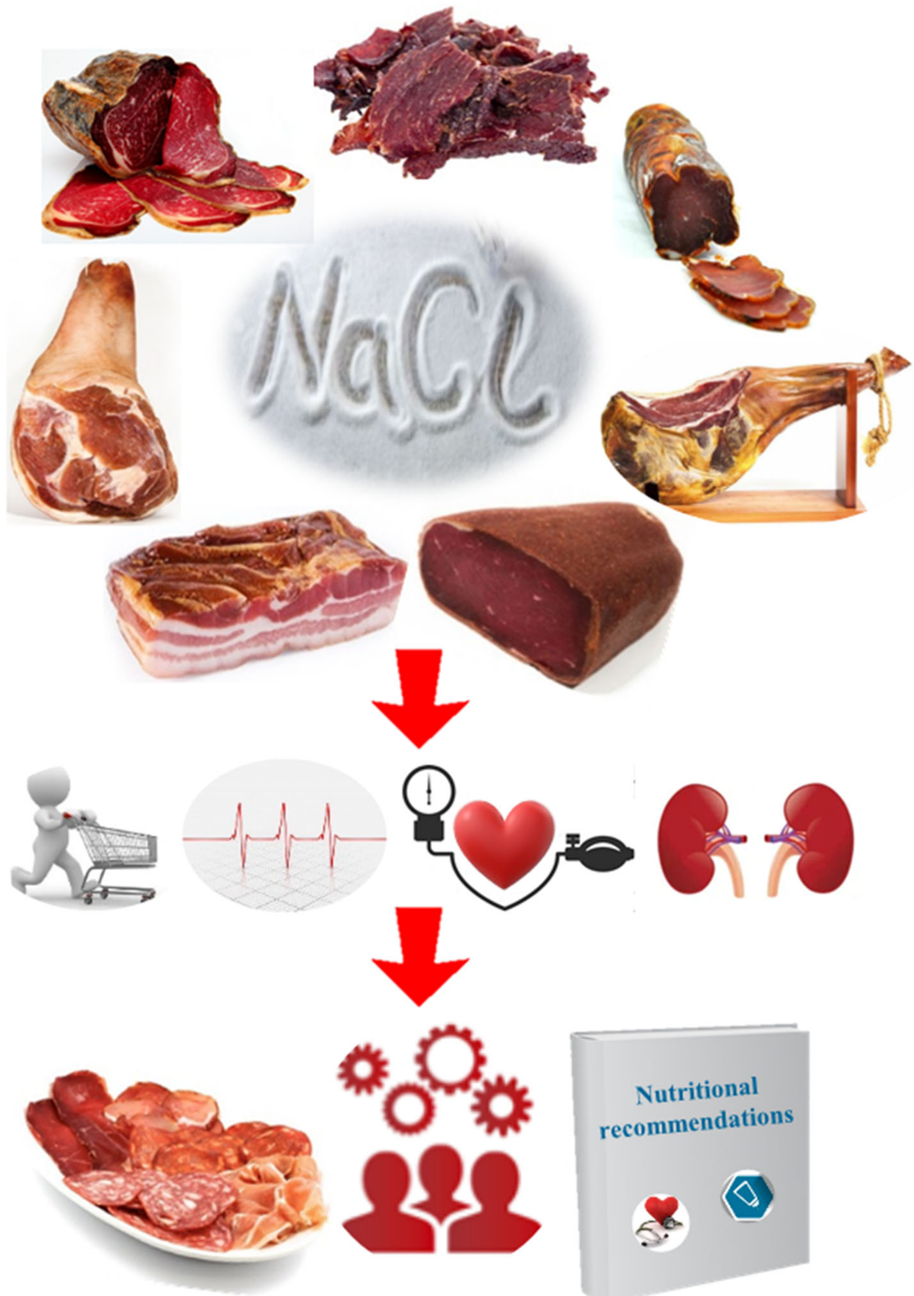

Figure 1. Health risks associated to the consumption of salted meats.

(Stanley, Bower, and Sullivan 2017). Figure 2 shows the strategies to reduce and substitute sodium chloride by other chloride salts. On the other hand, Weaver (2013) concluded that there was an association between potassium intake and reduced risk of coronary heart disease and stroke, in addition to low potassium intake and high sodium intake are more strongly related to the risk of cardiovascular disease.

Chloride salts are more used in salted meat products instead of non-chloride to reduce sodium content is mainly due to the action of ionic strength in the meat matrix, having an important role for development of several technological properties such as extraction of myofibrillar proteins, texture properties, water holding capacity, among others (Vidal, Biachi, et al. 2019; Vidal, Bernardinelli, et al. 2019, Vidal, Paglarini, et al. 2019).

In this context, food and related researchers have been exploring the effect of sodium replacement in salted meat products. Replacing NaCl by other chloride salts has been showing interesting results in meat products to support this approach, particularly those that NaCl is used as ingredient such as frankfurter (Horita et al. 2014) and dry-fermented sausage (dos Santos Alves et al. 2017; dos Santos et al. 2017).

Regarding salting methods used in meat products made from whole pieces, there are two fundamental techniques: the dry salting and the brine salting (immersion or injection) (Shahidi and Samaranayaka 2004). The oldest method to preserve the meat is dry salting since the meat samples are rubbed or covered with a high amount of sodium chloride and optional other curing agents. On the other hand, in the immersion procedure the meat samples are placed in

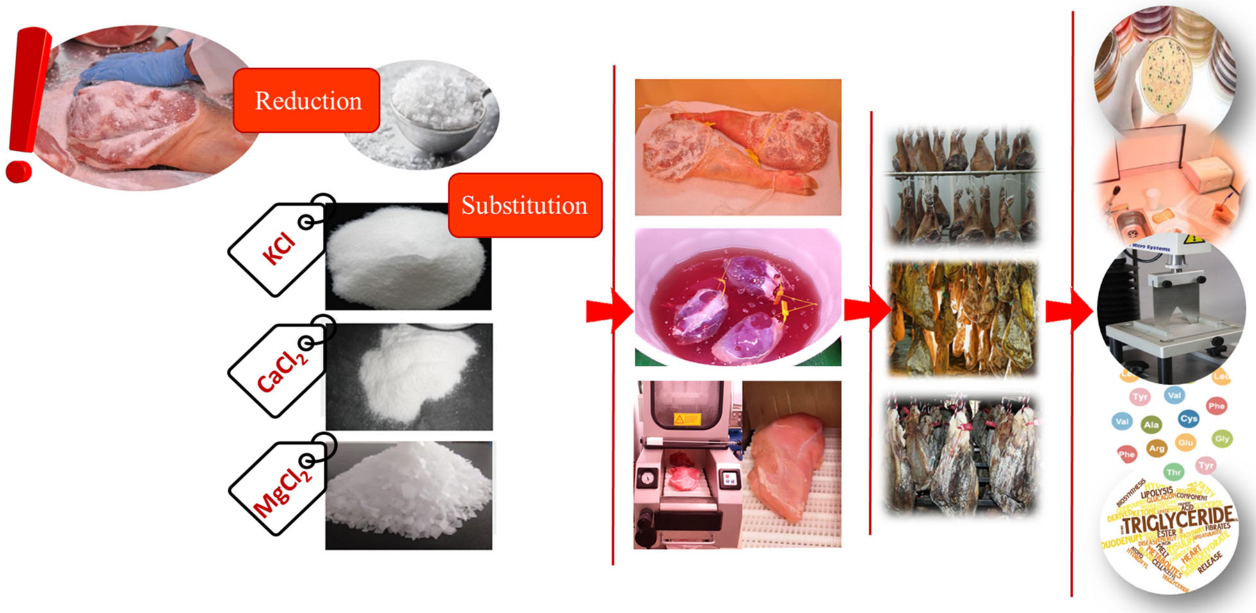

Figure 2. Strategies to reduce and substitute sodium chloride by other chloride salts.

containers and covered with brine-curing (10–30% of salt concentration). Finally, the injection method introduce smaller amounts of curing brine into the muscle, reducing the salting periods.

The aim of this review is to review the advances on sodium substitution in meat products made from whole pieces, particularly on the microbiological evolution and safety, proteolysis, lipolysis, oxidative reactions on proteins and lipid, and sensory characteristics to make this category of meat products healthier without changing its expected characteristics in the final product.

Effect of reduce or replace NaCl by chloride salts on microbial growth and safety

NaCl is an excellent preservative, inhibiting the growth and survival of undesirable microorganisms, prevents rapid deterioration and increases shelf-life (Inguglia et al. 2017). The microbial community in the processing of salted meat products changes during processing, particularly salting and ripening stage. The exposure to NaCl causes osmotic shock on microorganisms, which results in the loss of water from the cell causing microbial cell death or slowing its growth (Taylor and Davidson 2007). Moreover, NaCl retains water molecules with a consequent decrease of water activity below optimal growth conditions, which largely suppress microbial growth (Yotsuyanagi et al. 2016).

