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L-lysine and dietary fiber improve the physicochemical properties of sausage without added phosphate and reduced salt levels

Carlos Alberto Alves Junior, Elisa Rafaela Bonadio Bellucci, João Marcos dos Santos, Marcello Lima Bertuci, Andrea Carla da Silva Barretto*

Universidade Estadual Paulista/IBILCE – Depto. de Engenharia e Tecnologia de Alimentos, R. Cristóvão Colombo, 2265 – 15054-000 – São José do Rio Preto, SP – Brasil.

*Corresponding author <andrea.carla@unesp.br>

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ABSTRACT: The demand for clean label foods has driven research in the meat product sector. The objective of this study was to evaluate the effect on the physicochemical properties of adding L-lysine, wheat fiber (WTF) and microcrystalline cellulose (MCC) in sausage without the addition of sodium tripolyphosphate (STPP) and with reduced salt levels. Eight treatments were produced in total. Three control treatments were: CON1 - 0.5 % sodium tripolyphosphate and 2 % salt; CON2 - without STPP and 2 % salt; CON3 - without STPP and 1 % salt. Five other treatments were carried out without STPP and 1 % of salt: LYS - 0.8 % L-lysine; WTF - 2 % wheat fiber; MCC - 2 % microcrystalline cellulose fiber; LYSWTF - 0.8 % L-lysine and 2 % wheat fiber; LYSMCC - 0.8 % L-lysine and 2 % microcrystalline cellulose fiber. L-lysine and wheat fiber provided good emulsion stability for sausages. L-lysine and MCC increased the yield of the products. Microcrystalline cellulose increased the red color value (a*) of sausages. The intensity of the yellow color value (b*) was significantly affected by the removal of STPP and the reduction of salt levels, but L-lysine and MCC improved this parameter, providing similar results to CON1. Adding of L-lysine and dietary fiber increased hardness in sausages without added STPP and with salt reduction. L-lysine and wheat fiber are promising for reformulating emulsified meat product without phosphate added and with reduced salt levels due to lipid oxidation control and improvement in emulsion stability.

Keywords: clean label, amino acid, wheat fiber, microcrystalline cellulose

Introduction

The development of healthier meat products is one of the main objectives in the meat industry to improve consumer acceptability and aggregate value of products (Han and Bertram, 2017). The reformulation of meat products consists of reducing sodium, nitrite, nitrate, fat, and cholesterol levels, and modifying the fatty acid profile (Grasso et al., 2014). Nevertheless, it is considered a great challenge because the products need to be healthier while keeping the technological and sensory characteristics similar to conventional ones. Dietary fiber is added to reformulated meat products to improve their technological properties, such as emulsion stability, viscosity, sensory, and rheological characteristics (Das et al., 2020). It is also used to better the capacity of binding water and oil, water retention, and gel formation to increase shelf life and reduce cooking losses (Wu et al., 2021). Adding of up to 2 % of microcrystalline cellulose (MCC), resistant starch, and oat fiber helped reduce the water activity and increased hardness and chewiness in reduced fat–reduced salt fermented sausage (Santos et al., 2021).

Phosphates and sodium chloride (NaCl) are ingredients of meat products, contributing to the extraction of myofibrillar proteins and are promoters of technological and sensory properties, such as the formation of the three-dimensional gel network, emulsion stability, oxidative and microbiological stability, the water and fat retention capacity (Pinton et al., 2021; Câmara et al., 2020; Rodrigues et al., 2019). Sodium excess in the diet is known to cause cardiovascular disease and hypertension (Gomes et al., 2021). A phosphate-rich diet can increase the risk of cardiovascular diseases and hyperphosphatemia (Thangavelu et al., 2019; Pinton et al., 2019; Zhang et al., 2021).

L-lysine is an essential amino acid of great nutritional value and can increase myosin solubility at low ionic strength (Li et al., 2019; Li et al., 2018). Thus, L-lysine can potentially improve physicochemical and sensory properties, such as the water retention capacity, texture profile, flavor and global acceptance of meat products with reduced NaCl content (Guo et al., 2020; Zhou et al., 2014; Zheng et al., 2017).

In emulsified meat products, emulsion stability is critical, mainly because it depends on factors such as the temperature and pH of the meat, protein content, fat and NaCl content (Nieto and Lorenzo, 2021). Therefore, the objective of this study was to evaluate the effect on the physicochemical properties of adding L-lysine, wheat fiber, and microcrystalline cellulose to sausage without added phosphate and with reduced salt levels.

Materials and Methods

Materials

All raw meat was obtained from a commercial establishment with SIF (Federal Service of Inspection) certification. Wheat Fiber (WTF) (Creafibe WC-200) and microcrystalline cellulose (MCC) (Nutracel 611 SD®) were provided by Nutrassim Food Ingredients (Extrema, Brazil).

