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Sodium-reduced lean sausages with fish oil optimized by a mixture design approach

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ABSTRACT

A partial NaCl replacement by KCl and sodium tripolyphosphate on low-fat meat sausages formulated with fish oil was studied using a mixture design. Thermal behavior by modulated differential scanning calorimetry, physicochemical, and textural properties were determined; afterwards they were mathematically modeled as a function of salts content. The thermo-rheological behavior of the different formulations was also studied in a control-stress rheometer. The optimal sodium reduction was found employing a desirability function approach. This formulation was experimentally validated and employed for microstructure analysis by environmental scanning microscopy. The results obtained in this work revealed that partial sodium replacement affected the matrix microstructure, but this change had no impact on sensory acceptability. In comparison with US and Argentinean commercial sausages, our product has 58% and 70% less Na^+ respectively.

1. Introduction

It is well established that excess dietary salt consumed throughout life causes blood pressure to rise with age and greatly increases the risk of cardiovascular diseases, becoming the leading causes of death and disability in many Western countries. In Argentina they are responsible for 30% of diseases (Ministerio de Salud de la Nación, 2013). There is a consensus that a reduction in salt consumption will lower blood pressure, with great potential to produce significant individual and population health benefits (Angell, 2010).

Processed meat products contain in general relatively high amounts of saturated fats and sodium, and production of healthier animal protein foods requires that these two elements would be reduced. Direct reduction of fats and sodium can lead to technological difficulties, making these reductions a serious technological issue in the meat industry (García-García & Totosaus, 2008). Since sodium intake generally exceeds nutritional recommendations in industrialized countries and approximately 20–30% of common salt intake comes from meat products, there is increasing interest among consumers and processors in reducing the use of salt (minimizing sodium) in meat processing (Cofrades, López-López, Solas, Bravo, & Jiménez-Colmenero, 2008).

Salt is necessary during meat processing to induce structural changes through electrostatic interactions between muscle proteins and sodium and chloride ions; these cause swelling of myofibrils, depolymerization of myofilaments, and dissociation of the actomyosin complex. Reduced salt concentrations also lead to decreases in extracted and solubilized myofibrillar proteins, affecting the functionality of the entire meat system. The addition of calcium, magnesium, or potassium chloride salts to meat batters in the presence of NaCl enhances protein extraction and solubility, emulsion stability, and favors the orderly gelation of proteins. Moreover emulsified meat products such as mortadella require specific concentrations of NaCl in the original formulations to promote the extraction of myofibrillar proteins, especially actomyosin complex, which are soluble only in solutions of high ionic strength (Totosaus & Pérez-Chabela, 2009). Myofibrillar proteins extracted in the comminuting process in the presence of NaCl are responsible for the water-holding capacity, emulsification and fat binding properties in the batter and formation of stable gels in the cooking stage (Desmond, 2006).

Potassium chloride has been the most investigated substitute for NaCl in low- or reduced salt/sodium foods and its intake in various

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studies has reduced blood pressure in humans, although in some vulnerable group of population a diet rich in potassium could have damaging effects. From a technological point of view, this salt has been used to ensure the necessary ionic strength to develop stable emulsions; however, its use alone results in a bitter, astringent and metallic taste. At blends over 50:50 sodium chloride/potassium chloride in solution, show a significant increase in bitterness and loss of saltiness (Desmond, 2006). Thus, it is necessary to optimize product formulations with the use of other ingredients and additives besides KCl capable of stabilizing the emulsion.

Ingredient functionality in processed foods can be studied by mixture design methodology, in which the systematic experimental design validates the importance of ingredient interactions. Applying this methodology, García-García and Totosaus (2008) studied the effect of potato starch, locust bean gum and κ-carrageenan mixture interaction on the properties of low-fat sodium reduced sausages; they found that a low proportion of starch can be used as extender if κ-carrageenan and locust bean gum are included in similar proportions.

In a previous work, (Marchetti, Andrés, & Califano, 2014) a response surface methodology was applied in order to optimize carrageenans and milk proteins concentrate levels in low-fat meat sausages with pre-emulsified fish oil (5 g/100 g). Salts levels employed (NaCl = 1.4 g/100 g and sodium tripolyphosphate = 0.2 g/100 g) were below average contents of commercial products. The obtained product had similar physicochemical properties to a commercial product with 20 g/100 g of beef tallow. Moreover the optimized formulation had much better nutritional quality; nevertheless the salt level employed could be reduced to enhance nutritional benefits.

Thus, considering this optimized formulation as the non-sodium replaced one, in the present work the objectives were: i) to study the effect of the partial sodium replacement by potassium on the thermal and thermo-rheological properties of the batters and on the quality parameters of low-fat sausages prepared with pre-emulsified fish oil, ii) to find the optimum combination of NaCl, KCl, and sodium tripolyphosphate that results in a product with similar quality parameters to the non-replaced one, iii) to validate the sodium-reduced optimized formulation by manufacturing it and measuring its quality parameters, comparing the obtained results with the values predicted by mathematical models.

