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Physico-chemical and sensory properties of reduced-fat mortadella prepared with blends of calcium, magnesium and potassium chloride as partial substitutes for sodium chloride

C.N. Horita [a], M.A. Morgano [b], R.M.S. Celeghini [a], M.A.R. Pollonio [a,*]

[a] Department of Food Technology, Faculty of Food Engineering of State University of Campinas, UNICAMP, Cidade Universitária Zeferino Vaz, ZIP 13083-862, CP 6121, Campinas, SP, Brazil
[b] Food Technology Institute, ITAL, Brazil Avenue, 2880, ZIP 13070-178, Campinas, SP, Brazil

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Blends of calcium, magnesium and potassium chloride were used to partially replace sodium chloride (50–75%) in reduced-fat mortadella formulations. The presence of calcium chloride reduced the emulsion stability, cooking yield, elasticity and cohesiveness and increased hardness; however, it yielded the best sensory acceptance when 50% NaCl was replaced by 25% $CaCl_2$ and 25% KCl. There was no effect of the salt substitutes on mortadella color, appearance and aroma. All salt combinations studied showed stable lipid oxidation during its shelf life. The use of a blend with 1% NaCl, 0.5% KCl and 0.5% $MgCl_2$ resulted in the best emulsion stability, but the worst scores for flavor. This study suggests that it is possible to reduce the sodium chloride concentration by 50% in reduced-fat mortadella using the studied salt combinations with necessary adjustments to optimize the sensory properties ($MgCl_2$ 25%; KCl 25%) or emulsion stability ($CaCl_2$ 25%; KCl 25%).

1. Introduction

The positive correlation between diet and chronic diseases has led health agencies around the world to control the intake of certain food components that are thought to promote these disorders. Reducing sodium intake is among the most pressing challenges because of its proven role in the development of hypertension, one of the most important risk factors for cardiovascular disease (Dickinson & Havas, 2007; Fernándes-Ginés, Fernández-López, Sayas-Barberá, & Pérez-Alvarez, 2005).

Meat and meat products are important sources of protein and essential amino acids, fat, iron, zinc, conjugated linoleic acid (especially materials derived from ruminants) and vitamins B_1, B_2, B_6 and B_{12} (Biesalski, 2005). However, meat consumption has been criticized because it contains high levels of sodium and fat and little or no fiber or calcium. The reduction of sodium to develop healthier products is particularly challenging because it necessarily implies removing or partially replacing sodium chloride levels in the formulations, the main source of this mineral in meat products (Weiss, Gibis, Schuh, & Salminen, 2010). According to the World Health Organization (WHO) (2003), among all categories of industrialized foods, meat and meat products contribute about 16–25% of the recommended sodium intake. Besides being a low-cost ingredient, NaCl has excellent technological properties, and its reduction and/or replacement reduces the salty taste, noticeably decreasing flavor (Ruusunen & Puolanne, 2005) and the microbiological and physico-chemical stability and modifies the typical textural properties of meat products (Sofos, 1984; Terrell, 1983). Moreover, the success of this reformulation should occur with a simultaneous reduction of fat because risk factors for some chronic diseases, such as cardiovascular diseases, are not reduced by sodium reduction alone. The fat content is essential to ensure quality characteristics such as flavor, juiciness and texture, which are also affected by NaCl reduction in the formulations.

Emulsified meat products such as mortadella require specific concentrations of NaCl in the original formulations to promote the extraction of myofibrillar proteins, especially complex actomyosin, which are soluble only in solutions of high ionic strength. Myofibrillar proteins extracted in the comminution process in the presence of NaCl are responsible for the water-holding capacity, emulsification and fat-binding properties in the batter and the formation of stable gels in the cooking stage (Desmond, 2006, 2007). Potassium chloride (KCl) has been the most investigated substitute for NaCl and its intake in various studies has reduced blood pressure in humans. From the technological point of view, this salt has been used to ensure the ionic strength necessary to develop stable emulsions; however, its use alone results in a bitter, astringent and metallic taste (Geleijnse, Kok, & Grobbee, 2003; Haddad, 1978).

* Corresponding author. Tel.: +55 19 35214002.
E-mail address: marise@fea.unicamp.br (M.A.R. Pollonio).

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Other salt substitutes such as calcium chloride and magnesium chloride can be used to reduce the sodium content in meat products (Aliño, Grau, Fuentes, & Barat, 2010; Pojedinec et al., 2011). However, with respect to emulsified products, there has been very little research on the use of these salts on the stability of the end-products and sensory acceptance.

Mortadella is a product that is consumed and enjoyed worldwide. In many regions of Brazil, mortadella is commonly served as a side dish and has an important nutritional role in the Brazilian diet; it therefore constitutes a significant source of sodium for the population. Thus, from a public health perspective, reformulation studies of mortadella are necessary. The objective of this research was to study the physico-chemical and sensory characteristics of reduced-fat mortadella formulations with 50% and 75% reduction in sodium chloride by its partial substitution with blends of potassium, magnesium, and calcium chloride salts.

2. Materials and methods

2.1. Treatments

Six reduced-fat mortadella formulations were prepared with partial sodium chloride reduction (50 or 75%) followed by substitution with combinations of potassium chloride (KCl, 25 or 50%), magnesium chloride ($MgCl_2$, 25%) and calcium chloride ($CaCl_2$, 25%). The total content of added salt from these different combinations was kept constant at 2%. A control formulation containing 2% NaCl was used as a standard for the traditional mortadella. The levels of NaCl, $CaCl_2$, $MgCl_2$ and KCl and the remaining ingredients, raw materials and additives are described in Table 1. The proportions of beef and pork used in all formulations resulted in fat content of less than 10% in preliminary studies. Diced pork fat was not used, and the contribution of fatty raw material resulted mainly from the pig palette selected for this purpose.

2.2. Materials

Mortadellas were prepared using lean beef (*M. trapezius cervicis*, 71.10% moisture, 5.45% fat) and pork (*Triceps brachii*, 76.03% moisture, 10.53% fat) obtained from an industrial supplier (JBS S.A., Brazil). The proportions of lean beef and pork were established to result in a final product with a maximum fat content of 10%. Pork back fat and fat cubes were not used. The preparation of raw materials consisted of the complete removal of the subcutaneous connective tissue from the beef and pork meat. Excess external and intramuscular fat was removed only from the lean beef. The cuts were ground into 5-mm disks. Only onion, garlic, coriander, white pepper and Jamaica pepper (Fuchs, Brazil) were used as seasoning to allow for critical evaluation of the effects of NaCl replacement on the sensory properties (New Max Ltd). Food-grade MgCl2, CaCl2 and KCl were used (Merse, Brazil).