Sausage production

The study comprised eight treatments of sausage, all with the following ingredients: lean pork (Biceps femoris, Adductor, Semimembranosus, Pectineus and Semitendinosus) 27.5 %, beef chuck (27.5 %), pork back fat (15 %), sodium nitrite (0.015 %) and sodium erythorbate (0.05 %). The differences between treatments concern the amount of water, NaCl, sodium tripolyphosphate (STPP), L-lysine (LYS), wheat fiber (WTF), and microcrystalline cellulose (MCC) (Table 1). Twenty-five sausages were produced for each treatment in each repetition, totaling 600 sausages.

The meat raw materials: lean pork (moisture 70.67 %, protein 21.63 %, fat 5.10 %), beef chuck (moisture 71.51 %, protein 21.78 %, fat 3.50 %), and pork back fat (moisture 20.30 %, protein 8.11 %, fat 71.35 %) were stored at 4 ± 2 °C and were ground in a miller with an 8 mm disc and weighed on a semi-analytical scale BL320H. Subsequently, the raw meat was minced in a Super Sire cutter with sodium chloride and half of the water in a semi-solid state to start the emulsification process. Then, the other additives, the other half of the water, the fibers (wheat fiber and microcrystalline cellulose), and the L-lysine were added according to Table 1. This process took about 2.5 min and the temperature was monitored using a digital skewer thermometer without exceeding 9 °C at the end of the process to ensure the integrity of the raw batter.

The raw batter was stuffed in artificial cellulosic cases with a diameter of 25 mm, using an E-8 manual filler model. Afterward, the sausages were put into a Turbo 240 Classic industrial oven where they were cooked with an initial oven temperature of 50 °C for 8 min, increasing to 60 °C for another 8 min, and to 72 °C for 5 min to reach the internal product temperature of 72 °C. After cooking, the sausages were cooled in cold water, peeled, packaged in vacuum polyethylene nylon bags, and stored under refrigeration at 4 ± 2 °C for 30 days before the analyses.

Table 1 – Ingredient proportions added to the sausage of the different treatments (%).

Treatment	CON1	CON2	CON3	LYS	WTF	MCC	LYSWTF	LYSMCC
Water	27.5	28.0	29.0	28.2	27.0	27.0	26.2	26.2
NaCl[1]	2.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0
STPP[2]	0.5	–	–	–	–	–	–	–
L-lysine	–	–	–	0.8	–	–	0.8	0.8
Wheat Fiber	–	–	–	–	2.0	–	2.0	–
MCC fiber[3]	–	–	–	–	–	2.0	–	2.0

[1]sodium chloride; [2]sodium tripolyphosphate; [3]microcrystalline cellulose fiber.

Proximate composition and pH

The moisture, ash, and protein contents were determined according to the official method of the Association of Official Analytical Chemistry (AOAC, 2007). The fat content was determined according to the method described by Bligh and Dyer (1959). The carbohydrate content was obtained by the difference between 100 and the sum of moisture, ash, protein, and lipid contents. All analyses were performed in triplicate and the results were expressed as a percentage.

The pH was determined in triplicate using an mPA-210 digital pH meter with probe penetration directly into the product at a temperature of 25 °C.

Lipid oxidation

Thiobarbituric acid reactive substances (TBARS) were quantified following the methodology described by Vyncke (1975) on days 0, 15, and 30 at refrigerated storage. Briefly, 5 g of the sausage was mixed with 25 mL of trichloroacetic acid solution (7.5 %) using an IKA T18 digital ultra-turrax and centrifuged at 4,500 rpm for 10 min. Then, the supernatant was filtered and 5 mL of the filtrate was added to 5 mL of thiobarbituric acid solution and placed in a water bath at 90 °C for 40 min. The reading was taken at 532 nm. For the standard curve, 1,1,3,3-tetraethoxypropane (TEP) was used as standard and the TBARS result was expressed in mg of malonaldehyde (MDA) kg^{-1} of the sample.

Texture profile analysis (TPA)

The texture profile analysis (TPA) was performed in a TA-XT/Plus/50 texturometer following the method described by Bourne (1978). The parameters determined were hardness, cohesiveness, springiness, and chewiness. The sausage samples were cut with a stainless-steel cutter (20 mm diameter) and a cylindrical probe (36 mm diameter) was used with 50 % compression and test speed 5 mm s^{-1}, n = 10.