2. Materials and methods

2.1. Materials

Low-fat sausages were prepared using fresh lean beef meat (*adductor femoris* and *semimembranosus muscles*) obtained from local market (pH: 5.48 ± 0.01, fat content: 1.3 ± 0.17 g/100 g). Meat (9 kg, muscles from four different carcasses) without visible fat and connective tissue was passed through a grinder with a 0.95 cm plate (Meifa 32, Buenos Aires, Argentina). Lots of 500 g were vacuum packed in Cryovac BB4L bags (PO_2: 0.35 cm^3m^{-2} day^{-1} kPa^{-1} at 23 °C, Sealed Air Co., Buenos Aires, Argentina), frozen, and stored at −20 °C until used, no more than three weeks (Ayo, Carballo, Solas, & Jiménez-Colmenero, 2005).

As fat source, deodorized refined fish oil with 1000 ppm tocopherols added (Omega Sur S.A., Mar del Plata, Argentina) was used; its fatty acid (FA) composition was: monounsaturated FA (MUFA), 36.89%; saturated FA (SFA), 26.78%; total polyunsaturated FA (PUFA), 36.27%; and n-3 PUFA, 24.47% (EPA, 9.69% and DHA, 15.63%). As stabilizer or emulsifier agents food-grade commercial preparations of milk proteins concentrate (MPr, Milkaut, Santa Fe, Argentina) and 2:1 κ/ι carrageenans mixture (Carr, ADAMA S.A., Buenos Aires, Agentina) a synergistic combination (Candogan & Kolsarici, 2003) were used in previous optimized levels (Marchetti et al., 2014). Cold distilled water was used in all formulations (4 °C). Mixed phytosterols (Advasterol 90% with 16–24% campesterol, 19–32% stigmasterol and 32–50% β-sitosterol, AOM SA, Buenos Aires, Argentina) were included. Analytical grade sodium chloride (NaCl), potassium chloride (KCl), sodium nitrite ($NaNO_2$) sodium erythorbate, monosodium glutamate and sodium tripolyphosphate (TPP) were employed. The concentration of sodium nitrite was selected according to the level permitted by the Argentinean Regulations (0.015 g/100 g, Código Alimentario Argentino (1999)).

The following components were included to prepare 100 g of uncooked meat batter: meat (66.65 g), water (25 g); fish oil (5 g); salts mixture (NaCl + KCl + TPP = 1.6 g), sodium erythorbate (0.045 g); $NaNO_2$ (0.015 g); κ/ι carrageenans (0.593 g), milk protein concentrate (0.32 g), phytosterols (0.5 g), monosodium glutamate (0.02 g), ground pepper (0.2 g); nutmeg (0.05 g), carminic acid (0.0032 g, Naturis S.A., Buenos Aires, Argentina).

2.2. Experimental design

In a mixture experiment, the measured response is assumed to depend only on the relative proportion of ingredients or components present in the mixture, which usually sum 100%.

To diminish the sodium content of the product NaCl and TPP were partially replaced by KCl, using a three-component constrained simplex lattice mixture design. The mixture of components consisted of NaCl, KCl, and TPP, and the sum of the three salts was 1.6 g/100 g. Consequently a mixture design with constrains was chosen. This type of design is suggested when the proportions of some or all of the components are restricted by upper and lower bounds; the experimental region is just a sub-region of the entire mixture simplex (Cornell, 2011). Combinations of NaCl (0.5–1.4 g/100 g), KCl (0–0.7 g/100 g), and TPP (0–0.5 g/100 g) were used in a simplex-centroid augmented design. The maximum KCl was established according to Desmond (2006) to reach a replacement up to 50% of NaCl. Maximum level of TPP was fixed taken into account that Liu, Booren, Gray, and Crackel (1992) employed 0.5 g/100 g sodium tripolyphosphate in pork meat systems without adverse results.

The design consisted of eleven runs. The centroid point formulation (0) was prepared three times. Table 1 shows all the tested formulations; formulation 2 corresponded to a non-replaced sodium formulation (1.4 g/100 g NaCl and 0.2 g/100 g TPP, without KCl, (Marchetti et al., 2014).

2.3. Product manufacture

All formulations were manufactured following the methodology of Andrés, Zaritzky, and Califano (2009) and Marchetti et al. (2014). Briefly, after meat packages were thawed (approximately 18 h at 4 °C), each batch was homogenized and grounded in a commercial food processor (Universo, Rowenta, Germany, 14 cm blade) with the mixed salt according to the design. Carrageenans and milk proteins concentrate, sodium

Table 1
Actual and codified NaCl, KCl, and tripolyphosphate values according with the mixture design used.

Formulation	Actual values (g/100 g)			Codified values		
	NaCl	KCl	TPP	NaCl	KCl	TPP
0	0.966	0.366	0.266	0.604	0.229	0.167
1	1.1	0	0.5	0.688	0.000	0.313
2	1.4	0	0.2	0.875	0.000	0.125
3	0.5	0.6	0.5	0.313	0.375	0.313
4	0.9	0.7	0	0.563	0.438	0.000
5	1.4	0.2	0	0.875	0.125	0.000
6	1.15	0.45	0	0.719	0.281	0.000
7	0.8	0.3	0.5	0.500	0.188	0.313
8	0.733	0.533	0.333	0.458	0.333	0.208
9	1.183	0.183	0.233	0.740	0.115	0.146
10	0.7	0.7	0.2	0.438	0.438	0.125