The scientific evidence obtained from salted meat products indicated that microbial load can be influenced, to some extent, by NaCl replacers (Table 1). NaCl replacers can induce a similar inhibitory effect on viable microbial cells in the first steps of processing. This outcome was obtained in a study with Spanish lacón that reported similar reduction in total viable counts between fresh pieces prior to processing and after salting stage for all treatments (Lorenzo, Bermúdez, et al. 2015).

In a similar way to observed for conventionally salted meat products, the growth of salt tolerant microorganisms was favored during processing, but non-significant differences were observed on dry-cured loin (Aliño, Grau, Fuentes, et al. 2010) and ham (Blesa et al. 2008), regardless of NaCl replacer composition and proportion. Due to the dominance of salt tolerant microorganisms in the later steps of salted meat processing (Lorenzo, Bermúdez, et al. 2015; Purriños et al. 2013), the final counts between treatments were similar among treatments for other microorganisms: aerobic mesophilic and lactic acid bacteria for dry cured loin (Aliño, Grau, Fuentes, et al. 2010), lactic acid bacteria in jerked beef (Vidal, Biachi, et al. 2019), and jerked venison (Tangkham and LeMieux 2016). Regarding the effect on the growth of pathogenic microorganisms, the partial replacement of NaCl inhibited the growth of *Bacillus cereus*, *Listeria* spp., *Staphylococcus aureus*, *Clostridium perfringens*, *Salmonella* spp., and *Shigella* spp. in dry-cured ham (Blesa et al. 2008) and coliform counts in jerked beef (Vidal, Biachi, et al. 2019) in comparison to respective conventionally salted treatments at safe levels for consumption.

Due to the growth of microorganisms during processing of salted meat products with NaCl, the accumulation of microbial metabolites is a topic of major concern for technological and safety reasons. The potential replacement of NaCl by other chloride salts was recently evaluated in bacon (Li et al. 2016). The changes on the total volatile basic nitrogen (generated from spoilage microorganisms and enzymatic activity) were not influenced by NaCl replacers during processing a slight, but a significant reduction was obtained for treatment elaborated with 60% and 40% of NaCl and complementary proportions of KCl. This study also indicated that these two treatments were also associated with

Table 1. Effect of the partial NaCl substitution by other chloride salts on microbial counts of salted meat products.

Product	Salting mixtures (%)	Effect	Reference
Dry-cured lacón	C (100% NaCl); F1 (50% NaCl and 50% KCl); F2 (45% NaCl, 25% KCl, 20% $CaCl_2$ and 10% $MgCl_2$); and F3 (30% NaCl, 50% KCl, 15% $CaCl_2$ and 5% $MgCl_2$)	Lacón elaborated with 50% NaCl and 50% KCl presented the highest total viable and salt-tolerant counts after salting and dry-ripening period; F1, F2 and F3 displayed higher yeast count than C after salting and dry-ripening	Lorenzo, Bermúdez, et al. 2015
Dry-cured loins	C (100% NaCl); F1 (55% NaCl, 25% KCl, 15% $CaCl_2$ and 5% $MgCl_2$); F2 (45% NaCl, 25% KCl, 20% $CaCl_2$ and 10% $MagCl_2$); and F3 (30% NaCl, 50% KCl, 15% $CaCl_2$ and 5% $MgCl_2$)	Non-significant differences in aerobic mesophile, salt-tolerant flora, and lactic acid bacteria counts at the end of processing were observed among treatments	Aliño, Grau, Fuentes, et al. 2010
Dry-cured ham	C (100% NaCl); F1 (50% NaCl and 50% KCl); and F3 (55% NaCl, 25% KCl, 15% $CaCl_2$ and 5% $MgCl_2$)	Non-significant differences in aerobic mesophile, coliforms, lactic acid bacteria, and molds and yeasts counts were observed among treatments during ripening	Blesa et al. 2008
Jerked beef	C (100% NaCl); F1 (50% NaCl and 50% KCl); F2 (50% NaCl and 50% $CaCl_2$); and F3 (50% NaCl, 25% KCl and 25% $CaCl_2$)	Non-significant impact on thermotolerant and total coliform and lactic acid bacteria among treatments at the end of processing	Vidal, Biachi, et al. 2019
Jerked venison	C (100% NaCl); F1 (50% NaCl and 50% KCl); and F2 (100% KCl)	Non-significant differences among treatment on total arobic counts during storage	Tangkham and LeMieux 2016

C: Control; Fn: Formulation regarding the composition of salting mixture (NaCl, KCl, $CaCl_2$, and $MgCl_2$).

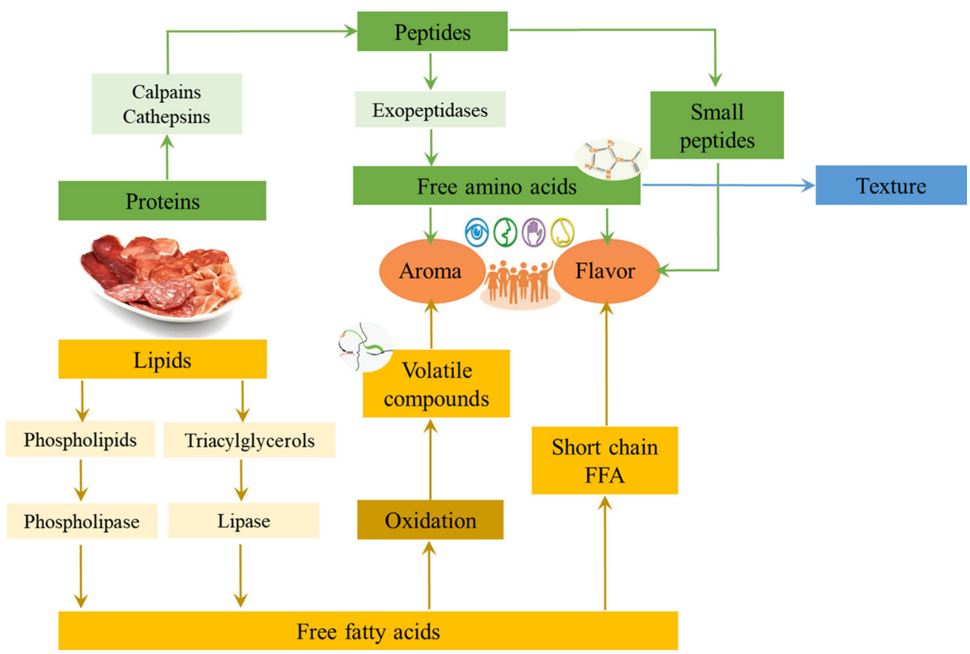

Figure 3. Lipolysis and proteolysis processes in salted meat.

reduced biogenic amine content, particularly for cadaverine (during processing), putrescine and histamine (both during processing and storage for up to 3 weeks). These outcomes support the microbial inhibition of NaCl replacers to obtain safe salted meat products with reduced sodium content and performed with other chloride salts, particularly with KCl.

Effect of reduce or replace NaCl by chloride salts on proteolytic reactions and protein oxidation

The enzymatic and oxidative reactions induced over muscle proteins are associated with quality of salted meat products. Proteolysis play a central role in the structural and chemical stability of muscle proteins by means of proteases (cathepsins), (tri- and di-) peptidades and (alanyl-, arginyl-, leucyl- and methionyl-) aminopeptidades. The breakdown of proteins takes place by the activity of proteases over the large proteins leading to formation of polypeptides. In turn, large peptides can be degraded to small peptides due to (tri- and di-) peptidades followed by the generation of free amino acids (FAA) from small peptides by aminopeptidades (Figure 3). The activity of these enzymes occurs simultaneously, particularly in the beginning of processing, and remain active during processing leading to accumulation of peptides and FAA as well as damage on muscle proteins. Consequently, the structure and related texture properties (such as hardness and fibrosity). Moreover, the activity of proteolytic enzymes can also be influenced by several factors such as temperature, pH, processing, ingredients, and water activity (Petrova et al. 2015; Toldrá 2002).

Effect of NaCl reduction or replacement on proteolysis

Regarding the influence of NaCl on proteolysis, it is known that NaCl can inhibit the activity of proteolytic enzymes, which can limit the degradation of muscle structure during processing (particularly during dry-ripening stage) and leads to expected final physico-chemical, texture, and sensory characteristics by following traditional practices to elaborate salted meat products such as dry-cured ham (Martín et al. 1998; Petrova et al. 2015).