Instrumental color

The instrumental color was measured using a ColorFlex45/0 colorimeter with 10° viewing angle, D65 illuminant using the Universal software version 4.10, previously calibrated using black glasses and white tiles. The samples were placed in a quartz capsule with an internal diameter of 75 mm. The CIELAB color specification system was used and the parameters obtained were L* (lightness), a* (redness), and b* (yellowness). The whiteness index (W) was calculated with the L*, a*, and b* values, using the Eq. (1).

$$W = 100 - \sqrt{\left(100 - L*^2\right) + a*^2 + b*^2}$$

The total color difference (ΔE) was used to determine the perceptible color difference between two colors and it was classified as small difference (ΔE < 1.5), distinct (1.5 < ΔE < 3), and very distinct (ΔE > 3) (Pathare et al., 2013). In this study, it was measured between CON1 and other treatments using the Eq. (2).

$$\Delta E* = \sqrt{\Delta a*^2 + \Delta b*^2 + \Delta L*^2}$$

Four readings for each parameter at equidistant points in the sample were collected. The mean of the measurements represented the reading for each sample.

Emulsion stability and yield

The stability of the emulsion (EE) was determined according to the methodology described by Henck et al. (2019) with some modifications. At first, 30 g of the raw emulsion was weighed in triplicate in Nylon Polyethylene bags sealed without vacuum with Nylon clamps. Then, the samples were placed in NT245 water bath at 70 ± 1 °C for 1 h. After cooling the samples in running water, the exuded liquid was weighed, and the percentage loss was calculated in relation to the initial weight. Emulsion stability is expressed as a percentage using Eq. (3).

$$\%EE = (100 - \%loss)$$

where: %*loss* = (weight of exudate liquid × 100) raw emulsion weight^{-1}.

The yield of the sausages was quantified by the difference in weight of the samples, before and after heat treatment and cooling at room temperature. Values are expressed as a percentage, according to Eq. (4).

$$Yield\ (\%) = (100 - \%\ weight\ loss)$$

where: % *weight loss* = [(starting weight – final weight) starting weight^{-1}] × 100.

Statistical analysis

The results were expressed as mean values and the standard error of the mean. Three procedures of sausage processing were elaborated at different days. Each repetition was considered a random variable, while the storage and treatment time were fixed variables and the results of analysis (chemical composition, the pH, color parameter, lipid oxidation, TPA, emulsion stability, and yield) were considered dependent variables. The data were statistically analyzed using analysis of variance (ANOVA) through the General Linear Model (GLM) and the means were compared by the Tukey test ($p < 0.05$). The statistical analyses were carried out using the Statistica software (StatSoft, Inc., version 7.0).

Results and Discussion

Proximate composition and pH value

The proximate compositions of the sausage treatments are shown in Table 2. The treatments with 2 % salt added (CON1 and CON2) presented a higher moisture percentage, the same as the LYS treatment. Thus, salt reduction without another alternative ingredient for replacement (CON3) affected ($p < 0.05$) the moisture content in sausages, as the reduction in ionic strength favored moisture loss. The reduction of salt levels decreases the binding strength of water with myoglobin, due to the critical property of the salt to solubilize and improve the myoglobin functionality in meat products (Vilar et al., 2020)

Regarding the LYS treatment, the L-lysin contributed to the non-reduction of moisture, providing results like CON1 and CON2 and improving the water-holding capacity (WHC) of sausage. Similar behavior has been reported. L-lysine and L-arginine in pork sausage without added phosphate and reduced salt levels showed that L-lysine significantly increased

Table 2 – Proximate composition of sausages.

Treatments	Moisture	Protein	Lipids	Ash	Carbohydrates	pH
	%					
CON1	65.48^a	13.69	16.87	2.98^a	0.98	6.43
CON2	65.37^a	14.48	17.57	1.16^b	1.42	6.22
CON3	63.48^b	15.38	18.24	0.94^{cd}	1.96	6.21
LYS	65.18^a	15.64	17.32	0.95^{cd}	0.91	6.19
WTF	64.27^b	13.87	18.12	0.93^d	2.81	6.22
MCC	61.86^c	15.56	17.56	0.93^d	4.09	6.19
LYSWTF	61.64^c	14.07	17.99	0.99^{cd}	5.31	6.17
LYSMCC	64.27^b	13.88	18.41	1.01^c	2.43	6.23
SEM	0.368	0.221	0.149	0.685		0.023
p-value	0.000	0.183	0.085	0.000		0.113

$^{a-d}$Means followed by different letters in the same column differ by the Tukey Test ($p \leq 0.05$); SEM = standard error of the mean. Treatments: CON1 - 0.5 % STPP and 2 % NaCl; CON2 - without STPP and 2 % NaCl; CON3 - without STPP and 1 % NaCl; LYS - without STPP, 1 % NaCl and 0.8 % L-lysine; WTF - without STPP, 1 % NaCl and 2 % wheat fiber; MCC - without STPP, 1 % NaCl and 2 % microcrystalline cellulose fiber; LYSWTF - without STPP, 1 % NaCl, 0.8 % L-lysine and 2 % wheat fiber; LYSMCC - without STPP, 1 % NaCl, 0.8 % L-lysine and 2 % microcrystalline cellulose fiber; Sodium tripolyphosphate (STPP).

