LWT - Food Science and Technology 132 (2020) 109845

Contents lists available at ScienceDirect

LWT

journal homepage: www.elsevier.com/locate/lwt

Pork skin-based emulsion gels as animal fat replacers in hot-dog style sausages

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ARTICLE INFO

Keywords:
Canola oil
Bamboo fiber
Inulin
By-products
Value-added

ABSTRACT

Pork skin-based emulsion gels (EGs) elaborated with canola oil, bamboo fiber and inulin were used to replace 50% and 100% of pork back fat in hot-dog sausages made with a high content of mechanically deboned chicken meat (MDCM). Nutritional, technological, and microstructural characteristics of sausages were assessed. Sausages containing EGs presented a higher amount of ω3 polyunsaturated fatty acids (PUFAs), and reduction of saturated fatty acids (SFAs) and ω6/ω3 ratio up to 77% and 76%, respectively. pH, aw, and texture parameters of sausages were not affected by EGs addition. Color parameters presented a lightly increase in L* values and a reduction in a* values in the sausages. The replacement of 50% of pork back fat by EGs did not affect all sensory parameters of sausages. Thus, we concluded that pork skin-based EGs are promising alternatives to replace pork back fat in low-cost sausages.

1. Introduction

Nowadays, the growing understanding of the relationship between diet and food ingredients, and its effect on health has moved consumers to become more conscious and looking for healthier processed foods (de Carvalho et al., 2020). Therefore, many researchers focused on new approaches to develop meat products with better nutritional characteristics; one of the most employed strategies is the reduction of animal fat, which has an elevated saturated fat level. More suitable ingredients, such as dietary fibers and edible oils, have been used as a fat substitute (Alves et al., 2016; Câmara et al., 2020; de Carvalho et al., 2020; Felisberto et al., 2015).

Marine and vegetable oils are rich in PUFAs content, and their use has been recommended in a healthy diet (Heck et al., 2019). Usually, oils are incorporated into meat products through pre-emulsions, and, more recently, emulsion gels (EGs) as a more suitable strategy to improve nutritional and technological aspects of meat products (dos Santos et al., 2020; Paglarini, Martini, et al., 2019).

Dietary fibers have health claims, and important technological properties, such as water/oil holding ability, stabilizer, thickener, and gelling properties (Biswas et al., 2011) to elaborate EGs with suitable qualities (dos Santos et al., 2020). Among the proteins that can be used as a structuring agent to create soft-solid EGs, collagen presents suitable functional properties due to its emulsifying and high gelling properties (Gómez-Guillén et al., 2011).

Besides, some by-products of the meat industry are rich in collagen content, such as pork skin that due the extender and binder characteristics has been used to enhanced meat product quality (de Oliveira Fagundes et al., 2017). However, both strategies the use of pork skin to elaborate EGs and the evaluation of them as fat replacers in low-cost sausages were not sufficiently addressed. Thus, this work aimed to evaluate the effects of pork skin-based EGs containing canola oil, bamboo fiber, and inulin as fat substitutes on nutritional, technological and, sensory characteristics of sausages made with a high amount of mechanically deboned chicken meat that are widely consumed in Brazil.

2. Materials and methods

2.1. Raw material and ingredients

Pork skin was donated by BRF S.A. Canola oil (Cargill, Brazil) was obtained from a local market. Bamboo fiber Creafibre QC90 (Nutrassim,

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https://doi.org/10.1016/j.lwt.2020.109845
Received 5 May 2020; Received in revised form 25 June 2020; Accepted 4 July 2020
Available online 7 July 2020

Extrema, MG, Brazil) and inulin Orafti GR (Beneo, São Paulo, SP, Brazil) were donated by the respective companies. Pork meat (*M. longissimus dorsi*) and pork back fat were purchased from a local market. Mechanically deboned chicken meat (MDCM) was provided by Cooperativa Holambra (Holambra, SP, Brazil). Sodium tripolyphosphate, sodium erythorbate, and sodium nitrite were donated by Kerry (Campinas, SP, Brazil), and sausage condiment 3951 was provided by New Max Ingredients (Americana, SP, Brazil).

2.2. Pork skin-based emulsion gels (EGs) elaboration

Based on nutritional and functional properties, two EGs from a previous study (dos Santos et al., 2020) were chosen to be applied as a fat replacer in sausages. EGs were formulated with 50% canola oil and 20% pork skin gel (PSG): one of which contained 10% bamboo fiber and 20% water (referred as EG-BF), and another contained 10% bamboo fiber, 10% inulin and 10% water (referred as EG-BFI). The EGs were kept under refrigeration and analyzed after 24 h. The physicochemical characterization of them is shown in Table 1.