Table 1
Formulations (%) of reduced-fat mortadella with different added levels of NaCl, KCl, $MgCl_2$ and $CaCl_2$.

Component	F1 (Control)	F2	F3	F4	F5	F6	F7
Lean beef	50.50	50.50	50.50	50.50	50.50	50.50	50.50
Pork	32.35	32.35	32.35	32.35	32.35	32.35	32.35
Ice	14.60	14.60	14.60	14.60	14.60	14.60	15.60
Condiments	0.185	0.185	0.185	0.185	0.185	0.185	0.185
Sodium nitrite	0.015	0.015	0.015	0.015	0.015	0.015	0.015
Sodium tripolyphosphate	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Sodium erythorbate	0.05	0.05	0.05	0.05	0.05	0.05	0.05
NaCl	2.00	1.00	1.00	0.50	0.50	1.00	1.00
$MgCl_2$	–	–	0.5	–	0.5	–	–
KCl	–	0.50	0.50	1.00	1.00	1.00	–
$CaCl_2$	–	0.50	–	0.50	–	–	–
Total	100	100	100	100	100	100	100

2.3. Mortadella processing

All mortadella formulations were processed in a pilot plant (New Max, Ltda.) on the same day according to industrial procedures. Batter formulations are shown in Table 1. Lean beef and pork with different previously weighed combinations of salts were placed in a cutter (Mado, model MTK 662, Germany) and comminuted for 3–4 min at low speed to extract myofibrillar proteins. When the temperature reached 7–8 °C, other condiments and additives were slowly added. The temperature of the batters never exceeded 17 °C. Subsequently, the meat emulsion was mechanically embedded (Mainca, model EC12, Spain) in permeable cellulose wrappers (Viskase, 15 cm ø) with approximately 0.5 kg of product per package. The mortadella pieces were placed in a steam oven (Eller, Italy) at an initial inside temperature of 60 °C and relative humidity 98–99% where they remained for 15 min. After that, the temperature was raised at 5 °C every 10 min to reach the final core temperature of 72 °C. At this point, the temperature inside the steam oven was around 85 °C. A thermocouple was placed in the center of the samples to monitor and control the internal temperature. After cooking (~2,5 h), the products were immediately cooled in an ice bath, vacuum-packaged (Selovac, Minivac CU18) and stored under refrigeration (5 °C) for physico-chemical and sensory analyses. For all analyses, samples were taken 24 h after processing and every 15 days during the shelf life established for this study (60 days).

2.4. Proximate analysis, sodium content and pH

The moisture, protein, and ash contents were determined according to the Association of Official Analytical Chemists (AOAC, 2005). The fat content was quantified as described by Bligh and Dyer (1959). All tests were performed in triplicate. The sodium content was determined in triplicate for each formulation as described by AOAC (2005). The pH was determined by homogenizing 10 g of each sample with distilled water in a 1:10 ratio in triplicate. The homogenate was subjected to meter electrodes (DM 22, Digimed, São Paulo, Brazil) for five minutes while the pH readings were performed.

2.5. TBARS analysis

Lipid oxidation was determined using the thiobarbituric acid reactive substances test (TBARS) as described for cured meats by Tarladgis, Watts, and Younathan (1960) and modified by Zipser and Watts (1962), which includes the addition of 0.5% sulfanilamide in a 20% HCl (v/v) solution. TBARS values are reported as milligrams of malonaldehyde per kilogram equivalent of sample. For each treatment, measurements were performed in triplicate.

2.6. Emulsion stability

The emulsion stability of the different formulations shown in Table 1 was performed according to Jimenez-Colmenero, Ayo, and Carballo (2005) with some modifications. Approximately 50 g of the batters formulated at a maximum temperature of 17 °C were weighed and placed in tubes to be centrifuged (1134 ×g, 5 min at 5 °C). Subsequently, the samples were heated at 40 °C for 15 min followed by 70° for 20 min. The tubes were left to stand upside-down for 45 min to release the exudates. The total amount of fluid released was expressed as a percentage of the sample weight. The content of released fat was determined by the difference in the total liquid released after drying in an oven at 100 °C for 16 h. Water released by evaporation was also expressed as a percentage of the sample weight. The test was performed in quadruplicate for each formulation.

2.7. Cooking yield (%)

The loss due to cooking in a steam oven for each treatment was determined in five replicates with samples marked immediately after embedding and weighed after cooling in an ice bath. The conditions of the steam oven for the measurement of cooking yields were the same as described in the mortadella processing.

The cooking yield was calculated as the cooked weight of the mortadella samples divided by the weight of the pre-cooked mortadella multiplied by 100 (Jimenez-Colmenero et al., 2005).

2.8. Texture profile analysis (TPA)

The texture profile analysis of mortadellas produced with a mix of potassium, calcium and magnesium chlorides as partial substitutes for sodium chloride was performed with a TA-xT2i texture analyzer (Texture Technologies Corp., Scarsdale, NY.) All samples were compressed to 30% of their original weight. Six 20-mm thick and 20-mm long portions were used for each treatment. A P-35 probe was used (long shaft, regular base). Measurements were made after the mortadella pieces reached room temperature.

The following parameters were determined: hardness (N/cm^2), maximum force required to compress the sample, springiness (cm), ability of the sample to recover its original form after the deforming force was removed, cohesiveness, extent to which the sample could be deformed prior to rupture (A2/A1, where A1 is the total energy required for the first compression, and A2 is the total energy required for the second compression), and chewiness (N/cm) work required to masticate the sample for swallowing (Mendoza, García, Casas, & Selgas, 2001).

2.9. Color

Color was measured using a Hunter Lab colorimeter (Colourquest-II, Hunter Associates Laboratory Inc., Virginia, USA) with a 20-mm port size, illuminant D_{65} and a 10^0 standard observer. CIELAB L*, a* and b* values were determined as indicators of lightness, redness and yellowness. Color variables were measured at four points on the central part of the cut surface of four slices per piece of mortadella. Assays were performed in triplicate for each treatment. All samples were at room temperature during the analysis.