the WHC in relation to the control treatment (Zheng et al., 2017). Adding of L-lysine at different levels in pork sausage increased the WHC compared to the control treatment (Zhou et al., 2014). In our study, the removal of sodium tripolyphosphate (STPP) does not seem to have affected the moisture content, possibly due to the excelent quality of raw meat used, exhibiting good WHC. The reduction of salt levels affected ($p < 0.05$) the moisture of all the other treatments. The addition of wheat fiber (WTF) had a more significant effect ($p < 0.05$) on moisture than the addition of microcrystalline cellulose fiber (MCC).

The protein content ranged from 13.69 % to 15.64 % and was similar between the different treatments of sausage ($p > 0.05$). The lipid content also showed no difference between the treatments ($p > 0.05$). There was no difference in the protein and lipid content because of the same quantity of ingredients used in raw meat in all treatments. The ash content was affected by removing sodium tripolyphosphate (CON2) and sodium tripolyphosphate and salt reduction (CON3). The addition of WTF and MCC did not affect the sausage ash content.

The pH value did not differ ($p > 0.05$) between the treatments, showing that without added STPP and with salt reduction, as well as the addition of L-lysine and dietary fiber did not affect the pH value. The removal of STPP and the addition of 0.75 % and 1 % of citrus fiber did not affect the pH values in bologna sausage (Powell et al., 2019). A reduction of 48 % of salt levels in frankfurters showed no effects on the pH values between the different treatments (O'Neill et al., 2018). Similar results have been found for the pH between the treatments with the addition of different levels of WTF and a control treatment without WTF (Carvalho et al., 2019).

Lipid oxidation

Lipid oxidation was affected by storage time ($p < 0.05$) for most treatments (Figure 1), except for CON1, LYSWTF, and LYSMCC. In general, lipid oxidation values increased with longer storage time. At day 0, no difference was found between the treatments ($p > 0.05$) and the TBARS values ranged from 0.524 to 0.664 mg MDA kg^{-1} of the sample. After 15 days, the highest lipid oxidation values were observed in CON2, which did not differ from the LYS treatment, while the lowest values were found in CON1, followed by treatments with fiber added (WTF and MCC). At 30 days, CON2 presented the highest lipid oxidation ($p < 0.05$), reaching 1,469 mg MDA kg^{-1} of the sample. This result shows that removing STPP from the formulation (CON2) increases lipid oxidation in sausage with added 2 % of salt, showing its antioxidant action. The TBARS values did not exceed 2.0 mg MDA kg^{-1} of the sample, considered the limit of acceptability and deterioration in meat products (Trindade et al., 2010).

The removal of STPP and the reduction of sodium chloride (CON3) showed that lipid oxidation was significantly reduced ($p < 0.05$) as NaCl accelerates lipid oxidation (15 and 30 days of storage). Commercial salt, associated with sodium chloride, has many metallic

