Design of a sodium-reduced preservative mixture for use in standard frankfurter sausages

Diego A. Restrepo-Molina [a], William Arroyave-Maya [a], Diana M. González-Rodríguez [b],
José U. Sepúlveda-Valencia [a] & Héctor J. Ciro-Velásquez [a]

[a] Department of Food and Agricultural Engineering, Faculty of Agricultural Sciences, Universidad Nacional de Colombia - Sede Medellín, Medellín Colombia. darestre@unal.edu.co, warroya@unal.edu.co, jusepul@unal.edu.co, hjciro@unal.edu.co
[b] Research Department, Institución Universitaria CEIPA, Sabaneta, Colombia. diana.gonzalez@ceipa.edu.co

Abstract
High sodium intake increases blood pressure, as well as the risks of heart disease and stroke. The objective of this research was to design a reduced sodium mixture for use in standard frankfurter sausages. A simplex experimental design with four salts was performed using sodium chloride (NaCl), sodium tripolyphosphate (TPPNa), potassium chloride (KCl) and tetrapotassium pyrophosphate (TKPP), with ten mixing points. Textural characteristics (TPA), ionic strength (IS) and cooking losses (CL) were evaluated. The results indicated that the lowest cooking losses were found when reducing the NaCl content by using the highest TPPNa levels (T2, T4, T6 and T9). Furthermore, formulations with larger amounts of TPPNa and TKPP (T2, T3 and T6) had the highest values of for hardness, cohesiveness and chewiness. Finally, T2 shows the best results for CL and texture variables

Keywords: meat products; sodium reduction; sausage emulsion; instrumental texture.

Diseño de una mezcla de conservantes reducida en sodio para la aplicación en salchichas tipo Frankfurt categoría estándar

Resumen
El alto consumo de sodio aumenta la presión arterial, así como el riesgo de enfermedad cardíaca y el accidente cerebrovascular. El objetivo de ésta investigación fue diseñar una mezcla reducida en sodio para la aplicación en salchichas tipo Frankfurt categoría estándar. Para ello se realizó un diseño de experimentos simplex con cuatro sales: cloruro sódico (NaCl), tripolifosfato de sodio (TPPNa), cloruro potásico (KCl) y pirofosfato tetrapotásico (TKPP), en diez puntos de mezcla. Se evaluaron las características texturales (TPA), la fuerza iónica y las pérdidas por cocción (PPC). Los resultados indicaron que al reducir el contenido de NaCl por los máximos niveles de TPPNa se encontraron las menores pérdidas por cocción (T2, T4, T6 y T9). Además, a mayor adición de TPPNa y PPTK (T2, T3 y T6), se obtuvieron los mayores valores para dureza, cohesividad y masticabilidad. Finalmente, el T2 mostró el mejor comportamiento para las variables de PPC y textura.

Palabras clave: productos cárnicos; reducción de sodio; emulsión tipo salchicha; textura instrumental.

1. Introduction

Sodium performs a series of vital functions in the body, including the maintenance of extracellular fluid volume, osmotic pressure, and pH and the transmission of nerve impulses [1-4]. Unlike other essential minerals such as calcium, there are no large reserves of sodium in the body and it is necessary to constantly replace sodium through the diet [3,4]. For many people, however, the current daily sodium intake exceeds the recommendations for good health [5], leading to water retention and an increased blood volume that could increase blood pressure and cause heart disease [6-10]. Sodium chloride (NaCl) is the main source of sodium in food, followed by polyphosphate mixtures. NaCl is the most

common food ingredient, which causes the stimulation of salty taste; it is the most used component after sugar and, among other functions, provides conservation and texture modification [11-13]. It is a basic component in meat products because it contributes to the reduction of cooking losses, affects water retention, color, fat binding properties, and flavor. It also decreases water activity (a_w), which significantly affects the shelf life of the product [14-20]. There are mixtures of polyphosphates on the market containing sodium tripolyphosphate as a main component, however, the use of pure tripolyphosphate in sausage formulations is widely practiced since it meets all functional requirements such as texture and cooking losses and provides an ideal pH for the medium in which they are used due to their regulatory action [21-25].