2.10. Sensory analysis

The sensory analysis protocol for the mortadellas developed in the experiments was previously approved by the Ethics in Research Committee of the State University of Campinas, SP, Brazil, under protocol number 370/2009. The sensory analysis was conducted by 112 panelists recruited among students, faculty and staff on campus, aged from 19–42 years. The acceptance test was used to assess the degree to which consumers liked or disliked the products mentioned in relation to aroma, flavor, texture and overall impression. The samples were presented in random blocks in a sequential monadic manner with regards to the effects of the position of the samples and contrast, as proposed by Macfie, Bratchell, Greenhoff, and Vallis (1989). A hedonic scale of nine points (0 — completely disliked and 9 — completely liked) in balanced complete blocks (each session assessed 3–4 formulations) was used. For data evaluation, a significance of 5% ($p<0.05$) was used. The tests were conducted at the Sensory Analysis Laboratory of the Department of Food Technology in individual booths with lighting representative of daylight.

2.11. Statistical analysis

The data were evaluated through variance analysis (ANOVA). The averages were compared by Tukey's test at a confidence level of 5% ($p<0.05$) using the version 9.1 SAS statistical package program (SAS, 2002).

3. Results and discussion

3.1. Proximate analysis, sodium content and pH

Data on the proximate composition of the formulations are presented in Table 2. None of the formulations were significantly different in moisture, fat or protein content ($p>0.05$). The final fat content was around 10%, confirming the objective of working with reduced-fat mortadella. The ash content of the F7 formulation was significantly lower than the others because this treatment had only 1% salt (NaCl) compared to the 2% salt used in the other formulations.

The sodium contents were compatible with the levels of NaCl reduction achieved, considering that the other sources of sodium from the additives and ingredients were kept constant in all batters. The F4 and F5 formulations, containing the lowest levels of NaCl (0.5%), were not significantly different ($p<0.05$), which was the same for formulations with 1% NaCl (F2, F3, F6 and F7) ($p<0.05$).

F2 (1.0%, 0.5% KCl, 0.5% $CaCl_2$) and F4 (0.5% NaCl, 1% KCl, 0.5% $CaCl_2$) had lower pH values (pH<0,05). Similar results were found in fermented meat products where the replacement of sodium by calcium chloride decreased the pH of the final product (Gimeno, Astiasarán, & Bello, 1999).

3.2. Emulsion stability and cooking yield

In studies of sodium chloride reduction in meat products, emulsion stability is an important parameter that influences the sensory properties and shelf life of the product. According to Table 3, the lowest emulsion stability with high levels of released liquid was observed for the F4 formulation (0.5% NaCl, 1% KCl and 0.5% $CaCl_2$) followed by F2 (1% NaCl, 0.5% KCl, 0.5% $CaCl_2$). This can be attributed to the presence of divalent cations (Ca^{++}), which contribute to reduced myofibrillar protein extraction (Barbut, 1995; Hamm, 1960).

Table 2
Proximate analysis, sodium content and pH of low NaCl mortadella formulations.

Formulation	Moisture (%)	Protein (%)	Lipids (%)	Ash (%)	Sodium (mg/100 g)	pH
F1	62.60 (0.07)[a]	23.42 (0.50)[a]	9.04 (0.11)[a]	4.38 (0.04)[a]	969 (13)[a]	6,46(0,025)[b]
F2	61.69 (0.23)[a]	23.32 (0.14)[a]	9.52 (0.17)[a]	4.16 (0.0157)[a]	496 (5)[b]	5,86(0,012)[d]
F3	62.50 (0.14)[a]	23.30 (0.07)[a]	9.41 (0.38)[a]	4.02 (0.02)[a]	485 (9)[b]	6,33(0,015)[c]
F4	62.13 (0.18)[a]	23.03 (0.48)[a]	9.14 (0.13)[a]	4.15 (0.02)[a]	317 (11)[c]	5,82(0,015)[d]
F5	62.01 (0.25)[a]	23.18 (0.11)[a]	9.64 (0.24)[a]	4.08 (0.02)[a]	322 (2)[c]	6,37(0,015)[c]
F6	61.92 (0.66)[a]	23.15 (0.34)[a]	8.96 (0.26)[a]	4.19 (0.10)[a]	489 (4)[b]	6,58(0,038)[a]
F7	62.96 (0.74)[a]	24.43 (0.03)[a]	8.68 (0.06)[a]	3.14 (0.04)[b]	488 (10)[b]	6,62(0,032)[a]

Values are the mean (standard deviation).
[a,b] Means in the same column with the same letters did not differ significantly at p<0.05 (Tukey's test).
F1 —2% NaCl; **F2**— 1.0%, 0.5% KCl, 0.5% $CaCl_2$; **F3 —** 1% NaCl, 0.5% KCl, 0.5% $MgCl_2$; **F4** — 0.5% NaCl, 1% KCl, 0.5% $CaCl_2$; **F5**— 0.5% NaCl, 1% KCl, 0.5% $MgCl_2$; **F6** — 1% NaCl, 1% KCl; **F7—** 1% NaCl.

Table 3
Emulsion stability and cooking yield for low NaCl mortadella formulations.

Samples	(%) Released liquid	(%) Lipids	(%) Moisture	(%) Cooking yield
F1	2,692(0,067)^{d}	2,533(0,061)^{d}	0,159(0,016)^{ef}	93.15(0.55)^{a}
F2	6,778(0,244)^{b}	6,396(0,245)^{b}	0,381(0,007)^{b}	91.88(0.79)^{b}
F3	3,265(0,028)^{c}	3,071(0,025)^{c}	0,194(0,005)^{cd}	93.01(0.56)^{ab}
F4	13,051(0,343)^{a}	12,415(0,347)^{a}	0,635(0,009)^{a}	91.88(0.57)^{b}
F5	3,651(0,069)^{c}	3,448(0,068)^{c}	0,203(0,005)^{c}	93.06(0.48)^{ab}
F6	2,425(0,005)^{d}	2,286(0,006)^{d}	0,138(0,005)^{f}	92.83(0.31)^{ab}
F7	3,338(0,027)^{c}	3,161(0,019)^{c}	0,177(0,009)^{d}	93.17(0.54)^{a}

(%) released liquid = (%) lipid + (%) water.
Values are means (standard deviation).
^{a,b,c,d,e,f} Means in the same column with the same letters did not differ significantly at $p<0.05$ (Tukey's test).
F1— 2% NaCl; **F2**— 1.0%, 0.5% KCl, 0.5% $CaCl_2$; **F3 —** 1% NaCl, 0.5% KCl, 0.5% $MgCl_2$; **F4** — 0.5% NaCl, 1% KCl, 0.5% $CaCl_2$; **F5**— 0.5% NaCl, 1% KCl, 0.5% $MgCl_2$; **F6** — 1% NaCl, 1% KCl; **F7 —** 1% NaCl.