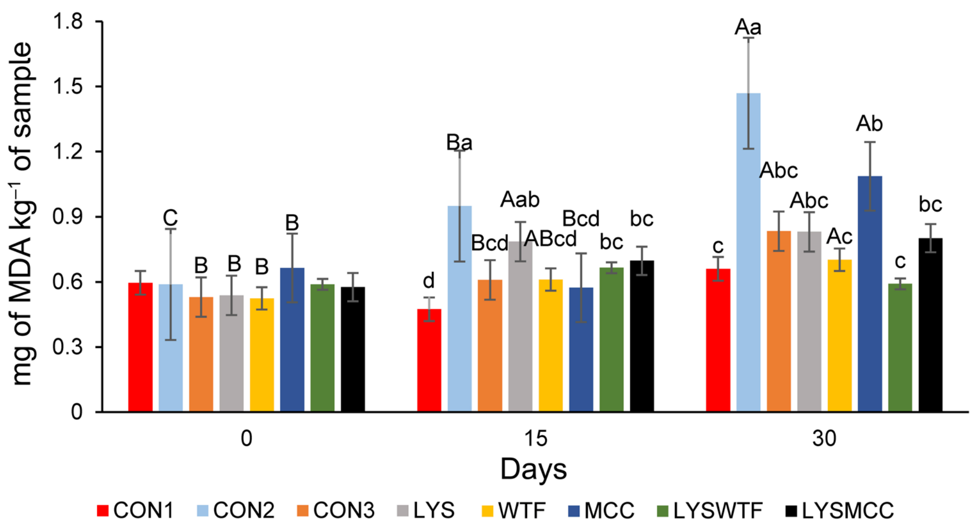

Figure 1 – Lipid oxidation (in mg of MDA kg^{-1} of sample) of sausages. [a–d]Means followed by different letters on the same day differ by the Tukey Test ($p \leq 0.05$); [A–C]Means followed by different letters in the same treatment differ by the Tukey Test ($p \leq 0.05$); Treatments: CON1- 0.5 % STPP and 2 % NaCl; CON2 - without STPP and 2 % NaCl; CON3 - without STPP and 1 % NaCl; LYS - without STPP, 1 % NaCl and 0.8 % L-lysine; WTF - without STPP, 1 % NaCl and 2 % wheat fiber; MCC - without STPP, 1 % NaCl and 2 % microcrystalline cellulose fiber; LYSWTF - without STPP, 1 % NaCl, 0.8 % L-lysine and 2 % wheat fiber; LYSMCC - without STPP, 1 % NaCl, 0.8 % L-lysine and 2 % microcrystalline cellulose fiber; Sodium tripolyphosphate (STPP).

components that can contribute to lipid oxidation (Overholt et al., 2016); however, it can present a pro-oxidant effect even when pure.

Texture profile analysis

The texture profile analysis (Table 3) shows that hardness increased ($p < 0.05$) with the removal of STPP and with salt reduction (CON2 and CON3), as well as with the addition of dietary fiber and L-lysine. The incorporation of WTF and MCC contributed to increase hardness. However, in treatments with L-lysine (LYS, LYSWTF, and LYSMCC), hardness was even higher ($p < 0.05$). Adding L-lysin to salt-reduced reconstructed ham showed that concentrations of 0.6 % and 0.8 % of L-lysin increased hardness compared to lower concentrations (0.2 % and 0.4 %) (Guo et al., 2020). When L-lysine is added at low concentrations, hardness can be negatively affected due to inhibition of L-lysine on thermal aggregation of myosin. Conversely, when added at high concentrations, it activated more myosin to be solubilized after curing, nullifying the thermal aggregation inhibition effect of myosin (Guo et al., 2020). The treatments with the addition of WFC and L-lysine (LYSWTF) showed the highest hardness values.

The removal of STPP (CON2) did not influence ($p > 0.05$) cohesiveness of sausages, unlike the salt reduction (CON3), which considerably reduced ($p < 0.05$) this parameter. L-lysine alone and L-lysine with microcrystalline cellulose (LYS and LYSMCC) compensated for this reduction, generating similar results ($p > 0.05$) to CON1.

As for springiness, all treatments were similar ($p > 0.05$) to CON1. L-lysine (LYS) showed springiness greater ($p < 0.05$) than WTF on sausage without added STPP and with reducted salt levels.

Table 3 – Texture profile of the sausages.

Treatments	Hardness	Cohesiveness	Springiness	Chewiness
CON1	12.47^{f}	0.65^{a}	0.74^{ab}	5.89^{c}
CON2	15.12^{e}	0.66^{a}	0.75^{ab}	7.50^{b}
CON3	16.63^{e}	0.51^{cd}	0.73^{ab}	6.17^{bc}
LYS	20.78^{bc}	0.62^{ab}	0.78^{a}	9.92^{a}
WTF	18.11^{d}	0.48^{d}	0.72^{b}	6.30^{bc}
MCC	18.58^{cd}	0.53^{cd}	0.74^{ab}	7.33^{bc}
LYSWTF	25.60^{a}	0.56^{bc}	0.75^{ab}	10.85^{a}
LYSMCC	22.67^{b}	0.60^{ab}	0.76^{ab}	10.31^{a}
SEM	0.500	0.009	0.004	0.249
p-value	0.000	0.000	0.028	0.000

[a–f]Means followed by different letters in the same column differ by the Tukey Test ($p \leq 0.05$); SEM = standard error of the mean. Treatments: CON1 - 0.5 % STPP and 2 % NaCl; CON2 - without STPP and 2 % NaCl; CON3 - without STPP and 1 % NaCl; LYS - without STPP, 1 % NaCl and 0.8 % L-lysine; WTF - without STPP, 1 % NaCl and 2 % wheat fiber; MCC - without STPP, 1 % NaCl and 2 % microcrystalline cellulose fiber; LYSWTF - without STPP, 1 % NaCl, 0.8 % L-lysine and 2 % wheat fiber; LYSMCC - without STPP, 1 % NaCl, 0.8 % L-lysine and 2 % microcrystalline cellulose fiber; Sodium tripolyphosphate (STPP).