Not all meat derivatives contain the same levels of NaCl; its content can vary considerably even within the same product. In cooked, processed and fermented sausages, percentages of 1.5-3% NaCl and 0.2-0.5% polyphosphate can be found. For sausages with high fat content, 2.0% NaCl and 0.25% polyphosphate mixtures are generally added [26,27]. NaCl and polyphosphate substitutes usually consist of one or more compounds. Potassium chloride (KCl) is a partial substitute for salty taste; it has been found that KCl can be used as a substitute for 33% to 50% of NaCl. It is limited by its effects of lowering blood pressure and generating a bitter taste [28-30]. It is a good preservative that reduces cooking losses, has excellent water retention capacity and does not affect texture. Potassium pyrophosphate can completely substitute for sodium polyphosphates in the formulation, resulting in the same performance. Other compounds that are usually present in these formulations are nucleotides, yeast extracts, organic acids, herbs and spices [31,32].

Ionic strength (IS) is one of the factors that affects cooking losses in emulsions. In the case of myofibrillar proteins, their solubility is affected by temperature, pH and salt concentration and type. Cations present in salts, according to the Hofmeister series, improve solubility in the following order $Ca^{2+} > Mg^{2+} > Na^+ > K^+$. When replacing sodium ions with potassium ions, the extracted proteins and the stability of the formed emulsion will be lower [33, 34]. It is difficult to reduce the amount of sodium obtained from NaCl and sodium phosphate, while still maintaining the physical properties of the product; this presents a challenge to food formulators [35]. Texture is one of the functional properties that determines the quality of meat derivatives; it can be measured in terms of hardness, juiciness, cohesiveness, gumminess, elasticity, adhesiveness, and chewiness. These properties are affected by changes in the stability of the matrix, which can be caused by the availability of protein, hydrophobic or hydrophilic components, by water-protein-fat-salt interactions, the amount of connective tissue, the amount of water available, and other factors. It has been found that texture profile analysis (TPA) provides a good correlation with the sensory analysis of meat products, such as frankfurter sausages [36, 37]. The objective of this research was to design a reduced sodium mixture for application in standard frankfurter sausages.

2. Materials and methods

2.1. Selection of sodium and potassium salt combinations

Sodium and potassium salt combinations (NaCl, TPPNa, KCl and TTPK) were selected, and values were established for each one taking into account the typical level of NaCl in a sausage according to a standard formulation of 1.8% to 2.3% NaCl, replacing a maximum of 50% with (KCl), as found in other studies [38] and based on the maximum allowed values of phosphates according to the norm NTC 1325 of 2008 [39] and it was defined as being a 0% to 0.5% polyphosphate range.

According to the simplex reticular design with expanded centroid in Fig. 1, the minimum and maximum levels for the X1 treatment (100% NaCl) were 0.0% and 2.3% respectively; for the X2 treatment (mixture 1: 78% NaCl and 22% TPPNa) they were 0.0%, and 2.3% and for the X3 treatment (mixture 2: 39% NaCl, 39% KCl and 22% TKPP) they were 0.0% and 2.3%.
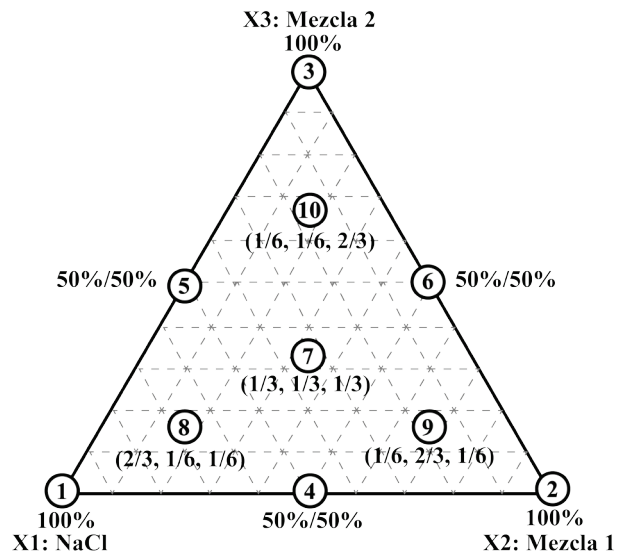

Figure 1. Simplex reticular design with expanded centroid.
Source: The Authors.