Furthermore, sodium tripolyphosphate used to increase water retention in emulsified meat products also chelates metal ions such as calcium and magnesium (Hamm, 1960; Irani & Callis, 1962) resulting in salts that are precipitated.

The formulations containing $CaCl_2$ (F2 — 1% NaCl, 0.5% KCl, 0.5% $CaCl_2$ and F4 — 0.5% NaCl, 1% KCl, $CaCl_2$ 0.5%) had the lowest values of pH ($p<0,05$) (Table 2), close to the isoelectric point of myosin (~5,4), when compared to the others batters. In the presence of divalent chlorinated salts, the solubility and extraction of myosin are reduced, especially in the presence of $CaCl_2$, resulting in a reduction in the functional properties of emulsified meat systems (Gordon & Barbut, 1992; Nayak, Kenney, Slider, Head, & Killefer, 1998a, 1998b). The F2 (1% NaCl, 0.5% KCl, 0.5% $CaCl_2$) and F4 (0.5% NaCl, 1% KCl, 0.5% $CaCl_2$) formulations had lower emulsion stability values even when compared to the F7 formulation with only 1% NaCl. Therefore, $CaCl_2$ negatively contributed to the stability of the emulsion regardless of other salts present in the blends.

The most stable emulsions with low values for the percentage of liquid released were F1 (2% NaCl) and F6 (1% NaCl, 1% KCl), which are composed only of monovalent cations. Seman, Olson, and Mandigo (1980), found that more liquid was released for a treatment containing NaCl and $MgCl_2$ compared to one containing a combination of NaCl and KCl.

The substitution of 50% NaCl by KCl (F6) did not significantly differ from the control formulation (CF) with 2% NaCl, confirming other studies (Desmond, 2007). The formulations that used $MgCl_2$ salt substitute blends (F3 — 1% NaCl, 0.5% KCl, 0.5% $MgCl_2$; and F5 — 0.5% NaCl, 1% KCl, 0.5% $MgCl_2$) did not significantly differ from the F7 formulation with a simple 50% NaCl reduction. This positive effect on emulsion stability can be due to a strong magnesium–protein interaction through polar groups in the peptide molecules which results in increased solubility of myosin (Nayak et al., 1998b). Regarding% cooking yield, F3 and F5 did not differ from the control formulation (2% NaCl). With respect to this property, partial substitution by $MgCl_2$ is a possible strategy.

With respect to the percentage of lipids extracted, the F6 formulation (1% NaCl, 1% KCl) did not differ from the control formulation (2% NaCl). All other formulations (F2, F3, F4, F5 and F7) had levels of released lipids above the CF ($p<0.05$). To reduce the released liquid and optimize emulsion stability of these formulations, it would be necessary to add additives or ingredients such as starch and carbohydrates, as suggested by Whiting (1987) and Aktas and Gençcelep (2006).

The high cooking-yields could thus create economically profitable products. The F2 (1% NaCl, 0.5% KCl, 0.5% $CaCl_2$) and F4 (0.5% NaCl, 1% KCl, 0.5% $CaCl_2$) formulations had lower cooking yields than the control sample (F1) ($p<0.05$). These results are in agreement with the emulsion stability values, in which the amount of released liquid was higher for samples F2 and F4.

3.3. Lipid oxidation stability

Lipid oxidation was evaluated by the levels of TBARS that developed during refrigerated storage (Table 4). Soon after processing (time zero), there were no differences among the formulations ($p<0.05$), as expected. The processing of the batters was conducted with good practice, and the raw materials and exposure to light, oxygen and temperature were controlled at all stages.

The F4 (0.5% NaCl, 1% KCl, 0.5% $CaCl_2$), F6 (1% NaCl, 1% KCl) and F7 (1% NaCl) formulations showed the lowest TBARS at 30 days compared to the CF (control formulation) with significant differences ($p<0,05$), indicating that KCl and $CaCl_2$ had the lowest pro-oxidant action. The samples containing $MgCl_2$ showed no difference compared to the CF, which contained 2% NaCl ($p<0.05$).

Despite the significant differences ($p<0.05$) observed throughout storage, the values for KCl, $CaCl_2$ and $MgCl_2$ containing samples were lower than those for the CF. Thus, all the salt combinations studied could be used to replace NaCl in emulsified mortadella-type sausages. Similarly, Rhee, Smith, and Terrell (1983) reported that KCl had lower pro-oxidant activity in meat than NaCl. In contrast, Flores, Nieto, Ferrer, and Flores (2005) reported an increase in lipid oxidation in fermented sausage products with 0.5% $CaCl_2$ as a partial substitute for NaCl. This difference can be explained by the different physico-chemical characteristics of the meat products (raw materials, ingredients, formulation, pH, water activity (aw) and moisture content). In addition in the reduced-sodium mortadella formulation, some of the ingredients and additives, such as polyphosphates, sodium nitrite and sodium erythorbate, have antioxidant properties (Hsu & Sun, 2006).

At the end of 60 days storage, there were similar decreases in TBARS values in all formulations. According to Melton (1983), although malonaldehyde is a secondary product of lipid oxidation, TBARS does not steadily increase during the storage of meat products and a decrease in malonaldehyde content occurs when the reaction

Table 4
TBARS values of low NaCl mortadella formulations (mg malonaldehyde/kg sample).