The removal of STPP (CON2) increased ($p < 0.05$) sausage chewiness. Therefore, in sausages with salt reduction and without added STPP (CON3), results were similar to CON1, which presented the lowest value for chewiness. The addition of L-lysine (LYS, LYSWTF, and LYSMCC) increased ($p < 0.05$) chewiness.

Studies have reported similar behavior in relation to TPA in meat products emulsified with the addition of WTF, MCC, and L-Lysine. An increase in hardness was reported in sausage with the addition of MCC (Schuh et al., 2013). In the reformulation of sausage with reduced fat content, WTF associated with chicken skin increased product hardness (Choe and Kim, 2019).

The addition of L-lysine to pork sausage showed an increase in hardness and chewiness of products (Zhou et al., 2014)

Instrumental color

Instrumental color parameters in the sausage treatments are presented in Table 4. At day 0, the treatments with added fiber only (WTF and MCC) presented the highest L* values and differed from CON2 ($p < 0.05$). LYSMCC had the highest L* value after 30 days (60.58) and was different from CON1 (58.97). Therefore, we conclude that sampling time does affect lightness, as seen in treatment CON2, which increased the L* value after 30 days. Studies reported different results for removing phosphate in emulsion-type sausages, which presented the lowest L*value (Choe et al., 2018).

The removal of STPP and the reduction of salt levels (CON2 and CON3) did not influence the a* parameter ($p > 0.05$). It was the same for the treatments with the addition of L-lysine and the dietary fiber, except for the MCC treatment at day zero, which presented a higher intensity of a*, indicating that MCC contributed to an increase in the intensity of the red color ($p < 0.05$). Initially, MCC presented a higher a* value, redder than CON1 ($p < 0.05$), while no difference was found between the treatments at 30 days. The addition of different levels of MCC showed similar a* values to the control treatment of emulsified sausage and beef emulsion models, respectively (Schuh et al., 2013; Vasquez-Mejia et al., 2019).

The removal of STPP (CON2) alone did not influence ($p > 0.05$) the b* value; however, along with the reduction of salt levels (CON3), this parameter was affected ($p < 0.05$) . Among the sausages with the addition of L-lysine and dietary fiber, only the LYS and MCC treatments showed b* ($p > 0.05$) values similar to CON1 at day 0. At day 30, the treatments with the addition of dietary fiber and L-lysine did not show any difference ($p > 0.05$) in relation to CON1.

The WTF treatment showed the highest whiteness values (Table 4) at 0 and 30 days. The addition of WTF increased whiteness in emulsified meat products without added phosphate and reduced salt. Similarly, an increase in whiteness was reported in bologna-type sausage with pork skin and amorphous cellulose (Faria et al., 2015)

All treatments presented color differences between distinct and very distinct compared with CON1 (Figure 2).

Emulsion stability and yield

Treatment CON1 had a higher value (89.93 %) for emulsion stability due to the sodium tripolyphosphate (STPP) and NaCl that helped in the extraction and solubilization of myofibrillar proteins, providing greater emulsion stability (Figure 3A). This result agrees with the result for moisture content for which CON1 presented higher moisture content than the other treatments. The removal of STPP (CON2) reduced ($p < 0.05$) emulsion stability and, along with the salt reduction (CON3), this reduction in stability was even more significant. A 50 % reduction of phosphate in

Table 4 – Instrumental color of sausages during refrigerated storage.

	CON1	CON2	CON3	LYS	WTF	MCC	LYSWTF	LYSMCC	SEM	*p-value*
L*										
0	59.22^{ab}	57.84^{Bb}	59.34^{ab}	59.08^{ab}	60.63^{a}	60.34^{a}	59.34^{ab}	59.84^{ab}	0.198	0.016
30	58.97^{b}	60.10^{Aab}	60.20^{ab}	59.18^{ab}	60.25^{ab}	60.41^{ab}	59.81^{ab}	60.58^{a}	0.132	0.013
SEM	0.452	0.560	0.232	0.217	0.126	0.122	0.365	0.256		
p-value	0.788	0.040	0.062	0.834	0.134	0.772	0.538	0.151		
a*										
0	8.26^{b}	10.21^{ab}	10.55^{ab}	10.09^{ab}	10.01^{ab}	11.43^{Aa}	9.85^{ab}	10.13^{ab}	0.223	0.050
30	9.22	10.22	9.99	10.33	10.17	10.56^{B}	10.27	10.24	0.158	0.592
SEM	0.442	0.359	0.376	0.411	0.355	0.207	0.382	0.409		
p-value	0.288	0.982	0.472	0.775	0.827	0.032	0.590	0.897		
b*										
0	11.93^{b}	11.86^{Ab}	12.70^{a}	12.19^{Aab}	12.56^{a}	12.17^{ab}	12.46^{Aa}	12.55^{a}	0.051	0.000
30	11.75^{ab}	11.48^{Bb}	12.36^{a}	11.46^{Bb}	12.19^{a}	12.40^{a}	12.07^{Bab}	12.33^{a}	0.066	0.000
SEM	0.119	0.095	0.102	0.145	0.102	0.098	0.099	0.072		
p-value	0.452	0.044	0.104	0.008	0.065	0.244	0.046	0.140		
Whiteness										
0	56.63^{ab}	54.97^{b}	56.06^{Bab}	56.07^{ab}	57.44^{a}	56.96^{ab}	56.29^{ab}	56.66^{ab}	0.176	0.026
30	55.51^{c}	56.58^{abc}	56.98^{Aabc}	55.93^{bc}	57.57^{a}	57.35^{ab}	57.00^{abc}	57.48^{ab}	0.146	0.000
SEM	0.421	0.536	0.233	0.153	0.104	0.102	0.442	0.294		
p-value	0.201	0.144	0.049	0.670	0.526	0.055	0.446	0.177		