An in-depth evaluation of NaCl replacing by KCl on the activity of endoproteases was carried in dry-cured loins (Armenteros et al. 2009b). This particular study revealed that while the activity of Cathepsin B and Cathepsin B + L improved as NaCl was partially replaced by KCl (up to 70%), the activity of Dipeptidyl peptidase I and III were reduced in a concentration-dependent manner. It is also important mentioning that some enzymes were not influenced by NaCl content, such as cathepsin H and alanyl aminopeptidase. According to authors, the enhanced activity of cathepsin B and B + L activity could explain the enhanced degradation of high molecular weight protein into low molecular weight peptides and FAA (particularly glutamine, proline, and valine) between traditionally salted (100% NaCl) and NaCl partially replaced dry-cured loins (65–30% NaCl and 35–70% KCl). Another relevant experiment with dry-cured loin was carried out by the same research group and indicated that replacing NaCl by other chloride salts (Armenteros et al. 2009a). The authors observed that cathepsin B, B + L, alanyl and leucyl aminopeptidase increased as NaCl proportion in the salting mixture was improved. However, the activity of dipeptidyl peptidase I and III was reduced.

In a similar way, the impact on the development of proteolysis during ripening of traditional Chinese bacon (Gan et al. 2019). The authors observed a progressive increase on the total free amino acid content during 2 weeks, which was support by the simultaneous reduction in the band intensity of large proteins (myosin heavy chain of 220 kDa) into small peptides. In a similar way, another experiment with dry-cured bacon elaborated indicated that proteolysis both sarcoplasmatic and myofibrillar proteins by NaCl and KCl at complementary proportions (100–30% and 0–70%, respectively) (Wu et al. 2014). Particularly for the 60% NaCl and 40% KCl, slightly differences were reported in comparison to control (100% NaCl) for both sarcoplasmatic and myofibrillar peptides after ripening stage. Conversely, the evaluation of bacons produced with 70% NaCl and 30% KCl was reduced with meaningful changes in the peptides of molecular weight below 100 kDa. However, non-significant changes on amino acid nitrogen, peptide nitrogen, and proteolysis index were reported among treatments.

The influence of NaCl in the activity of endogenous proteases and peptidases was observed evaluated during the processing of dry-cured ham (Armenteros et al. 2012). The main enzymes in the beginning of processing were cathepsine B + L, dipeptidyl peptidases I, and alanyl aminopeptidase among cathepsines, dipeptidyl peptidases, and aminopeptidases. However, the enzymatic activity of all tested enzymes (which included cathepsins, dipeptidyl peptidases, and aminopeptidases) was gradually decreased during the 270 days of processing. Moreover, the influence of NaCl partial substitution on the free amino acid profile was observed for argenine but the impact on the main FAA (leucine, lysine, and alanine) was not significant during processing.

The increased activity of some endogenous enzymes seems to influence the total free amino acid of salted meat products, particularly between control and other treatments with reduced NaCl proportion at the end of ripening period (Armenteros et al. 2009b, 2009a, 2012; Cittadini et al. 2020; Lorenzo, Cittadini, et al. 2015). However, the relation between individual free amino acid (FAA) and NaCl substitution seems not related to NaCl content (from 100% to 30% in salt mixture) or salt composition (KCl, $CaCl_2$, or $MgCl_2$). For instance, leucine was indicated as one of the main FAA among many salted meat products at the end of processing (Table 2). While significant increase in leucine content was reported for lacón (Lorenzo, Bermúdez, et al. 2015) and dry-cured loin (Armenteros et al. 2009a), non-significant differences were observed for dry-cured ham (Armenteros et al. 2012). In addition, Cittadini et al. (2020) noticed that arginine was the main FAA in dry-cured cecina salted with 50% NaCl and 50% KCl; whereas leucine was the most abundant FAA in dry-cured cecina salted with 45% NaCl, 25% KCl, 20% $CaCl_2$ and 10% $MgCl_2$. They concluded that proteolytic phenomenon increase as NaCl content decrease and the different chloride salts did not have the same inhibitory effect on the proteolytic enzymes.

Effect of NaCl reduction or replacement on protein oxidation

Protein oxidation is associated with important structural and chemical changes on meat proteins, which can influence the quality of meat products. Among the many factors related to protein oxidation, ingredients can influence the evolution of proteins oxidation during processing and shelf-life (Estévez 2011; Soladoye et al. 2015). The influence of NaCl replacing by other chlorine salts in protein oxidation was evaluated during the processing of bacon (Gan et al. 2019). This study indicated that replacing NaCl by KCl (particularly for 50 and 30% NaCl and complementary percentages of KCl) was associated with enhanced carbonyl formation (a mark of protein oxidation progression) in comparison to control treatment (100% NaCl) during processing. Conversely, the thiol content reduced during processing and displayed similar values among treatment among treatments.

The influence of NaCl substitution in protein oxidation could be associated with the changes in the structure of myofibrillar proteins induced by indirect effects. A possible explanation could be attributed to electrostatic repulsions and protein assembling (Soladoye et al. 2015) or even the enhanced activity of endogenous enzymes (Armenteros et al. 2009a, 2009b) that could facilitate the diffusion of pro-oxidant factors such as free radicals. The oxidative state of iron, in myoglobin, This particular association between proteolysis and protein oxidation was observed in Chinese traditional bacon (Gan et al. 2019). However, more experiments are necessary to characterize the how different ions (Ca^{2+} and Mg^{2+}) influence protein oxidation in salted meat products.

Table 2. Effect of the partial NaCl substitution by other chloride salts on proteolysis and protein oxidation of salted meat products.

Product	Salting mixtures (%)	Effect on proteolysis rate, proteolytic enzymes and free amino acid	Effect on protein oxidation	Reference
Dry-cured lacón	C (100% NaCl); F1 (50% NaCl and 50% KCl); F2 (45% NaCl, 25% KCl, 20% $CaCl_2$ and 10% $MgCl_2$); and F3 (30% NaCl, 50% KCl, 15% $CaCl_2$ and 5% $MgCl_2$)	F1-F3 displayed higher free amino acid content C treatment; main FAA: *leucine, valine and alanine*	n.d.	Lorenzo, Bermúdez, et al. 2015
Dry-cured loin	C (100% NaCl); F1 (65% NaCl and 35% KCl); F2 (50% NaCl and 50% KCl), and F3 (30% NaCl and 70% KCl)	Replacing NaCl by other chloride salts favored the activity of cathepsin B and B + L while the activity of Dipeptidyl peptidase I and III were reduced (F1, F2 and F3); non-significant differences were observed on other enzymes in the final product; main FAA: *leucine, alanine, lysine, and phenylalanine*	n.d.	Armenteros et al. 2009b
Dry-cured loin	C (100% NaCl); F1 (55% NaCl, 25% KCl, 15% $CaCl_2$ and 5% $MgCl_2$); F2 (45% NaCl, 25% KCl, 20% $CaCl_2$ and 10% $MgCl_2$); and F3 (30% NaCl, 50% KCl, 15% $CaCl_2$ and 5% $MgCl_2$)	Reducing NaCl improved the activity of cathepsin B, B + L, alanyl and leucyl aminopeptidase while the activity of dipeptidyl peptidase I and III were reduced; non-significant effect on other enzymes in the final product; main FAA: *leucine, lysine, and phenylalanine*	n.d.	Armenteros et al. 2009a
Dry-cured bacon	C (100% NaCl); F1 (60% NaCl and 40% KCl); and F2 (30% NaCl and 70% KCl)	Non-significant effect on amino acid nitrogen, peptide nitrogen, and proteolysis index as NaCl proportion was reduce; slight changes on the content of low molecular weight peptides in F1 and F2 in comparison to C treatment	n.d.	Wu et al. 2014
Dry-cured bacon	C (100% NaCl); F1 (60% NaCl and 40% KCl); F2 (30% NaCl and 70% KCl)	n.d.	Carbonyl formation and thiol loss were slowed during processing for F1 and F2 treatments in comparison to C treatment	Wu et al. 2016
Chinese traditional bacon	C (100% NaCl); F1 (70% NaCl and 30% KCl); F2 (50% NaCl and 50% KCl); and F3 (30% NaCl and 70% KCl)	F2 indicated that proteolysis rate was enhanced by replacing NaCl with KCl; proteolysis was associated with protein oxidation	F2 and F3 displayed higher carbonyl content than C treatment; non-significant between treatment for thiol content	Gan et al. 2019
Dry-cured ham	C (100% NaCl); F1 (50% NaCl and 50% KCl); and F2 (55% NaCl, 25% KCl, 15% $CaCl_2$ and 5% $MgCl_2$)	F1 inhibited cathepsin B and B + L and prevented the inhibition of cathepsin H of processing in comparison to C and F2; The activity of all enzymes was gradually reduced; NaCl substitution had mild effect on the activity of cathepsins (B, B + L, and H), dipeptidyl peptidases (I-IV), and (alanyl-, arginyl-, leucyl- and methionyl-) aminopeptidases; slight effect on FAA profile and non-significant effect on FAA content during processing; main FAA: *leucine, lysine, and alanine*	n.d.	Armenteros et al. 2012

C: Control; Fn: Formulation regarding the composition of salting mixture (NaCl, KCl, $CaCl_2$, and $MgCl_2$); n.d.: not determined.