	0 days	15 days	30 days	45 days	60 days
F1	0.142(0.000)^{aC}	0.219(0.001)^{aB}	0.292(0.019)^{aA}	0.253(0.001)^{abAB}	0.210(0.025)^{aB}
F2	0.159(0.000)^{aC}	0.206(0.005)^{abB}	0.287(0.001)^{abA}	0.284(0.018)^{aA}	0.232(0.007)^{aB}
F3	0.133(0.000)^{aC}	0.226(0.001)^{aB}	0.292(0.017)^{aA}	0.267(0.006)^{abA}	0.215(0.006)^{aB}
F4	0.121(0.006)^{aB}	0.185(0.013)^{bcA}	0.227(0.001)^{bcA}	0.224(0.031)^{abA}	0.180(0.006)^{aAB}
F5	0.121(0.018)^{aB}	0.200(0.015)^{abAB}	0.250(0.030)^{abcA}	0.245(0.025)^{abA}	0.184(0.035)^{aAB}
F6	0.112(0.006)^{aC}	0.157(0.003)^{cB}	0.200(0.009)^{cA}	0.201(0.013)^{bA}	0.21(0.001)^{aA}
F7	0.130(0.030)^{aB}	0.221(0.008)^{aA}	0.228(0.012)^{bcA}	0.219(0.013)^{abA}	0.239(0.018)^{aA}

Values are means (standard deviation).
$^{a, b, c}$ Means in the same column with the same letter did not differ significantly at $p<0.05$ and
A,B,C the same row with the same letter did not differ significantly (Tukey's test).
F1— 2% NaCl; **F2**— 1.0%, 0.5% KCl, 0.5% $CaCl_2$; **F3 —** 1% NaCl, 0.5% KCl, 0.5% $MgCl_2$; **F4** — 0.5% NaCl, 1% KCl, 0.5% $CaCl_2$; **F5**— 0.5% NaCl, 1% KCl, 0.5% $MgCl_2$; **F6** — 1% NaCl, 1% KCl; **F7 —** 1% NaCl.

rate of the carbonyls with protein becomes higher than their rate of formation.

3.4. Texture profile analysis

In emulsified meat products, texture is related to the ability to bind water and fat that should develop during batter preparation and be maintained after heat treatment. Ionic strength is a key factor influencing these properties (Hamm, 1986). The NaCl concentrations normally added to meat products produce the ionic strength required for dissolution and extraction of the myofibrillar proteins responsible for emulsification, gelatinization, water-holding capacity, among others. Thus, when NaCl is reduced, the amount of extracted protein may also be decreased (Gordon & Barbut, 1992), thereby lowering the water-holding capacity and gel strength (Whiting, 1984). These changes are reflected in the final texture characteristics of comminuted products, especially in reduced-fat formulation, as in the present work. The results for mortadella texture profiles with NaCl reduction and partial replacement with other chlorinated salts are described in Table 5.

The reduction of NaCl influenced the texture properties of mortadella after processing and during storage. The variation in hardness in comminuted meat products may be related to the reduction of the water-holding capacity. The F4 (0.5% NaCl, 1% KCl, 0.5% $CaCl_2$) formulation was the hardest and coincided with the lowest emulsion stability and greatest volume of released liquid.

A negative contribution of $CaCl_2$ to the overall characteristics of the product is confirmed by the texture profile of products containing this salt in the blend. Totosaus, Alfaro-Rodrigues, and Pérez-Chabela (2004), found that sausages with reduced salt and fat contents also had higher hardness values with 0.5% $CaCl_2$, explained by the formation of a gel by the compact protein matrix.

There was no difference in hardness among the CF ($p<0.05$) and F2 (1.0% NaCl, 0.5% KCl), F3 (1% NaCl, 0.5% KCl), F5 (0.5% NaCl, 1% KCl, 0.5% $MgCl2_2$) and F7 (1% NaCl) formulations. The F6 formulation (1% KCl, 1% NaCl) was the least hard and was also different from the formulations that contained 1% NaCl with $CaCl_2$ (F2 and F4). Thus, the use of $CaCl_2$ under the conditions studied was primarily responsible for increased hardness compared to the CF. Substitution of 50% NaCl by KCl did not influence the hardness of the processed mortadella.

Springiness refers to the degree of recovery of sliced mortadella height (Yang, Choi, Jeon, Park, & Joo, 2007) and is related to water binding and fat properties. The springiness of the mortadella sausage samples did not differ significantly among the F1, F3, F4, F5, F6 and F7 formulations. F2 containing $CaCl_2$ (0.5%) was significantly less springiness ($p<0.05$).

Cohesiveness is a measure of the degree of difficulty of breaking down the internal structure of the sausages. The cohesiveness of samples varied with the blend of substitute salts used to replace NaCl. The lowest value for cohesiveness was observed for the F2 formulation (1% NaCl, 0.5% KCl, 0.5% $CaCl_2$), and was different from the other values ($p<0.05$). The results indicate that the 50% reduction in NaCl without the addition of any other salts produced no significant difference in cohesiveness. Likewise, the replacement of 50% NaCl by KCl did not affect cohesiveness, regardless of which third salt was used to make up the 2% salt concentration in the formulation. In

Table 5
Texture profile analysis in low NaCl mortadella formulations during storage.