$^{a-c}$Means followed by different letters on the same line differ by the Tukey Test ($p \leq 0.05$); $^{A-B}$Means followed by different letters in the same column differ by Tukey Test ($p \leq 0.05$); SEM = standard error of the mean; Treatments: CON1- 0.5 % STPP and 2 % NaCl; CON2 – without STPP and 2 % NaCl; CON3 – without STPP and 1 % NaCl; LYS- no STPP, 1 % NaCl and 0.8 % L-lysine; WTF - without STPP, 1 % NaCl and 2 % wheat fiber; MCC - without STPP, 1 % NaCl and 2 % microcrystalline cellulose fiber; LYSWTF- no STPP, 1 % NaCl, 0.8 % L-lysine and 2 % wheat fiber; LYSMCC - without STPP, 1 % NaCl, 0.8 % L-lysine and 2 % microcrystalline cellulose fiber; Sodium tripolyphosphate (STPP).

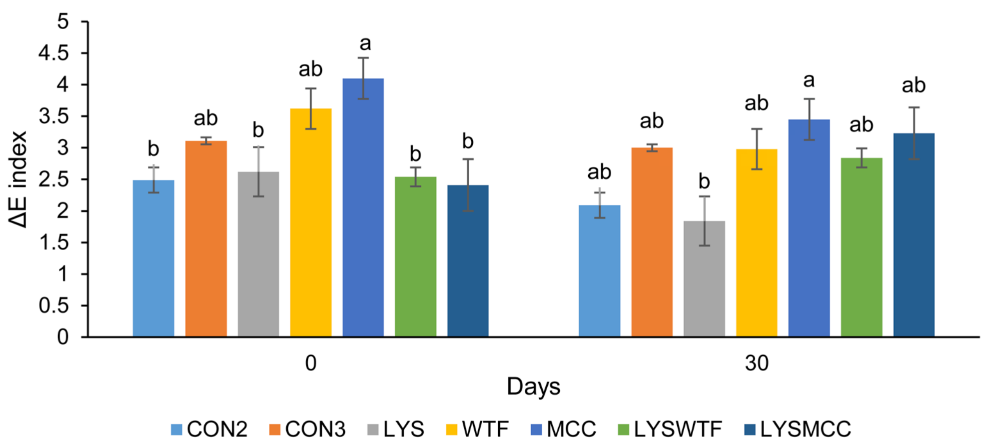

Figure 2 – ΔE index of sausages. $^{a-d}$Means followed by different letters on the same day differ by the Tukey Test ($p \leq 0.05$); Treatments: CON1- 0.5 % STPP and 2 % NaCl; CON2 - without STPP and 2 % NaCl; CON3 - without STPP and 1 % NaCl; LYS - without STPP, 1 % NaCl and 0.8 % L-lysine; WTF - without STPP, 1 % NaCl and 2 % wheat fiber; MCC - without STPP, 1 % NaCl and 2 % microcrystalline cellulose fiber; LYSWTF - without STPP, 1 % NaCl, 0.8 % L-lysine and 2 % wheat fiber; LYSMCC - without STPP, 1 % NaCl, 0.8 % L-lysine and 2 % microcrystalline cellulose fiber; Sodium tripolyphosphate (STPP).