Table 1.
Amounts of NaCl and sodium phosphate salts for each treatment according to increased simplex lattice design assignment (% present in the total formulation of the sausage).

	Combinations			Composition*			
Run	NaCl[2]	Mix1	Mix2	NaCl	TPPNa	KCl	TKPP
	(%)	(%)	(%)	(%)	(%)	(%)	(%)
T1	2.30	0.00	0.00	2.30	0.00	0.00	0.00
T2	0.00	2.30	0.00	1.80	0.50	0.00	0.00
T3	0.00	0.00	2.30	0.90	0.00	0.90	0.50
T4	1.15	1.15	0.00	2.05	0.25	0.00	0.00
T5	1.15	0.00	1.15	1.60	0.00	0.45	0.25
T6	0.00	1.15	1.15	1.35	0.25	0.45	0.25
T7	0.77	0.77	0.77	1.67	0.17	0.30	0.17
T8	1.54	0.38	0.38	1.99	0.08	0.15	0.08
T9	0.38	1.54	0.38	1.73	0.34	0.15	0.08
T10	0.38	0.38	1.54	1.28	0.08	0.60	0.34

T: treatment, Mix1: mixture 1: 78% NaCl and 22% TPPNa, Mix2: mixture 2: 39% NaCl, 39% KCl and 22% TKPP, TPPNa: sodium tripolyphosphate, TKPP: tetrapotassium pyrophosphate, *Added as P_2O_5.
Source: The Authors.

To select the interaction of chlorides and phosphates, evaluations of weight loss by cooking (CL) and texture characteristics were performed for ten treatments with different salt combinations: 100% NaCl (T1); 100% mixture 1 (78% NaCl and 22% TPPNa) (T2); 100% mixture 2 (39% NaCl, 39% KCl and 22% TKPP) (T3); combination of 50% NaCl and 50% mixture 1 (T4); combination of 50% NaCl and 50% mixture 2 (T5); combination of 50% mixture 1 and 50% mixture 2 (T6); combination of 1/3 NaCl, 1/3 mixture 1 and 1/3 mixture 2 (T7); combination of 2/3 NaCl, 1/6 mixture 1 and 1/6 mixture 2 (T8); combination of 1/6 NaCl, 2/3 mixture 1 and 1/6 mixture 2 (T9); combination of 1/6 NaCl, 1/6 mixture 1 and 2/3 mixture 2 (T10). The amounts allocated for each treatment and the composition of the combinations are presented in Table 1.

2.2. Meat raw materials

The source of the lean meat was pork loin (*Longissimus dorsi*) at a temperature of 4 ° C with pH values between 5.6 and 6.0; pork bacon fat (dorsal fat) was used as a source of fat at a temperature of 4 ° C with pH values between 5.8 and 6.2; meat and bacon were individually chopped and ground in a meat grinder (ButcherBoy®, model TCA 32) using a 3 mm disc. The meat and additives were provided by local supplier, which fulfilled all the current colombian regulations (temperature, pH, technical and hygienic conditions).