Effect of reduce or replace NaCl by chloride salts on lipolytic reactions and lipid oxidation

The processing of salted meat products can influence the structure and stability of lipids by means of enzymatic and chemical reactions known as lipolysis and lipid oxidation, respectively (Nachtigall et al. 2019). The evolution of lipolysis involves the catalytic and gradual breakdown of triacylglycerides and phospholipids that releases free fatty acids (FFA). It is known that acid lipase, phospholipase, and acid and neutral esterase are the main enzymes involved in the evolution of lipolysis during processing of salted meat products, which usually display high activity in the beginning of processing (Figure 3). The activity of lipolytic enzymes is gradually reduced during processing, which is influenced by aw and salt content, for instance (Jin et al. 2010; Muriel et al. 2007; Petrova et al. 2015).

Effect of NaCl reduction or replacement on lipolysis

Processing of salted meat products is also characterized by the development of oxidative reactions on the lipid fraction. The general concept involves the generation of reactive

Table 3. Effect of the partial NaCl substitution by other chloride salts on lipolysis and lipid oxidation of salted meat products.

Product	Salting mixtures (%)	Effect on lipolysis and lipolytic enzymes	Effect on lipid oxidation	Reference
Dry-cured lacón	C (100% NaCl); F1 (50% NaCl and 50% KCl); F2 (45% NaCl, 25% KCl, 20% $CaCl_2$ and 10% $MgCl_2$); and F3 (30% NaCl, 50% KCl, 15% $CaCl_2$ and 5% $MgCl_2$)	F3 displayed the highest while F1 showed the lowest FFA content after the dry-ripening period; main FFA: *oleic, palmitic, and linoleic acid*	F2 displayed the highest while F1 and F3 displayed the lowest oxidation levels after the dry-ripening period	Lorenzo, Bermúdez, et al. 2015
Dry-cured loin	C (100% NaCl); F1 (39.7% NaCl, 51.3% KCl, 9% L-histidine and L-lysine)	Consumption of phospholipids and generation of FFA; C and F1 induced similar effect on FFA release; phospholipase activity was less affected in F1 treatment than in C; L-histidine and L-lysine did not inhibit the activity of phospholipase and acid lipase; main FFA: *oleic, linoleic, and palmitic acid*	Non-significant effect between treatments for peroxide values; F1 displayed lower TBARS values after the dry-ripening period in comparison to C treatment	Zhang et al. 2015
Dry-cured loin	C (100% NaCl); F1 (65% NaCl and 35% KCl); F2 (50% NaCl and 50% KCl), and F3 (30% NaCl and 70% KCl)	Non-significant effect of NaCl substitution on the FFA content; main FFA: *oleic, linoleic, and palmitic acid*	n.d.	Armenteros et al. 2009b
Dry-cured loin	C (100% NaCl); F1 (55% NaCl, 25% KCl, 15% $CaCl_2$ and 5% $MgCl_2$); F2 (45% NaCl, 25% KCl, 20% $CaCl_2$ and 10% $MgCl_2$); and F3 (30% NaCl, 50% KCl, 15% $CaCl_2$ and 5% $MgCl_2$)	The lowest SFA and MUFA content was observed in F2; non-significant effect for total PUFA and total FFA among treatments; main FFA: *oleic, linoleic, and palmitic acid*	n.d.	Armenteros et al. 2009a
Dry-cured ham	C (100% NaCl); F1 (50% NaCl and 50% KCl); and F2 (55% NaCl, 25% KCl, 15% $CaCl_2$ and 5% $MgCl_2$)	F2 had lower inhibitory effect on lipolysis than C and F1; NaCl and KCl displayed the most intense inhibitory effect on acid lipase; main FFA: *oleic, linoleic, and palmitic acid*	F1 and F2 achieved high TBARS values (>1.5 μg malondialdehyde/g muscle) faster than C during processing	Ripollés et al. 2011
Jerked beef	C (100% NaCl); F1 (50% NaCl and 50% KCl); F2 (50% NaCl and 50% $CaCl_2$); and F3 (50% NaCl, 25% KCl and 25% $CaCl_2$)	n.d.	F2 had the highest TBARS values at the end of ripening period	Vidal, Biachi, et al. 2019
Pastirma	C (100% NaCl); F1 (85% NaCl and 15% KCl); and F2 (70% NaCl and 30% KCl)	n.d.	Non-significant differences among treatments during processing	
Chinese traditional bacon	C (100% NaCl); F1 (70% NaCl and 30% KCl); F2 (50% NaCl and 50% KCl); and F3 (30% NaCl and 70% KCl)	n.d.	F3 had the lowest TBARS values after the ripening period in comparison to other treatments	Gan et al. 2019
Dry-cured bacon	C (100% NaCl); F1 (60% NaCl and 40% KCl); F2 (30% NaCl and 70% KCl)	n.d.	Lipid oxidation was induced by high proportion of KCl in salting mixture; glutathione peroxidase activity was inversely associated with was directly related to NaCl proportion in salting mixture while a direct relation was observed for catalase	Wu et al. 2016

C: Control; Fn: Formulation regarding the composition of salting mixture (NaCl, KCl, $CaCl_2$, and $MgCl_2$); FFA: Free fatty acid; SFA: Saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: Polyunsaturated fatty acids; TBARS: Thiobarbituric acid reactive substances; n.d.: not determined.

species from fatty acids by means of initiators, chain reactions (highly reactive free radicals) and formation of end degradation products (which includes malonaldehyde and cholesterol oxides). The progression of lipolysis and lipid oxidation leads, under controlled conditions, to development of characteristic attributes in the salted products at the end of processing. However, factors that induce intense and prolonged lipolytic and oxidative activity should be avoided due to potential loss of quality (Bermúdez et al. 2014; Ladikos and Lougovois 1990; Petrova et al. 2015). Particularly for NaCl, this salt is usually present in high content in salted meat products and known to influence the progression of lipolysis during the processing of this class of meat products (Lorenzo, Fonseca, et al. 2015; Mariutti and Bragagnolo 2017). The Table 3 presents the impact of NaCl substitution on the lipolysis and lipid oxidation of salted meat products.

The impact of NaCl substitution by different proportions of KCl, $CaCl_2$ and $MgCl_2$ in the lipolysis of lacón was evaluated by Lorenzo, Cittadini, et al. (2015). The authors observed that lipolysis stated in the salting stage for all treatments. The maximum values of total FFA were observed at the end of dry-ripening period, particularly for the salting mixture composed of 30% NaCl, 50% KCl, 15% $CaCl_2$ and 5% $MgCl_2$ that displayed the highest FFA content. Oleic acid was the main FFA followed by palmitic, and linoleic acid for all treatments.

The influence of NaCl replacing was also observed on the lipolitic stability of pork loin during processing (Zhang et al. 2015). This expeirment explored two salting mixtures: NaCl and the combination of NaCl, KCl, with the combination of L-histidine and L-lysine (39.7%, 51.3%, and 9%, respectively) and indicated similar impact in the release of fatty acids from phospholipids between salting mixtures. An interesting outcome obtained in this research is the individual impact of increasing concentration (up to 0.4 M) of NaCl, KCl, of L-histidine and L-lysine on the activity of phospholipase, acid lipase, and neutral lipase. While NaCl and KCl dispayed similar effect to inhibit the activity of these three enzymes, only neutral lipase was inhibited by L-histidine and L-lysine and induced the catalytic effect of phospholipase and acid lipase.

A similar outcome was obtained in another experiment (Armenteros et al. 2009b). The impact of NaCl substitution by KCl (from 100 to 305 and from 0% to 70% in the salting mixture, respectively) was not associated with significant differences on the FFA profile of dry-cured loin. In addition, Cittadini et al. (2020) also noticed that the partial replacement of NaCl by other salts (50% NaCl and 50% KCl; 45% NaCl, 25% KCl, 20% $CaCl_2$ and 10% $MgCl_2$) did not show significant differences in either contents of monounsaturated (MUFA), saturated (SFA) or polyunsaturated (PUFA) FFA content in the dry-cured foal cecina. However, another study obtained a different outcome for salting mixtures with $CaCl_2$ and $MgCl_2$ (Armenteros et al. 2009a). The release of SFA and MUFA during processing of pork loin was reduced in the dry-cured loin containing 45% NaCl, 25% KCl, 20% $CaCl_2$ and 10% $MgCl_2$ in comparison to control (100% NaCl) and other treatments with other chloride salts. Moreover, non-significant differences were indicated for free PUFA and total FFA content among treatments. The authors argued that the differences observed in the composition of FFA could be attributed to Mg^{2+} content.

The influence of NaCl substitution on lipolysis was also evaluated during the processing of dry-cured ham (Ripollés et al. 2011). The main effect was associated with the salting mixture containing 55% NaCl, 25% KCl, 15% $CaCl_2$ and 5% $MgCl_2$ in comparison to control and other combinations of NaCl with chloride salts, particularly for free saturated fatty acids (SFA) and monounsaturated fatty acid (MUFA). Moreover, the authors also evaluated the impact of individual chloride salts on the activity of acid lipase (up to 0.4 M for NaCL, KCl, $CaCl_2$, and 5% $MgCl_2$) observed that NaCl and KCl induced the more intense inhibitory effect on the acid lipase activity than $CaCl_2$, and $MgCl_2$ at lower concentrations (0.0021 and 0.0015 M) obtained at the end of dry-ripening period.