sample	0 day	15 days	30 days	45 days	60 days
Hardness (N)					
F1	$17.54(0.76)^{Bbc}$	$17.68(0.47)^{Bd}$	$18.14(0.33)^{Bc}$	$21.69(0.62)^{Aab}$	$17.15(1.01)^{Bc}$
F2	$19.37(1.77)^{Ab}$	$21.41(1.04)^{Ae}$	$21.56(1.63)^{Aab}$	$21.86(0.51)^{Aab}$	$19.97(0.99)^{Ab}$
F3	$17.07(1.15)^{Bbc}$	$20.35(1.46)^{Abc}$	$20.23(1.21)^{Aabc}$	$19.96(0.65)^{Abc}$	$20.49(0.66)^{Ab}$
F4	$23.92(1.12)^{ABa}$	$23.24(1.11)^{Aa}$	$23.65(1.36)^{Aba}$	$24.21(1.79)^{Aa}$	$23.64(1.31)^{Aa}$
F5	$17.33(0.85)^{BCbc}$	$20.75(0.20)^{Ab}$	$18.99(1.45)^{ABc}$	$19.78(1.43)^{Abc}$	$16.45(0.23)^{Cc}$
F6	$15.62(0.65)^{Bc}$	$18.52(0.57)^{Acd}$	$19.35(0.15)^{Abc}$	$19.36(1.02)^{Abc}$	$18.18(1.19)^{Abc}$
F7	$19.50(0.96)^{Ab}$	$19.90(0.80)^{Abc}$	$20.27(0.51)^{Aabc}$	$18.10(1.47)^{Ac}$	$18.98(1.98)^{Abc}$
Elasticity					
F1	$0.92(0.01)^{Aa}$	$0.91(0.03)^{Aa}$	$0.93(0.01)^{Aa}$	$0.92(0.01)^{Aa}$	$0.93(0.01)^{Aa}$
F2	$0.81(0.02)^{Bb}$	$0.81(0.02)^{Bb}$	$0.91(0.01)^{Aa}$	$0.91(0.01)^{Aa}$	$0.90(0.01)^{Aab}$
F3	$0.93(0.01)^{Aa}$	$0.89(0.03)^{Aa}$	$0.93(0.02)^{Aa}$	$0.93(0.01)^{Aa}$	$0.91(0.01)^{Aab}$
F4	$0.91(0.01)^{ABa}$	$0.89(0.01)^{Ba}$	$0.92(0.01)^{Aa}$	$0.92(0.01)^{Aa}$	$0.92(0.01)^{Aa}$
F5	$0.92(0.01)^{Aa}$	$0.92(0.01)^{Aa}$	$0.91(0.02)^{Aa}$	$0.93(0.01)^{Aa}$	$0.93(0.01)^{Aa}$
F6	$0.93(0.01)^{Aa}$	$0.92(0.01)^{Aa}$	$0.92(0.01)^{Aa}$	$0.90(0.01)^{Aa}$	$0.92(0.01)^{Aa}$
F7	$0.91(0.02)^{ABa}$	$0.92(0.01)^{Aa}$	$0.91(0.01)^{Aa}$	$0.91(0.01)^{Aa}$	$0.880(0.02)^{Bb}$
Cohesiveness					
F1	$0.83(0.01)^{BCbc}$	$0.82(0.01)^{Ca}$	$0.83(0.01)^{Bab}$	$0.83(0.02)^{Ba}$	$0.85(0.01)^{Aa}$
F2	$0.71(0.02)^{Bd}$	$0.69(0.01)^{Bd}$	$0.82(0.01)^{Ab}$	$0.82(0.01)^{Aa}$	$0.83(0.01)^{Aa}$
F3	$0.85(0.01)^{Aa}$	$0.80(0.01)^{Bbc}$	$0.85(0.03)^{Aa}$	$0.84(0.01)^{Aa}$	$0.84(0.01)^{Aa}$
F4	$0.83(0.01)^{Aabc}$	$0.78(0.01)^{Bc}$	$0.82(0.03)^{Ab}$	$0.84(0.03)^{Aa}$	$0.84(0.01)^{Aa}$
F5	$0.84(0.01)^{Aab}$	$0.81(0.02)^{Ba}$	$0.84(0.01)^{Aab}$	$0.84(0.01)^{Aa}$	$0.85(0.02)^{Aa}$
F6	$0.83(0.01)^{Aabc}$	$0.81(0.01)^{Bab}$	$0.84(0.02)^{Aab}$	$0.84(0.01)^{Aa}$	$0.84(0.01)^{Aa}$
F7	$0.81(0.01)^{Bc}$	$0.81(0.01)^{Bab}$	$0.82(0.01)^{ABb}$	$0.81(0.01)^{Bb}$	$0.84(0.01)^{Aa}$
Chewiness					
F1	$13.34(0.52)^{Bbc}$	$13.13(0.20)^{Bb}$	$14.01(0.34)^{Bc}$	$16.58(0.55)^{Aab}$	$13.53(0.84)^{Bbc}$
F2	$11.18(1.45)^{Bd}$	$14.17(0.85)^{Aab}$	$16.182(1.43)^{Aab}$	$16.24(0.67)^{Aab}$	$15.02(0.66)^{Ab}$
F3	$13.42(0.64)^{Bbc}$	$14.48(1.48)^{ABab}$	$16.05(0.95)^{Aabc}$	$15.57(0.36)^{Abc}$	$15.58(0.62)^{Ab}$
F4	$17.95(0.57)^{Aa}$	$17.83(0.83)^{Aab}$	$17.03(0.99)^{Aa}$	$18.67\ (2.05)^{Aa}$	$18.31(1.34)^{Aa}$
F5	$13.37(0.57)^{Bbc}$	$15.55(0.56)^{Aa}$	$14.43(1.42)^{ABbc}$	$15.46(1.03)^{Abc}$	$12.89(0.22)^{Bc}$
F6	$12.07(0.44)^{Ccd}$	$13.59(0.67)^{Bb}$	$14.96(0.19)^{ABabc}$	$15.05(0.95)^{Abc}$	$14.11(0.63)^{ABbc}$
F7	$14.40(0.80)^{Ab}$	$14.70(0.64)^{Aab}$	$15.14(0.34)^{Aabc}$	$13.32(1.09)^{Ac}$	$13.95(1.34)^{Abc}$

Values are means (standard deviation).
[a, b, c, d] Means in the same column with the same lowercase letters did not differ significantly at $p<0.05$ (Tukey's test).
[A, B, C] Means in the same row with the same capital letters did not differ significantly at $p<0.05$ (Tukey's test).
F1— 2% NaCl; **F2**— 1.0%, 0.5% KCl, 0.5% $CaCl_2$; **F3 —** 1% NaCl, 0.5% KCl, 0.5% $MgCl_2$; **F4** — 0.5% NaCl, 1% KCl, 0.5% $CaCl_2$; **F5**— 0.5% NaCl, 1% KCl, 0.5% $MgCl_2$; **F6** — 1% NaCl, 1% KCl; **F7 —** 1% NaCl.

contrast, the CF was different from F2 and F3 because both contained only 0.5% KCl. The results indicate that KCl and NaCl salts are the most important in influencing cohesiveness.

The interpretation of chewiness values is similar to that of the previously mentioned attributes. Once more, the presence of $CaCl_2$ had an undesirable effect on texture, and formulation F4 (0.5% NaCl, 1.0% KCl, 0.5% $CaCl_2$) had the highest value for this parameter, followed by F2 (1.0% NaCl, 0.5% KCl, 0.5% $CaCl_2$). Chewiness did not differ when the NaCl concentration was reduced by 50% but were higher and significantly different when a combination of monovalent salts (KCl + NaCl in the same proportion) was used.

During 60 days of storage under refrigeration, the hardness, chewiness and elasticity values barely changed for the control formulation (2% NaCl), which showed higher values after 45 days of storage ($p<0.05$). For cohesiveness, there was a trend toward higher values, which were significantly different at 60 days for all formulations and can be explained by the probable release of liquid at the end of that period. The 50% reduction in NaCl (F7) did not produce significant effects on hardness, elasticity or chewiness during refrigerated storage.