2.3. Preparation of sausages

Sausage batches were made at 4.0 kg per formulation with three replicates. Lean meat (25.17%) was placed in a cutter (Cruells® Model C-30BL) and mixed with the other ingredients of the formula in the following order: chlorides and sodium phosphates (percentages for each treatment are show in Table 1), sodium erythorbate (0.03%), and sodium nitrite (0.02%). These ingredients were added in the presence of ice (37.08%) so that the mixture did not exceed 8°C. Once it reached this temperature, dorsal fat (15.73%) was added along with flavorings (1.95%): a mixture of spices containing paprika powder (49.4%), nutmeg powder (18.5%), garlic powder (12.3%), onion powder (12.3%), white pepper powder (7.4%), natural paprika powder (0.23%), liquid smoke (0.18%), and cardamom oil (0.1%), preservatives: sodium diacetate (0.78%) and potassium lactate (3.00%), extenders: cassava starch (7.87%), isolated soy protein (5.66%), and dye: red 4R puncture (0.01%).

The emulsion or meat paste that was obtained was embedded by means of a piston stuffer (Cato® ESG30) into an artificial cover (24 mm diameter cellophane) and was divided into units that were each approximately 12 cm long. Next, the sausages were cooked in an automatic oven (HansDampf® Gold version 6.1) using the following processing cycle: step drying (55 °C/8 min, 65 °C/5 min, 70 °C/4 min), at 70 °C they were then smoked with liquid smoke by a sprinkler (one part of liquid smoke to five parts water). Then they were subjected to 80°C (cooking with 100% steam) until reaching an internal temperature of 65 °C, and then the product was subjected to 90 °C until reaching an internal temperature of 72 °C. After the heating cycle, it was cooled by thermal shock with water at 4 °C. Finally, the sausages were packed in bags of polyamide / low density polyethylene, with an oxygen permeability of 60 cc/m^2/24 h/atm (at 23 °C and 0% RH) and were stored under refrigeration for 48 h, after which they were used for the different analyses [40].

2.4. Measurement of cooking losses

The cooking loss of sausages was calculated as the loss of mass during heat treatment. Determinations were carried out in triplicate following the formula [41-44] eq. (1):

$$CL = \frac{A - B}{A} \times 100 \qquad (1)$$

Where:
CL= Cooking losses, in %.
A = kg of sausage dough before cooking.
B = kg of sausage dough after cooking (after a 30 min rest at room temperature).

2.5. Calculation of ionic strength

Ionic strength (IS) is a function of the concentration of all ions present in meat matrix. It was calculated with the following formulation [45] eq. (2):

$$IS = \frac{1}{2} \sum_{B=1}^{n} C_B Z_B^2 \qquad (2)$$

Where:
C_B = molar concentration of ions.
Z_B = load of each ion.

2.6. Instrumental measurement of texture

The determination of textural characteristics (TPA) was performed on a TA-XT2 texture analyzer (Stable Micro Systems®). This analysis method is referred to in the literature as a standardized instrumental method [42,45-48]. Five samples of sausage at room temperature with fixed dimensions (20 mm diameter and 25 mm high) were taken from each treatment and axially compressed to 80% of their original height, using a compression plate of 75 mm in diameter (P/75). Force vs. time curves were obtained using a load cell of 25 kg and a pre-test, test, and post-test speed of 4.0 mm/s. During the analysis, parameters of hardness, cohesiveness and chewiness were determined [42,49,50]; these were obtained using the Exponent Stable Micro System Software, version 3.0.5.0. Values recorded for each parameter correspond to the average of five measurements.

2.7. Design and statistical analysis

The statistical design that was used was a "mix design" called "simplex reticular design with extended centroid" within "response surface" methodology [51, 52]. The design was defined by a triangle (Fig. 1) that in turn represented all of the mixing possibilities in proportion to the sodium and

potassium salts that were added to the standard frankfurter sausage.

3. Results and discussion

In Table 2, the CL results for 10 treatments of standard frankfurter sausage are presented; these data were analyzed using the R Studio statistical program (Version 0.97.551) to obtain the response surface and respective ANOVA for this variable at a 5% level of significance. The results show that the highest values for this variable were obtained for T1, T8, T5 and T3 treatments in that order. This indicates that there is a direct relationship between the substitution of sodium for potassium and the increase in CL. However, for treatments containing only mixture 2 with NaCl, a synergistic effect was observed, given that the sausage which contains only NaCl was the one with the lowest yield.