Effect of NaCl reduction or replacement on lipid oxidation

The progression of lipid oxidation is directly associated with the oxidative balance within the meat structure wherein the activity of pro-oxidant (such as high temperature, presence of transition metals, and exposure to oxygen) and antioxidant (antioxidant enzymes, for instance) factors play a major role in the oxidative stability of fatty acids in salted meat products (Mariutti and Bragagnolo 2017). In this regard, lipid oxidation of lacón during processing was also influenced NaCl substitution (Lorenzo, Cittadini, et al. 2015). While the lacóns elaborated with 45% NaCl, 25% KCl, 20% $CaCl_2$ and 10% $MgCl_2$ displayed the highest malonaldehyde content, the two salting mixtures composed of 50% NaCl with 50% KCl and 30% NaCl, 50% KCl, 15% $CaCl_2$ with 5% $MgCl_2$ displayed the lowest values after the dry-ripening stage.

Regarding the evolution of lipid oxidation of pork loin during processing, (Zhang et al. (2015) noticed remarkable different between treatment for each processing stage (raw meat, end of salting, and during and after dry-curing) were not indicated by the authors. In addition, the evolution of lipid oxidation was also influenced by the NaCl substitution in dry-cured ham (Ripollés et al. 2011). The thiobarbituric acid reactive substances (TBARS) assay on dry-cured hams indicated values higher than 1.5 μg malondialdehyde/g muscle after 100 days while the control treatment achieved this values after 330 days of processing.

On the other hand, the evolution of lipid oxidation during the processing of jerked beef was influenced by salting mixture (Vidal, Biachi, et al. 2019). The generation of lipid oxidation products was improved by salting jerked beef with 50% NaCl +50% $CaCl_2$ at the end of ripening period while the other formulation displayed lower TBARS values. Conversely, the NaCl substitution did not induce significant on the lipid oxidation during the processing of pastirma (a traditional Turkish dry-cured meat product) (Hastaoglu and Vural 2018). This study evaluated two combinations of NaCl with KCl (85% NaCl with 15% KCl and 70% NaCl with 30% KCl) and a control treatment with 100% NaCl. The authors reported similar evolution of lipid oxidation during processing regardless of salting mixture. It is worth mentioning that after the second drying period, the meat pieces are covered with fenugreek paste (composed of garlic, fenugreek flour, bitter pepper, sweet pepper, and water) and rested for 24 h, which seemed to induce the remarkable increase in TBARS level of final product. After this stage, the formation of lipid oxidation products increased remarkably from vales around 0.5 mg malondialdehyde/kg to values in the range of 1.5–2.5 mg malondialdehyde/kg.

In the case o traditional Chinese bacon, the partial replacing of NaCl by KCl (from 100% to 30% and from 0% to 70%, respectively) lead to a mild inhibition of lipid oxidation during processing (Gan et al. 2019). at the end of

Table 4. Effect of the partial NaCl substitution by other chloride salts on sensory attributes of salted meat products at the end of processing.

Product	Salting mixtures (%)	Effect on sensory properties	Reference
Dry-cured lacón	C (100% NaCl); F1 (50% NaCl and 50% KCl); F2 (45% NaCl, 25% KCl, 20% $CaCl_2$ and 10% $MgCl_2$); and F3 (30% NaCl, 50% KCl, 15% $CaCl_2$ and 5% $MgCl_2$)	C treatment received the highest scores for saltiness and the lowest for bitterness; non-significant effect on intensity of color and odor, and hardness	Lorenzo, Bermúdez, et al. 2015
Dry-cured loin	C (100% NaCl); F1 (65% NaCl and 35% KCl); F2 (50% NaCl and 50% KCl), and F3 (30% NaCl and 70% KCl)	F1 and F2 were similarly or more preferred than C; F3 was less preferred than C treatment	Armenteros et al. 2009b
Dry-cured loin	C (100% NaCl); F1 (55% NaCl, 25% KCl, 15% $CaCl_2$ and 5% $MgCl_2$); F2 (45% NaCl, 25% KCl, 20% $CaCl_2$ and 10% $MgCl_2$); and F3 (30% NaCl, 50% KCl, 15% $CaCl_2$ and 5% $MgCl_2$)	F1 was similarly or more preferred than C; F2 and F3 were less preferred than C for most of sensory attributes	Armenteros et al. 2009a
Dry-cured ham	C (100% NaCl); F1 (50% NaCl and 50% KCl); and F2 (55% NaCl, 25% KCl, 15% $CaCl_2$ and 5% $MgCl_2$)	F1 and C were similarly preferred for aroma, hardness, and juiciness; F2 was less preferred than C for aroma, taste and hardness	Armenteros et al. 2012
Jerked beef	C (100% NaCl); F1 (50% NaCl and 50% KCl); F2 (50% NaCl and 50% $CaCl_2$); and F3 (50% NaCl, 25% KCl and 25% $CaCl_2$)	F1 received the same scores to C for all attributes; F2 and F3 received scores different than C	Vidal, Biachi, et al. 2019
Dry-cured bacon	C (100% NaCl); F1 (80% NaCl and 20% KCl); F2 (60% NaCl and 40% KCl); and F3 (40% NaCl and 60% KCl)	F1 received similar scores to C for all attributes; non-significant differences among treatments for color and aroma	Li et al. 2016
Dry-cured bacon	C (100% NaCl); F1 (60% NaCl and 40% KCl); and F2 (30% NaCl and 70% KCl)	F1 received similar scores to C for almost all attributes; non-significant differences among treatments for redness and yellowness	Wu et al. 2014
Pastirma	C (100% NaCl); F1 (85% NaCl and 15% KCl); and F2 (70% NaCl and 30% KCl)	F1 received the highest scores for color; F2 received the lowest scores for flavor and chewiness; non-significant differences among treatments for aroma	

C: Control; Fn: Formulation regarding the composition of salting mixture (NaCl, KCl, $CaCl_2$, and $MgCl_2$).

ripening period, the bacon elaborated with 30% NaCl and 70% KCl displayed the lowest TBARS levels, while the other combinations of NaCl and KCl displayed intermediate values. The highest values were reported for control treatment. Interestingly, another experiment indicated an oposite outcome regarding the impact of NaCl substitution on the oxidative stability of lipids during the processing of dry-cured bacon (Wu et al. 2016). In this case, reducing the proportion of NaCl in the salting mixture (from 100% to 30%) favored the progresison of oxidative reactions in the lipids of dry-cured bacons. The authors also evaluated the impact of NaCl substitution on the activity of antioxidants enzymes (glutathione peroxidase and catalase) found in vivo. While the activity of glutathione peroxidase was better preserved by reducing NaCl proportion in the salting mixture during processing, catalase activity was reduced as NaCl proportion was reduced.

In foal cecina, Cittadini et al. (2020) observed that lipid oxidation was affected by NaCl replacement. In this study, samples salted with the mixture of chlorinated salts presented the higher TBARs values (5.05 mg MDA/kg *vs.* 3.66 and 3.31 mg MDA/kg, for cecinas salted with 45% NaCl, 25% KCl, 20% $CaCl_2$ and 10% $MgCl_2$; 100% NaCl and 50% NaCl and 50% KCl, respectively). These authors suggested that the presence of $CaCl_2$ in the mixture used to salt cecinas could be responsible for promoting lipid oxidation. On the other hand, the lower values obtained in samples salted with 50% NaCl and 50% KCl was linked to the substitution of NaCl by KCl, which would reduce the prooxidant effect of sodium chloride (Cittadini et al. 2020).

The influence of NaCl substitution by chloride salts seems to induce minor changes in the evolution of lipolytic reactions of salted meat products, particularly for products elaborated with KCl. However, a more complex scenario is observed for the effect of NaCl substitution on the evolution of lipid oxidation. Reducing NaCl proportion in the salting mixture does not necessarily slow the progress of lipid oxidation. For instance, pro-oxidant effect was associated with high proportions of KCl (Ripollés et al. 2011; Wu et al. 2016). Moreover, the role of divalent salts in both lipolysis and lipid oxidation remains unclear (particularly Mg^{2+}) due to contrasting results observed among studies (Armenteros et al. 2009a; Lorenzo, Bermúdez, et al. 2015). Finally, lipolysis and lipid oxidation seems to take place at same time, indicating that the release of fatty acids is not a necessary stage prior to oxidation. This outcome was reported by other authors in salted meat produtcs (Jin et al. 2010; Muriel et al. 2007).