The formulations containing 0.5% $CaCl_2$ (F2 and F4) showed no change in the hardness during refrigerated storage. When there was a 50% reduction in NaCl (F2), the elasticity and cohesiveness increased significantly after 30 days of storage and chewiness after 15 days. The F4 formulation with a 75% reduction in NaCl and higher levels of KCl (50%) remained stable across all texture parameters during storage, despite the previously discussed unfavorable values at time zero.

The presence of $MgCl_2$ in the formulations as a partial replacement for NaCl resulted in a significant increase in hardness, a reduction in cohesiveness and increased chewiness after 15 days ($p<0.05$) for both formulations (F3: 1% NaCl, 0.5% KCl, 0.5% $MgCl_2$ and F5: 0.5% NaCl, 1% KCl, 0.5% $MgCl_2$). For sample F5, there was a significant reduction in hardness and chewiness at the end of 60 days, which was likely produced by microbial deterioration. There was no change in elasticity during this period.

3.5. Objective color determination

The results for color determination are given in Table 6. For all treatments, the effects of salt reduction during refrigerated storage was not important for L*, a* and b* values, which express the luminosity, red and yellow intensities, respectively, and did not differ significantly from the control formulation ($p<0.05$). These results are in agreement with those of several authors. Crehan, Troy, and Buckley (2000) reduced the NaCl concentration from 2.5% to 1.5% in cooked sausages and found no changes in L* values. However, for fermented products with reduced sodium content (1% NaCl, 0.55% KCl and 0.74% $CaCl_2$), L* values may be higher than in their respective controls (Gimeno et al., 1999). This difference may be explained by the different physico-chemical characteristics (pH, aw and moisture) of the meat products. In a study of salt reduction in sausages, Sofos (1983) also found no significant difference ($p<0.05$) in a* and b* during storage of a product with 1.5% sodium chloride for 38 days.

3.6. Sensory evaluation of low NaCl mortadella formulations

The results obtained for the sensory evaluation (consumer test) of the appearance, aroma, flavor and texture by 112 consumers are presented in Table 7.

There were no significant differences ($p>0.05$) between all treatments with reduced NaCl containing different blends of salt substitutes and the control formulation (F1) regarding appearance, aroma and texture. For flavor, considered crucial for reduced-sodium mortadella formulations, the treatment that was most rejected by the judges (that with the lowest score) was the F5 formulation (0.5% NaCl, 1% KCl, 0.5% $MgCl_2$). The following lowest scores were for the F3 (1% NaCl, 0.5% KCl, 0.5% $MgCl_2$), F4 (0.5% NaCl, 1% KCl, 0.5% $CaCl_2$) and F6 (1% NaCl, 1% KCl) formulations, which were all significantly different from the control formulation F1 ($p<0.05$). Treatments F2 (1.0% NaCl, 0.5% KCl, 0.5% $CaCl_2$) and F7 (1% NaCl) did not differ significantly ($p<0.05$) from the control formulation in terms of taste, thus

Table 6
L* values (luminosity), a* values (red color intensity), b* values of (yellow color intensity) of low NaCl mortadella formulations.

	0 day	15 days	30 days	45 days	60 days
L					
F1	58.71 (1.54)^{Aab}	58.55(0.39)^{Aa}	56.52(0.46)^{Aa}	57.66(3.36)^{Aa}	57.45(2.47)^{Aa}
F2	60.82 (1.05)^{Aa}	60.58(1.28)^{Aa}	59.05(0.45)^{Aa}	58.99(0.90)^{Aa}	59.60(1.40)^{Aa}
F3	57.92 (0.29)^{Ab}	59.03(1.36)^{Aa}	57.23(1.96)^{Aa}	57.83(0.68)^{Aa}	58.42(2.76)^{Aa}
F4	60.17 (0.66)^{Aab}	60.47(1.34)^{Aa}	58.94(0.59)^{Aa}	59.44(1.75)^{Aa}	60.00(1.03)^{Aa}
F5	58.99 (0.88)^{Aab}	58.45(0.94)^{Aa}	57.97(1.45)^{Aa}	58.86(1.01)^{Aa}	58.86(2.87)^{Aa}
F6	59.51 (1.43)^{Aab}	60.64(1.62)^{Aa}	59.59(1.65)^{Aa}	58.41(1.64)^{Aa}	59.91(2.12)^{Aa}
F7	60.01 (0.83)^{Aab}	59.46(0.43)^{Aa}	57.74(1.86)^{Aa}	59.47(2.10)^{Aa}	59.39(2.15)^{Aa}
a					
F1	12.70 (0.88)^{Aab}	13.69(0.32)^{Aa}	13.90(0.26)^{Aa}	13.58(0.42)^{Aab}	12.84(1.05)^{Aa}
F2	12.95 (0.46)^{Aab}	13.40(0.23)^{Aa}	13.34(0.53)^{Aa}	13.64(0.13)^{Aab}	12.73(0.77)^{Aa}
F3	13.86 (0.76)^{Aa}	13.27(0.47)^{Aa}	13.48(0.75)^{Aa}	14.20(0.40)^{Aa}	13.05(0.34)^{Aa}
F4	12.77 (0.13)^{Aab}	12.99(0.47)^{Aa}	13.51(0.38)^{Aa}	13.67(0.64)^{Aab}	12.88(0.47)^{Aa}
F5	13.29 (0.21)^{Aab}	13.36(0.41)^{Aa}	13.47(0.12)^{Aa}	13.67(0.08)^{Aab}	11.48(1.27)^{Ba}
F6	12.67 (0.78)^{Aab}	13.01(0.28)^{Aa}	13.01(0.55)^{Aa}	13.31(0.49)^{Aab}	12.07(0.83)^{Aa}
F7	12.30 (0.74)^{Ab}	13.03(0.23)^{Aa}	12.90(0.18)^{Aa}	13.03(0.32)^{Ab}	11.84(1.20)^{Aa}
b					
F1	11.71 (0.39)^{Aa}	11.18(0.47)^{Aa}	11.76(0.20)^{Aa}	11.36(0.51)^{Aa}	11.18(0.66)^{Aa}
F2	11.52 (0.32)^{ABa}	11.02(0.11)^{Ba}	11.55(0.23)^{Aa}	11.33(0.09)^{ABa}	11.24(0.30)^{ABa}
F3	12.18(0.41)^{Aa}	11.47(0.45)^{Aa}	11.53(0.75)^{Aa}	11.75(0.22)^{Aa}	11.74(0.28)^{Aa}
F4	11.47 (0.15)^{Aa}	11.49(0.16)^{Aa}	11.46(0.20)^{Aa}	11.24(0.35)^{Aa}	11.24(0.55)^{Aa}
F5	12.00 (0.14)^{Aa}	11.75(0.14)^{Aa}	12.07(0.32)^{Aa}	12.00(0.34)^{Aa}	12.23(0.53)^{Aa}
F6	11.86 (0.31)^{Aa}	11.65(0.38)^{Aa}	11.82(0.46)^{Aa}	11.98(0.55)^{Aa}	11.87(0.56)^{Aa}
F7	12.09 (0.46)^{Aa}	11.78(0.29)^{Aa}	11.65(0.40)^{Aa}	11.57(0.41)^{Aa}	12.12(0.60)^{Aa}