T4, T6 and T9 treatments had the lowest CL values and no statistically significant differences were observed between them ($P>0.05$). The trend showed an inverse relationship between the increase in TPPNa concentration and cooking losses (correlation coefficient of -0.72), besides confirming a synergistic effect between the polyphosphate ions and the chloride ions. In studies with meat products, an increase in cooking losses has been related to a reduction in sodium content or an increase in fat content [53,54]. However, the use of polyphosphates has a compensating synergistic effect, making cooking losses decrease, as was found in this study [44,55- 57].

In Fig. 2, the response surface obtained from the evaluated sampling points is shown. Level curves show concentrations with the same percentages of cooking losses; the trend of the contour lines is quadratic. Gray scale bands represent the trend of the values (from higher to lower intensity). The synergistic action of the cooking losses variable due to the effect of mixture 1 was observed because of the presence of the polyphosphate ion. Considering that the T4 treatment represents typical addition values of NaCl and TPPNa for standard frankfurter sausages, the region comprised by T2, T4, T6 and T9 treatments presents a high probability of integrating the best salt combinations.

Table 2.
Cooking losses (CL) and ionic strength (IS) of standard frankfurter sausages made with different combinations of NaCl.

Run	Combination			CL (%)	IS
	NaCl (%)	Mix1 (%)	Mix2		
T1	2.30	0.00	0.00	9.28^{a*}	0.40
T2	0.00	2.30	0.00	4.57^{cd}	0.57
T3	0.00	0.00	2.30	6.13^{b}	0.46
T4	1.15	1.15	0.00	3.39^{e}	0.48
T5	1.15	0.00	1.15	8.74^{a}	0.43
T6	0.00	1.15	1.15	3.78^{de}	0.51
T7	0.78	0.76	0.76	5.48^{bc}	0.48
T8	1.54	0.38	0.38	9.21^{a}	0.44
T9	0.38	1.54	0.38	4.04^{de}	0.53
T10	0.38	0.38	1.54	5.45^{bc}	0.47

* Different letters indicate that there are statistically significant differences.
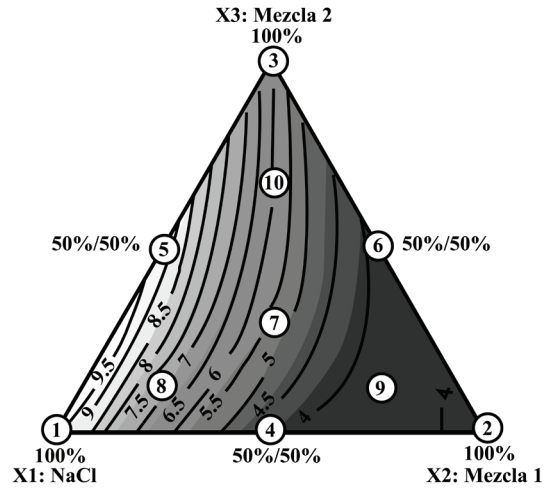Source: The Authors.

Figure 2. Percentage of cooking losses (CL) of standard frankfurter sausages according to treatments.
Source: The Authors.

Table 3.
Textural characteristics of standard sausages for different treatments.

Run	Texture Characteristics (TPA) *		
	Hardness (gf)	Cohesiveness (dimensionless)	Chewiness (gf)
T1	13169 ^{e}	0.347 ^{c}	2402 ^{cd}
T2	26273 ^{a}	0.424 ^{ab}	10277 ^{ab}
T3	28112 ^{a}	0.483 ^{a}	13391 ^{a}
T4	16443 ^{cd}	0.346 ^{c}	4719 ^{cd}
T5	13552 ^{of}	0.314 ^{c}	2188 ^{cd}
T6	20484 ^{ab}	0.362 ^{bc}	6482 ^{bc}
T7	17268 ^{bc}	0.359 ^{bc}	5156 ^{cd}
T8	12771 ^{c}	0.305 ^{c}	1906 ^{d}
T9	19637 ^{b}	0.359 ^{bc}	4610 ^{cd}
T10	18481 ^{bc}	0.342 ^{c}	5271 ^{cd}

* Different letters indicate that there are statistically significant differences.
Source: The Authors.