Effect of reduce or replace NaCl by chloride salts on sensory attributes

The intense modifications caused during processing of salted meat products leads to formation of compounds associated with characteristic sensory attributes (color, flavor, and texture, for instance). This scenario is largely influenced by modifications in the structure and chemical composition of proteins and lipids by the progression of enzymatic (release of peptides, amino acids and FFA) and oxidative reactions (which in turn induce the formation of volatile compounds) (Aristoy and Toldrá 1995; Flores et al. 1997; Toldrá, Flores, and Sanz 1997). It is interesting notice that some products formed (directly or indirectly) are associated with basic tastes and also more complex sensations such as tenderness and juiciness (García-González et al. 2008; Guàrdia et al. 2010). In the same line, texture is another relevant sensory attribute that characterize salted meat products (Guàrdia et al. 2010). Moreover, salting steps has been associated with significant changes in the sensory characteristics of salted meat products (Garrido et al. 2012; Purriños et al. 2012).

The influence of NaCl substitution by other chloride salts in the sensory attributes of salted meat products is shown in Table 4. The common outcome obtained for the majority of the studies is the potential role of KCl had by inducing minor changes in the perception of many sensory attributes. For instance, the experiment carried out with lacón salted with NaCl and other salts (KCl, $CaCl_2$ and $MgCl_2$) indicated non-significant effect on intensity of color and odor, and hardness at the end of ripening period (Lorenzo, Bermúdez, et al. 2015). However, the authors also observed that the lacóns elaborated with KCl, $CaCl_2$ and $MgCl_2$ were perceived as less salty and bitterer than control treatment.

In the case of dry-cured loin, non-significant differences were obtained for the preference of aroma, texture, taste, and overall quality between control and NaCl + KCl (up to 50% of NaCl substitution) salting mixtures (Armenteros et al. 2009b). Interestingly, the authors indicated that the color of loins salted with 65% NaCl + 35% KCl was more preferred than control formulation. A similar outcome was obtained by the same research group using the salting mixture composed of 55% NaCl, 25% KCl, 15% $CaCl_2$ and 5% $MgCl_2$ (Armenteros et al. 2009a) in dry-cured loin. In addition, the other salting mixtures (45% NaCl + 25% KCl + 20% $CaCl_2$ + 10% $MgCl_2$ and 30% NaCl + 50% KCl + 15% $CaCl_2$ + 5% $MgCl_2$) were less preferred than control treatment.

The sensory evaluation of the dry-cured ham salted with different chloride salts indicated a similar outcome for control and 50% NaCl + 50% KCl treatments for aroma, hardness, and juiciness (Armenteros et al. 2012). However, the hardness of this NaCl and KCl combination was less preferred in comparison to control. The authors also observed that the salting mixture composed of 55% NaCl, 25% KCl, 15% $CaCl_2$ and 5% $MgCl_2$ was less preferred than control for aroma, taste and hardness. Likewise, the composition of salting mixture induced significant differences in the sensory characteristics of jerked beef (Vidal, Biachi, et al. 2019). These differences were obtained for the products elaborated with $CaCl_2$ (50% NaCl + 50% $CaCl_2$ and 50% NaCl + 25% KCl + 25% $CaCl_2$) that received lower scores for juiciness and higher scores for apparent fibrosity, rancid aroma, bitter taste, after taste, and fibrosity in comparison to other treatments (control and 50% NaCl +50% KCl).

In the same line, the combined use of NaCl and KCl (80% and 20%, respectively) in the salting of bacon was associated with similar scores to control treatments regarding color, aroma, hardness, saltiness, bitterness, and overall acceptability (Li et al. 2016). It is worth mentioning that marked differences were reported between control and salting mixture composed of 40% NaCl + 60% KCl for hardness, saltiness, and bitterness. A similar outcome was reported for another experiment with NaCl and KCl (from 100% to 30% and from 0% and 70%, respectively) in bacon (Wu et al. 2014). Finally, the influence of NaCl substitution in the sensory properties of pastirma indicated that using the combination of 85% NaCl and 15% KCl in the salting mixture was associated with higher scores for color in comparison to other treatments. Conversely, reducing the proportion of NaCl (70% NaCl and 30% KCl) in the salting mixture lead to reduction on scores for flavor and chewiness, in comparison to control treatment.

Conclusion

It is well known that NaCl cannot be totally eliminated from meat manufactured due to its functionality on the main characteristics of the final products. In this regard, NaCl substitution in salted meat products is a complex and challenging task that involves the evaluation of multiple reactions and modifications in their structure and composition during processing. Taking into account the impact on microbial load, safety, proteolysis, lipolysis, oxidative reactions and sensory attributes, KCl is the most promising chloride salt to partially replace NaCl (around to 50%) in a binary salting mix. Proportions with more than 50% of KCl were associated with significant changes in the characteristics of salted meat products during processing. In this regard, several studies have shown that replacing NaCl by other chloride salts (KCl, $CaCl_2$ and $MgCl_2$) proved to be effective and a safe option for inhibiting the growth of microorganisms in salted meat products. Thus, a salting mixture composed by 55% NaCl, 25% KCl, 15% $CaCl_2$ and 5% $MgCl_2$ can be used for reducing sodium in meat products.

There are other alternative substances used as salt substitutes such as salts of organic acids (sodium lactate, potassium lactate and sodium diacetate), small peptides (L-ornithyl taurine or L-ornithyl-β-alanine and the methyl and ethyl esters of glycine), flavor enhancers (monosodium glutamate, disodium inosinate, yeast extract and hydrolyzed vegetable proteins) which can be also used as NaCl replacement in meat products made from whole pieces. In this regard, the use of lysine and yeast extract can minimize the negative sensory effects provided by the addition of $CaCl_2$ without changing the physicochemical quality parameters and safety of salted meat treatments.

Since NaCl substitution can influence the development of major reactions during processing, it is of great value determine how these changes influence the product under storage conditions. The characterization of economic viability of NaCl substitution is another relevant aspect. Although scientific evidence supports the substitution of NaCl for other chloride salts, moving this information toward a higher productive level for commercialization purposes still require major efforts in order to define appropriate market niches, adequate marketing and labeling, for instance.

Disclosure statement

None.

Funding

Vitor A. S. Vidal and Marise A. R. Pollonio would like to thank CNPq (process numbers: 140533/2015-0 and 406671/2016-8) for its support. Paulo E. S. Munekata acknowledges postdoctoral fellowship support from Ministry of Economy and Competitiveness (MINECO, Spain) "Juan de la Cierva" program (FJCI-2016-29486). Jose M. Lorenzo is member of the HealthyMeat network, funded by CYTED (ref. 119RT0568). Thanks to GAIN (Axencia Galega de Innovación) for supporting this research (grant number IN607A2019/01).

ORCID

Vitor A. S. Vidal http://orcid.org/0000-0002-9194-5901
Jose M. Lorenzo http://orcid.org/0000-0002-7725-9294
Paulo E. S. Munekata http://orcid.org/0000-0001-5559-1408
Marise A. R. Pollonio http://orcid.org/0000-0002-9273-1710

References

Aliño, M., R. Grau, A. Fuentes, and J. M. Barat. 2010. Characterisation of pile salting with sodium replaced mixtures of salts in dry-cured loin manufacture. *Journal of Food Engineering* 97 (3):434–9. doi: 10.1016/j.jfoodeng.2009.10.039.

Aliño, M., R. Grau, F. Toldrá, E. Blesa, M. J. Pagán, and J. M. Barat. 2010. Physicochemical properties and microbiology of dry-cured loins obtained by partial sodium replacement with potassium, calcium and magnesium. *Meat Science* 85 (3):580–8. doi: 10.1016/j.meatsci.2010.03.009.

Aristoy, M. C., and F. Toldrá. 1995. Isolation of flavor peptides from raw pork meat and dry-cured ham. *Developments in Food Science* 37 (C):1323–44. 10.1016/S0167-4501(06)80236-0.

Armenteros, M., M. C. Aristoy, J. M. Barat, and F. Toldrá. 2009a. Biochemical and sensory properties of dry-cured loins as affected by partial replacement of sodium by potassium, calcium, and magnesium. *Journal of Agricultural and Food Chemistry* 57 (20):9699–705. doi: 10.1021/jf901768z.

Armenteros, M., M. C. Aristoy, J. M. Barat, and F. Toldrá. 2009b. Biochemical changes in dry-cured loins salted with partial replacements of NaCl by KCl. *Food Chemistry* 117 (4):627–33. doi: 10.1016/j.foodchem.2009.04.056.

Armenteros, M., M. C. Aristoy, J. M. Barat, and F. Toldrá. 2012. Biochemical and sensory changes in dry-cured ham salted with partial replacements of NaCl by other chloride salts. *Meat Science* 90 (2):361–7. doi: 10.1016/j.meatsci.2011.07.023.

Bermúdez, R., D. Franco, J. Carballo, and J. M. Lorenzo. 2014. Physicochemical changes during manufacture and final sensory characteristics of dry-cured Celta ham. Effect of muscle type. *Food Control* 43:263–9. doi: 10.1016/j.foodcont.2014.03.028.