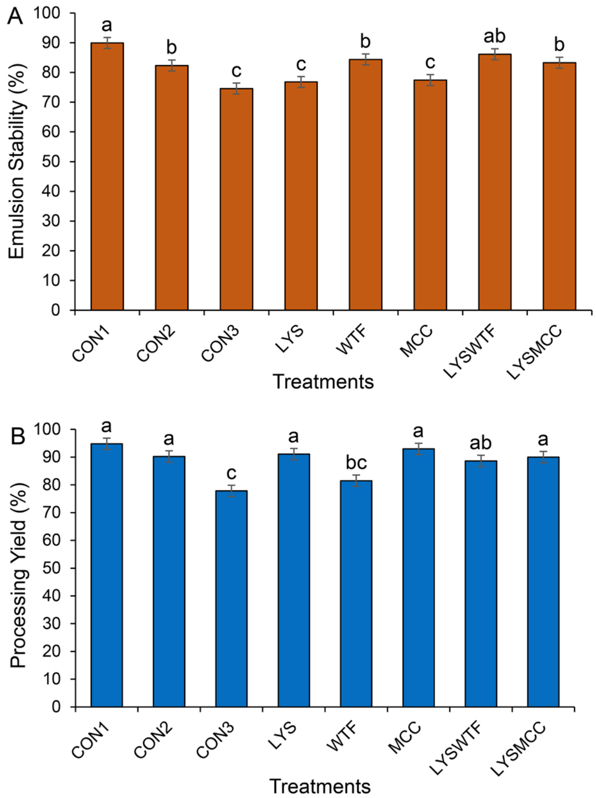

Figure 3 – Emulsion stability (A) and processing yield (B) of sausages. [a–c]Means followed by different letters in the same column differ by the Tukey Test ($p \leq 0.05$); Treatments: CON1- 0.5 % STPP and 2 % NaCl; CON2 - without STPP and 2 % NaCl; CON3 - without STPP and 1 % NaCl; LYS - without STPP, 1 % NaCl and 0.8 % L-lysine; WTF - without STPP, 1 % NaCl and 2 % wheat fiber; MCC - without STPP, 1 % NaCl and 2 % microcrystalline cellulose fiber; LYSWTF - without STPP, 1 % NaCl, 0.8 % L-lysine and 2 % wheat fiber; LYSMCC - without STPP, 1 % NaCl, 0.8 % L-lysine and 2 % microcrystalline cellulose fiber; Sodium tripolyphosphate (STPP).

frankfurter-type sausages reduced in the emulsion stability of the products (Zhang et al., 2021). On the other hand, the removal of 50 % of NaCl from the sausage formulation caused a reduction in the emulsion stability of the products (Horita et al., 2014).

The addition of L-lysine together with wheat fiber (LYSWTF) increased the stability of the sausage emulsion, showing similar results ($p > 0.05$) to CON1. The addition of WTF to an emulsified chicken-based product provided greater emulsion stability to the product (Wu et al., 2021).

Treatment CON1 had the highest yield, around 95 %, and the removal of STPP (CON2) had no influence ($p > 0.05$) (Figure 3B). However, salt reduction in sausages without added STPP reduced ($p < 0.05$) the yield. The addition of L-lysine and MCC favored the yield of sausages. The higher the level of L-lysine added, the higher the yield in pork sausage (Zhou et al., 2014). Adding MCC (3 %) to fried hamburgers promoted less weight loss after frying, showing that MCC helps prevent weight loss in meat products after heat treatment (Gibis et al., 2015).

Conclusions

Adding L-lysine to sausage without added phosphate and with reduction of salt levels affected moisture, cohesiveness, b* value, and yield. L-lysine and WTF provided better emulsion stability to sausages. This study demonstrated that L-lysine and WTF are promising ingredients to improve physicochemical properties, such as lipid oxidation, emulsion stability, and yield of emulsified meat products without added phosphate and reduced salt levels. Future studies should be carried out in emulsified meat products without added phosphate and salt reduction, with the addition L-Lysine and other dietary fibers.

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Authors' Contributions

Conceptualization: Alves Júnior, C.A.; Bellucci, E.R.B.; Barretto, A.C.S. **Data curation**: Alves Júnior, C.A.; Bellucci, E.R.B.; Barretto, A.C.S. **Formal analysis**: Alves Júnior, C.A.; Santos, J.M.; Bertuci, M.L.; Barretto, A.C.S. **Funding acquisition**: Alves Júnior, C.A. **Investigation**: Alves Júnior, C.A.; Santos, J.M.; Bertuci, M.L.; Barretto, A.C.S. **Methodology**: Alves Júnior, C.A.; Barretto, A.C.S. **Project administration**: Alves Júnior, C.A. **Resources**: Alves Júnior, C.A. **Supervision**: Alves Júnior, C.A.; Barretto, A.C.S. **Writing-original draft**: Alves Júnior, C.A.; Barretto, A.C.S. **Writing-review & editing**: Alves Júnior, C.A.; Bellucci, E.R.B.; Santos, J.M.; Bertuci, M.L.; Barretto, A.C.S.

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