Ionic strength (IS) for each treatment, caused by the chloride and phosphate ions, is shown in Table 2. The presence of the phosphate ion $[P_3O_{10}]^{5-}$ increased the IS required to solubilize and extract myofibrillar proteins responsible for the retention of moisture. It has been reported in other studies that, due to the small size of the phosphate ions molecules, an increase in protein solubility occurred, linking them firmly to the water molecules, which increased emulsion stability. The same effect occurred with chloride ions [26,57-59].

In Table 3, results of the texture profile analysis, related through hardness, cohesiveness and chewiness, are shown for the 10 treatments of standard frankfurter sausages. Using these data, the response surface and ANOVA values were obtained for each texture descriptor.

In Fig. 3, response surfaces obtained from the sampling points under evaluation are shown. Contour lines show concentrations with the same levels of hardness, cohesiveness and chewiness; the trend of the contour lines is quadratic.
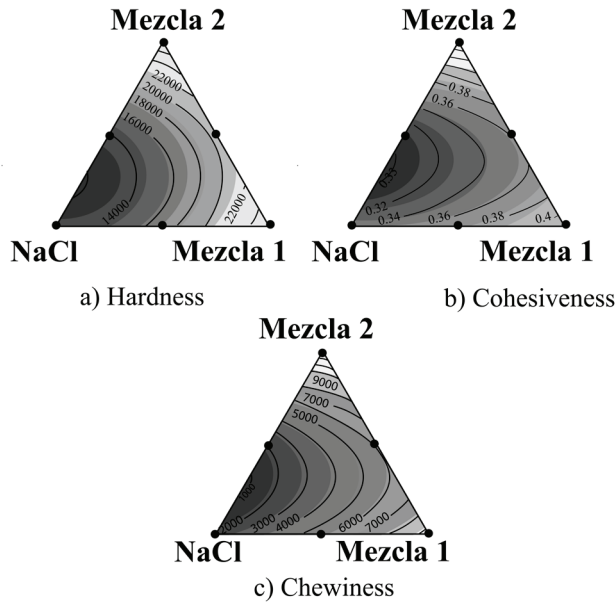
Figure 3. Response surface and contours for TPA related through: a) hardness, b) cohesiveness and c) chewiness, of standard frankfurter sausages with treatment different.
Source: The Authors.

TPA (Table 3) shows high values for the treatments in which mixture 1 and mixture 2 were the major components: T2, T3, T6, T9, T10, T7 and T4.

Values for the hardness, cohesiveness and chewiness variables were low in treatments in which NaCl was the majority: T8, T1 and T5. In treatments with higher TPPNa and TKPP content was observed that final texture characteristics increased. T2 and T3 treatments have higher values for texture attributes, however, no statistically significant differences (P >0.05) between these two treatments were observed in the hardness, cohesiveness and chewiness variables. With respect to the results obtained in other variables, treatments 2 and 3 are in the region described above as the one in which the best mixture could be found. This allowed to design a sausage mixture that had reduced sodium without altering any of its quality properties.

Textural characteristics were influenced by the increase in the amount of phosphate ions present (in mixture 1 as TPPNa and in mixture 2 as TKPP), and by the decrease in the amount of NaCl. Phosphate ions acting in a synergistic manner with chloride ions produced a positive effect on texture properties due to an increase in the emulsion stability. This happened because of the change in total loads within the meat matrix, which was observed and is consistent with the previously stated results of SI. In addition, myofibrillar proteins were extracted in greater proportion and were solubilized to a greater extent, immobilizing water molecules. This led to an increase in water retention capacity, and an avoidance of deformations in the final structure of the sausage. This situation allowed to emulsify more fat, which is expressed in the uniformity of the physical structure of the product [38, 44]. Several authors have related the effect of the increase in values of textural variables in meat products to the increase in the amount of phosphate [60-61]

Considering the behavior of each response surface and that T4 treatment represents the typical addition values of NaCl and TPPNa for standard frankfurter sausages, it was found that T6 treatment was similar in the variables of cooking losses and textural characteristics (represented by hardness, cohesiveness and chewiness), and it had lower sodium concentrations. However, it will be necessary to perform a sensory analysis with a trained panel to complete the study and corroborate public acceptance; it is recommended including treatments T2, T3 and T4 in this analysis.