Bibbins-Domingo, K., G. M. Chertow, P. G. Coxson, A. Moran, J. M. Lightwood, M. J. Pletcher, and L. Goldman. 2010. Projected effect of dietary salt reductions on future cardiovascular disease. *Obstetrical and Gynecological Survey* 65 (7):441–2. 10.1097/OGX.0b013e3181e5f253.

Blesa, E., M. Aliño, J. M. Barat, R. Grau, F. Toldrá, and M. J. Pagán. 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 (1-2):135–42. doi: 10.1016/j.meatsci.2007.07.008.

Cittadini, A., R. Domínguez, B. Gómez, M. Pateiro, C. Pérez-Santaescolástica, O. López-Fernández, M. V. Sarriés, and J. M. Lorenzo. 2020. Effect of NaCl replacement by other chloride salts on physicochemical parameters, proteolysis and lipolysis of dry-cured foal "cecina". *Journal of Food Science and Technology* 57 (5): 1628–35. doi: 10.1007/s13197-019-04195-6.

Cook, N. R., L. J. Appel, and P. K. Whelton. 2016. Sodium intake and all-cause mortality over 20 years in the trials of hypertension prevention. *Journal of the American College of Cardiology* 68 (15): 1609–17. doi: 10.1016/j.jacc.2016.07.745.

Devlieghere, F., L. Vermeiren, E. Bontenbal, P.-P. Lamers, and J. Debevere. 2009. Reducing salt intake from meat products by combined use of lactate and diacetate salts without affecting microbial stability. *International Journal of Food Science & Technology* 44 (2): 337–41. doi: 10.1111/j.1365-2621.2008.01724.x.

Domínguez, R., P. Munekata, A. Cittadini, and J. M. Lorenzo. 2016. Effect of the Partial NaCl Substitution by Other Chloride Salts on the Volatile Profile during the Ripening of Dry-Cured Lacón. *Grasas y Aceites* 67 (2):e128. doi: 10.3989/gya.0505152.

dos Santos Alves, L. A. A., J. M. Lorenzo, C. A. A. Gonçalves, B. A. dos Santos, R. T. Heck, A. J. Cichoski, and P. C. B. Campagnol. 2017. Impact of lysine and liquid smoke as flavor enhancers on the quality of low-fat Bologna-type sausages with 50% replacement of NaCl by KCl. *Meat Science* 123:50–6. https://linkinghub.elsevier.com/retrieve/pii/S0309174016302662. doi: 10.1016/j.meatsci.2016.09.001.

dos Santos, B. A., P. C. B. Campagnol, M. B. Fagundes, R. Wagner, and M. A. R. Pollonio. 2017. Adding blends of NaCl, KCl, and CaCl2 to low-sodium dry fermented sausages: Effects on lipid oxidation on curing process and shelf life. *Journal of Food Quality* 2017: 1–11. doi: 10.1155/2017/7085798.

Estévez, M. 2011. Protein carbonyls in meat systems: A review. *Meat Science* 89 (3):259–79. doi: 10.1016/j.meatsci.2011.04.025.

Flores, M., M. C. Aristoy, A. M. Spanier, and F. Toldrá. 1997. Non-volatile components effects on quality of "Serrano" dry-cured ham as related to processing time. *Journal of Food Science* 62 (6):1235–9. doi: 10.1111/j.1365-2621.1997.tb12252.x.

Gan, X., H. Li, Z. Wang, A. M. Emara, D. Zhang, and Z. He. 2019. Does protein oxidation affect proteolysis in low sodium Chinese traditional bacon processing? *Meat Science* 150 (2):14–22. doi: 10.1016/j.meatsci.2018.10.007.

García-González, D. L., N. Tena, R. Aparicio-Ruiz, and M. T. Morales. 2008. Relationship between sensory attributes and volatile compounds qualifying dry-cured hams. *Meat Science* 80 (2):315–25. doi: 10.1016/j.meatsci.2007.12.015.

Garrido, R., R. Domínguez, J. M. Lorenzo, I. Franco, and J. Carballo. 2012. Effect of the length of salting time on the proteolytic changes in dry-cured lacón during ripening and on the sensory characteristics of the final product. *Food Control* 25 (2):789–96. doi: 10.1016/j.foodcont.2011.11.036.

Guàrdia, M. D., A. P. S. Aguiar, A. Claret, J. Arnau, and L. Guerrero. 2010. Sensory characterization of dry-cured ham using free-choice profiling. *Food Quality and Preference* 21 (1):148–55. doi: 10.1016/j.foodqual.2009.08.014.

Hastaoglu, E., and H. Vural. 2018. New approaches to production of Turkish-type dry-cured meat product "pastirma": Salt reduction and different drying Techniques. *Korean Journal for Food Science of Animal Resources* 38 (2):224–39. doi: 10.5851/kosfa.2018.38.2.224.

Horita, C. N., V. C. Messias, M. A. Morgano, F. M. Hayakawa, and M. A. R. Pollonio. 2014. Textural, microstructural and sensory properties of reduced sodium frankfurter sausages containing mechanically deboned poultry meat and blends of chloride salts. *Food Research International* 66:29–35. doi: 10.1016/j.foodres.2014.09.002.

Inguglia, E. S., Z. Zhang, B. K. Tiwari, J. P. Kerry, and C. M. Burgess. 2017. Salt reduction strategies in processed meat products – A review. *Trends in Food Science & Technology* 59:70–8. doi: 10.1016/j.tifs.2016.10.016.

Jiménez-Colmenero, F., J. Ventanas, and F. Toldrá. 2010. Nutritional composition of dry-cured ham and its role in a healthy diet. *Meat Science* 84 (4):585–93. doi: 10.1016/j.meatsci.2009.10.029.

Jin, G., J. Zhang, X. Yu, Y. Zhang, Y. Lei, and J. Wang. 2010. Lipolysis and lipid oxidation in bacon during curing and drying-ripening. *Food Chemistry* 123 (2):465–71. doi: 10.1016/j.foodchem.2010.05.031.

Kilic, B. 2009. Current trends in traditional Turkish meat products and cuisine. *LWT - Food Science and Technology* 42 (10):1581–9. doi: 10.1016/j.lwt.2009.05.016.

Ladikos, D., and V. Lougovois. 1990. Lipid oxidation in muscle foods: A review. *Food Chemistry* 35 (4):295–314. doi: 10.1016/0308-8146(90)90019-Z.

Li, F., H. Zhuang, W. Qiao, J. Zhang, and Y. Wang. 2016. Effect of partial substitution of NaCl by KCl on physicochemical properties, biogenic amines and N-nitrosamines during ripening and storage of dry-cured bacon. *Journal of Food Science and Technology* 53 (10): 3795–805. doi: 10.1007/s13197-016-2366-x.

Lorenzo, J. M., R. Bermúdez, R. Domínguez, A. Guiotto, D. Franco, and L. Purriños. 2015. Physicochemical and microbial changes during the manufacturing process of dry-cured lacón salted with potassium, calcium and magnesium chloride as a partial replacement for sodium chloride. *Food Control* 50:763–9. doi: 10.1016/j.foodcont.2014.10.019.

Lorenzo, J. M., A. Cittadini, R. Bermúdez, P. E. Munekata, and R. Domínguez. 2015. Influence of partial replacement of NaCl with KCl, CaCl2 and MgCl2 on proteolysis, lipolysis and sensory properties during the manufacture of dry-cured lacón. *Food Control* 55: 90–6. doi: 10.1016/j.foodcont.2015.02.035.

Lorenzo, J. M., S. Fonseca, M. Gómez, and R. Domínguez. 2015. Influence of the salting time on physico-chemical parameters, lipolysis and proteolysis of dry-cured foal "cecina. *LWT - Food Science and Technology* 60 (1):332–8. doi: 10.1016/j.lwt.2014.07.023.

Lorenzo, J. M., B. Prieto, J. Carballo, and I. Franco. 2003. Compositional and degradative changes during the manufacture of dry-cured "lacón. *Journal of the Science of Food and Agriculture* 83 (6):593–601. doi: 10.1002/jsfa.1375.

Mariutti, L. R. B., and N. Bragagnolo. 2017. Influence of salt on lipid oxidation in meat and seafood products: A review. *Food Research International (Ottawa, Ont.)* 94:90–100. doi: 10.1016/j.foodres.2017.02.003.

Martín, L., J. J. Córdoba, T. Antequera, M. L. Timón, and J. Ventanas. 1998. Effects of salt and temperature on proteolysis during ripening of Iberian ham. *Meat Science* 49 (2):145–53. doi: 10.1016/S0309-1740(97)00129-0.

Muriel, E., A. I. Andres, M. J. Petron, T. Antequera, and J. Ruiz. 2007. Lipolytic and oxidative changes in Iberian dry-cured loin. *Meat Science* 75 (2):315–23. doi: 10.1016/j.meatsci.2006.07.017.

Nachtigall, F. M., V. A. S. Vidal, R. D. Pyarasani, R. Domínguez, J. M. Lorenzo, M. A. R. Pollonio, and L. S. Santos. 2019. Substitution effects of NaCl by KCl and CaCl2 on lipolysis of salted meat. *Foods* 8 (12):595. doi: 10.3390/foods8120595.