Values are means (standard deviation).
[a, b] Means in the same column with the same lowercase letters did not differ significantly at $p<0.05$ (Tukey's test).
[A, B] Means in the same row with the same capital letters did not differ significantly at $p<0.05$ by the Tukey's test.
F1— 2% NaCl; **F2**— 1.0%, 0.5% KCl, 0.5% $CaCl_2$; **F3 —** 1% NaCl, 0.5% KCl, 0.5% $MgCl_2$; **F4** — 0.5% NaCl, 1% KCl, 0.5% $CaCl_2$; **F5**— 0.5% NaCl, 1% KCl, 0.5% $MgCl_2$; **F6** — 1% NaCl, 1% KCl; **F7 —** 1% NaCl.

Table 7
Mean sensory scores of low NaCl mortadella formulations.

	Appearance	Aroma	Flavor	Texture
F1	6.84(1.46)[a]	6.88(1.50)[a]	6.70(1.69)[a]	6.384(1.84)[ab]
F2	6.51(1.62)[a]	6.80(1.48)[a]	6.31(1.64)[ab]	6.55(1.89)[a]
F3	6.84(1.39)[a]	6.85(1.33)[a]	5.48(1.65)[c]	5.97(1.71)[ab]
F4	6.66(1.64)[a]	6.38(1.56)[a]	5.51(1.96)[c]	6.54(1.79)[a]
F5	6.95(1.52)[a]	6.81(1.49)[a]	4.55(2.19)[d]	5.80(1.95)[b]
F6	6.70(1.41)[a]	6.69(1.41)[a]	5.88(1.59)[bc]	6.27(1.66)[ab]
F7	6.70(1.64)[a]	6.70(1.60)[a]	6.03(1.75)[abc]	6.56(1.71)[a]
LSD	0.603	0.588	0.709	0.701

LSD — least significant difference.
[a, b, c] Means in the same column with the same letters did not differ significantly at $p<0.05$ (Tukey's test).
F1— 2% NaCl; **F2**— 1.0%, 0.5% KCl, 0.5% $CaCl_2$; **F3 —** 1% NaCl, 0.5% KCl, 0.5% $MgCl_2$; **F4** — 0.5% NaCl, 1% KCl, 0.5% $CaCl_2$; **F5**— 0.5% NaCl, 1% KCl, 0.5% $MgCl_2$; **F6** — 1% NaCl, 1% KCl; **F7 —** 1% NaCl.

becoming likely substitutes for sodium chloride in this respect. Totosaus et al. (2004) performed a partial replacement of sodium chloride by $CaCl_2$ in emulsified products using k-carrageenan and found no sensory differences compared to the control sample, similar to the results found in this study.

Although the F7 sample produced a sensory acceptance similar to that of the control, it is worth highlighting its limitation with regards to lower microbial stability by having the lowest salt content (1% NaCl) of all treatments.

Potassium chloride is the most-used substitute in the preparation of low-sodium meat products, but as observed in this study, depending on the level of substitution, it results in sensory rejection because it produces a bitter and metallic taste (Guardia, Guerrero, Gelabert, Gou, & Arnau, 2008; Seman et al., 1980). In the study by Gelabert, Gou, Guerrero, and Arnau (2003), a bitter taste was detected in fermented sausages with sodium chloride replaced by KCl, which was accepted up to a replacement of 40%. In the study by Keeton (1984), the acceptance of cured hams was observed up to a 33.3% replacement of sodium chloride by potassium chloride, although a slight bitter taste was detected in these samples when compared to the control (100% sodium chloride). In agreement with previous reports, the bitter taste was the most perceptible attribute in fermented meat products with partial replacement of NaCl by KCl (Gou, Guerrero, Gelabert, & Arnau, 1996; Zanardi, Ghidini, Conter, & Ianieri, 2010). The trained taste panel in the study by Zanardi et al. (2010) also detected a decrease in the salty flavor and a lighter color in low-sodium salami samples, resulting in lower overall acceptability compared to the control. In this study, the emulsified mortadella-type sausages showed similar results, with higher rejection due to taste for the F4 (0.5% NaCl, 1% KCl, 0.5% $CaCl_2$), F5 (0.5% NaCl, 1% KCl, 0.5% $MgCl_2$) and F6 (1% NaCl, 1% KCl) samples in which there was a 50% replacement of NaCl by KCl.

4. Conclusion

The partial replacement of NaCl by blends of KCl, $CaCl_2$ and $MgCl_2$ in emulsified meat products such as mortadella can be performed to develop healthier products with reduced sodium contents. The product with the best sensory acceptance resulted from the use of 1% NaCl, 0.5% KCl and 0.5% $CaCl_2$ (F2). However, $CaCl_2$ reduced emulsion stability and% cooking yield. The blends containing $MgCl_2$ (F3 — 1% NaCl, 0,5% KCl, 0,5% $MgCl_2$ e F5 — 0.5% NaCl, 1% KCl and $MgCl_2$ 0.5%) did not show differences in emulsion stability and texture parameters such as hardness, cohesiveness, elasticity and chewiness compared to the control sample, but had low sensory acceptability, especially regarding flavor.

Thus, it is necessary to optimize these formulations with the use of other ingredients and additives capable of stabilizing the emulsion, such as starches or others thickeners and bitter-masking compounds such as yeast extract or a mix of natural herbs.

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