4. Conclusions

Evaluation of the formulations with T4 (2.0% NaCl and 0.3% of TPPNa), T6 (1.4% NaCl, 0.4% of KCl, 0.2% of TPPNa and 0.3% of TKPP), T9 (1.7% NaCl, 0.2% of KCl, 0.3% of TPPNa and 0.1% of TKPP) and T2 (1.8% NaCl and 0.5% of TPPNa) treatments allowed to conclude that a greater addition of TPPNa resulted in lower CL values, which were directly related to the increase in FI and texture properties. Of all the formulations of standard frankfurter sausage tested, the lowest CL value was obtained using T4 treatment (2.0% NaCl and 0.3% of TPPNa). Treatment 2 had the highest FI value, and formulations with treatments 2 and 3 had the best texture properties. All of these treatments are in the same region of response surface, which allows to propose a future design using only formulations that fall within this area.

Conflict of interests

The manuscript was prepared and reviewed with the participation of all authors, who declared that there is no conflict of interest that jeopardizes the validity of the results presented.

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D.A. Restrepo-Molina, received the BSc. Eng in Chemical Engineering in 1983 from the Universidad Nacional de Colombia, the MSc. degree in Science and Technology of Foods in 1998 from the University of La Havana, Cuba. Currently, he is an associate professor in the Agricultural and Food Engineering Department, Facultad de Ciencias Agrarias, Universidad Nacional de Colombia, Medellín. His research interests include: food technology, food science, meat products, food processing; food rheology.
ORCID: 0000-0002-5623-3319

D.M. González-Rodríguez, received the BSc. Eng in Chemical Engineering in 2010 from the Universidad Nacional de Colombia, the MSc. degree in Science and Technology of Foods in 2014 from the Universidad Nacional de Colombia. Currently, she is research professor in the Ceipa Business School. Her research interests include: modeling, food science, social science, management, curricular innovation and entrepreneurship.
ORCID: 0000-0001-6748-8635

H.J. Ciro-Velásquez, received the BSc. Eng in Mechanical Engineering in 1995 from the Universidad Nacional de Colombia, the MSc. degree in Mechanical Engineering in 1998 from the University of Puerto Rico-Mayaguez Campus, and the PhD degree in Food Engineering in 2010 from the Universidade Estadual de Campinas-Brazil. Currently, he is an associate professor in the Agricultural and Food Engineering Department, Facultad de Ciencias Agrarias, Universidad Nacional de Colombia, Medellín. His research interests include: simulation, modeling and food processing; food rheology; and food drying.
ORCID: 0000-0002-4398-0470

W. Arroyave-Maya, received the BSc. Eng in Chemical Engineering in 2002 from the Universidad Nacional de Colombia, the MSc. degree in Science and Technology of Foods in 2014 from the Universidad Nacional de Colombia. Currently. His research interests include: food additives, meat products, food processing.
ORCID: 0000-0003-2114-3046

J.U. Sepulveda-Valencia, received the BSc. Business Administration in 1985 from the Universidad Cooperativa de Colombia, the MSc. degree in Science and Technology of Foods in 2003 from the University of La Havana, Cuba. Currently, he is an associate professor in the Agricultural and Food Engineering Department, Facultad de Ciencias Agrarias, Universidad Nacional de Colombia. His research interests include: food technology, food science, dairy products, meat products, food processing; food additives.
ORCID: 0000-0001-5660-4514