Pandya, J. K., K. E. Decker, T. Goulette, and A. J. Kinchla. 2020. Sodium reduction in Turkey breast meat by using sodium anion species. *LWT* 124:109110. doi: 10.1016/j.lwt.2020.109110.

Pateiro, M., D. Franco, J. A. Carril, and J. M. Lorenzo. 2015. Changes on physico-chemical properties, lipid oxidation and volatile compounds during the manufacture of celta dry-cured loin. *Journal of Food Science and Technology* 52 (8):4808–18. doi: 10.1007/s13197-014-1561-x.

Petrova, I., I. M. Aasen, T. Rustad, and T. M. Eikevik. 2015. Manufacture of dry-cured ham: A review. Part 1. Biochemical changes during the technological process. *European Food Research and Technology* 241 (5):587–99. doi: 10.1007/s00217-015-2490-2.

Purriños, L., R. Bermúdez, D. Franco, J. Carballo, and J. M. Lorenzo. 2011. Development of volatile compounds during the manufacture of dry-cured "Lacón," a Spanish traditional meat product. *Journal of Food Science* 76 (1):C89–C97. doi: 10.1111/j.1750-3841.2010.01955.x.

Purriños, L., D. Franco, J. Carballo, and J. M. Lorenzo. 2012. Influence of the salting time on volatile compounds during the manufacture of dry-cured pork shoulder "lacón." *Meat Science* 92 (4):627–34. doi: 10.1016/j.meatsci.2012.06.010.

Purriños, L., M. C. García Fontán, J. Carballo, and J. M. Lorenzo. 2013. Study of the counts, species and characteristics of the yeast population during the manufacture of dry-cured "lacón" Effect of salt level. *Food Microbiology* 34 (1):12–8. doi: 10.1016/j.fm.2012.11.003.

Ripollés, S., P. C. B. Campagnol, M. Armenteros, M. C. Aristoy, and F. Toldrá. 2011. Influence of partial replacement of NaCl with KCl, CaCl2 and MgCl2 on lipolysis and lipid oxidation in dry-cured ham. *Meat Science* 89 (1):58–64. doi: 10.1016/j.meatsci.2011.03.021.

Shahidi, F., and A. G. P. Samaranayaka. 2004. Curing brine. In *Encyclopedia of meat sciences*, eds. Werner K. Jensen, 366–74. Oxford: Elsevier.

Stanley, R. E., C. G. Bower, and G. A. Sullivan. 2017. Influence of sodium chloride reduction and replacement with potassium chloride based salts on the sensory and physico-chemical characteristics of pork sausage patties. *Meat Science* 133:36–42. doi: 10.1016/j.meatsci.2017.05.021.

Soladoye, O. P., M. L. Juárez, J. L. Aalhus, P. Shand, and M. Estévez. 2015. Protein oxidation in processed meat: Mechanisms and potential implications on human health. *Comprehensive Reviews in Food Science and Food Safety* 14 (2):106–22. doi: 10.1111/1541-4337.12127.

Strazzullo, P., L. D'Elia, N.-B. Kandala, and F. P. Cappuccio. 2009. Salt intake, stroke, and cardiovascular disease: Meta-analysis of prospective studies. *BMJ (Clinical Research ed.)* 339 (7733):b4567. doi: 10.1136/bmj.b4567.

Tangkham, W., and F. LeMieux. 2016. Sensory, physicochemical and microbiological characteristics of Venison Jerky cured with NaCl and KCl. *Journal of Food Research* 5 (4):36. doi: 10.5539/jfr.v5n4p36.

Taylor, T. M., and P. M. Davidson. 2007. Chemical Preservatives and Natural Antimicrobial Compounds. In *Food Microbiology: Fundamentals and Frontiers*, eds. M. P. Doyle and L. R. Beuchat, 3rd ed., 713–45. Washington: American Society of Microbiology. 10.1128/9781555815912.ch33.

Toldrá, F. 2002. Characterization of proteolysis. In *Dry-cured meat products*, 113–34. Trumbull: Food & Nutrition Press.

Toldrá, F., M. Flores, and Y. Sanz. 1997. Dry-cured ham flavour: Enzymatic generation and process influence. *Food Chemistry* 59 (4): 523–30. doi: 10.1016/S0308-8146(97)00013-7.

Torres, E., A. M. Pearson, J. I. Gray, P. K. Ku, and M. Shimokomaki. 1989. Lipid oxidation in charqui (salted and dried beef). *Food Chemistry* 32 (4):257–68. doi: 10.1016/0308-8146(89)90085-X.

Vidal, V. A. S., J. P. Biachi, C. S. Paglarini, M. B. Pinton, P. C. B. Campagnol, E. A. Esmerino, A. G. da Cruz, M. A. Morgano, and M. A. R. Pollonio. 2019. Reducing 50% sodium chloride in healthier jerked beef: An efficient design to ensure suitable stability, technological and sensory properties. *Meat Science* 152:49–57. doi: 10.1016/j.meatsci.2019.02.005.

Vidal, V. A. S., O. D. Bernardinelli, C. S. Paglarini, E. Sabadini, and M. A. R. Pollonio. 2019. Understanding the effect of different chloride salts on the water behavior in the salted meat matrix along 180 days of shelf life. *Food Research International (Ottawa, Ont.)* 125:108634. doi: 10.1016/j.foodres.2019.108634.

Vidal, V. A. S., C. D. S. Paglarini, A. Ferreira, J. R. D. Santos, and M. A. R. Pollonio. 2019. Influence of the addition of KCl and CaCl2 blends on the physicochemical parameters of salted meat products throughout the processing steps. *Food Science and Technology*. 10.1590/fst.14919.

Vidal, V. A. S., C. S. Paglarini, M. Q. Freitas, L. O. Coimbra, E. A. Esmerino, M. A. R. Pollonio, and A. G. Cruz. 2020. Q Methodology: An interesting strategy for concept profile and sensory description of low sodium salted meat. *Meat Science* 161:108000. doi: 10.1016/j.meatsci.2019.108000.

Vidal, V. A. S., J. B. Santana, C. S. Paglarini, M. A. A. P. da Silva, M. Q. Freitas, E. A. Esmerino, A. G. Cruz, and M. A. R. Pollonio. 2020. Adding lysine and yeast extract improves sensory properties of low sodium salted meat. *Meat Science* 159:107911. doi: 10.1016/j.meatsci.2019.107911.

Weaver, C. 2013. White vegetables: A forgotten source of nutrients potassium and health 1 – 3. *American Society for Nutrition* 4: 3685–775. 10.3945/an.112.003533.smoking.

Whelton, P. K., L. J. Appel, R. L. Sacco, C. A. M. Anderson, E. M. Antman, N. Campbell, S. B. Dunbar, E. D. Frohlich, J. E. Hall, M. Jessup, et al. 2012. Sodium, blood pressure, and cardiovascular disease: Further evidence supporting the American Heart Association sodium reduction recommendations. *Circulation* 126 (24):2880–9. doi: 10.1161/CIR.0b013e318279acbf.

Wu, H., W. Yan, H. Zhuang, M. Huang, J. Zhao, and J. Zhang. 2016. Oxidative stability and antioxidant enzyme activities of dry-cured bacons as affected by the partial substitution of NaCl with KCl. *Food chemistry* 201:237–42. doi: 10.1016/j.foodchem.2016.01.025.

Wu, H., Y. Zhang, M. Long, J. Tang, X. Yu, J. Wang, and J. Zhang. 2014. Proteolysis and sensory properties of dry-cured bacon as affected by the partial substitution of sodium chloride with potassium chloride. *Meat Science* 96 (3):1325–31. doi: 10.1016/j.meatsci.2013.10.037.

Wu, H., H. Zhuang, Y. Zhang, J. Tang, X. Yu, M. Long, J. Wang, and J. Zhang. 2015. Influence of partial replacement of NaCl with KCl on profiles of volatile compounds in dry-cured bacon during processing. *Food Chemistry* 172:391–9. doi: 10.1016/j.foodchem.2014.09.088.

Yotsuyanagi, S. E., C. J. Contreras-Castillo, M. M. H. Haguiwara, K. M. V. A. B. Cipolli, A. L. S. C. Lemos, M. A. Morgano, and E. A. Yamada. 2016. Technological, sensory and microbiological impacts of sodium reduction in frankfurters. *Meat Science* 115:50–9. doi: 10.1016/j.meatsci.2015.12.016.

Zhang, Y. W. W., L. Zhang, T. Hui, X. Y. Y. Guo, and Z. Q. Q. Peng. 2015. Influence of partial replacement of NaCl by KCl, l-histidine and l-lysine on the lipase activity and lipid oxidation in dry-cured loin process. *LWT - Food Science and Technology* 64 (2):966–73. doi: 10.1016/j.lwt.2015.06.073.