2.3. Experimental design and sausages preparation

The whole experiment was performed in triplicate. Samples were manufactured with the same ingredients and formulation separated per day in time. The proximate composition and pH of the raw materials is presented in Table 1.

Six treatments were elaborated in this study, as shown in Table 2. Of these six treatments, four were made with replacement of 50% and 100% of pork back fat by EG-BF (F1 and F2) and EG-BFI (F3 and F4), and the other two are control treatments with 20% and 10% of pork back fat (FC1 and FC2). The sausages were elaborated according to procedures described by Horita et al. (2014). The sausages were stuffed into 23 mm diameter Nojax cellulose casings (Viskase, Atibaia, SP, Brazil) with approximately 50 g of meat batter and they were cooked in a steam cooker Multifan-plug (Arprotec®, Valinhos, SP, Brazil), where the temperature was gradually increased until the internal temperature reached 72 °C. The products were then cooled using a water bath and stored under refrigeration (4 °C). The following day, the casings were removed, and the sausages were vacuum packed in plastic bags (Spel Embalagens, Atibaia, SP, Brazil) containing four units per package, and then stored at 4 °C (±1 °C) until analyses and sensory evaluation.

2.4. Proximate analysis

The proximate composition of sausages (moisture, ash, and protein contents) was determined according to the methodology described by the Association of Official Analytical Chemists (AOAC, 2005). The lipid content was measured following the method of Bligh and Dyer (1959). The fiber content was estimated according to the formulation and purity of inulin (96.5%) and bamboo fiber (99.6%) according to the suppliers' information.

Table 1
Characterization of raw materials (g/100 g) used in sausages formulations.

Raw material	Moisture	Lipid	Protein	Ash	pH
EG-BF	36.02 ± 0.38	49.75 ± 3.81	4.10 ± 0.08	0.06 ± 0.005	5.57 ± 0.04
EG-BFI	25.92 ± 0.03	49.75 ± 2.77	4.14 ± 0.06	0.06 ± 0.007	5.44 ± 0.05
Pork meat	73.70 ± 0.21	3.09 ± 0.15	22.20 ± 0.57	1.08 ± 0.04	5.99 ± 0.65
MDCM	78.26 ± 0.07	9.25 ± 0.01	11.95 ± 0.30	0.64 ± 0.009	6.28 ± 0.04
Pork backfat	9.55 ± 0.43	80.49 ± 0.89	9.72 ± 1.04	0.18 ± 0.07	6.05 ± 0.05

EG-BF: Emulsion gel with bamboo fiber; EG-BFI: Emulsion gel with bamboo fiber and inulin. MDCM: mechanically deboned chicken meat. Media ±standard deviation.

Table 2
Sausages formulations (g/100 g).

Ingredients	Treatments					
	FC1	FC2	F1	F2	F3	F4
Pork meat	20.0	20.0	20.0	20.0	20.0	20.0
MDCM	45.0	45.0	45.0	45.0	45.0	45.0
Pork back fat	20.0	10.0	10.0	–	10.0	–
EG-BF	–	–	10.0	20.0	–	–
EG-BFI	–	–	–	–	10.0	20.0
Water	13.0	23.0	13.0	13.0	13.0	13.0

Treatments: FC1: 20% pork back fat; FC2: 10% pork back fat; F1: 10% EG-BF; F2: 20% EG-BF; F3: 10% EG-BFI; F4: 20% EG-BFI; MDCM: mechanically deboned chicken meat; EG-BF: emulsion gel with bamboo fiber; EG-BFI: emulsion gel with bamboo fiber and inulin.

2.5. Fatty acid profile

The fatty acid profile of sausages was analyzed according to the Ce1-62 methodology of American Oil Chemists' Society (AOCS, 2009) in a capillary column gas chromatograph GC-6850 Series GC System (Agilent, Santa Clara, California, USA). The qualitative lipid composition was determined by comparing the peak retention times with those of the respective fatty acid standards. The quantitative lipid composition was performed by area normalization.

2.6. Meat emulsion stability

The emulsion stability was evaluated according to Hughes et al. (1997). The emulsion stability was expressed in percentage as the difference between the initial weight of the sample and the weight of the liquid released after heat treatment.

2.7. Color, pH and aw determination

The pH of sausages was evaluated using MA 130 Mettler pH meter coupled with a penetration probe at different places of the sample. The water activity (a_w) was measured by an Aqualab water activity meter (Decagon, Pullman, USA). The color was measured using a CM-5 spectrophotometer (Konica Minolta, Tokyo, Japan), operating with D65 illuminant, 10° observer angle, SCE mode (regarding sample brightness), and CIELab color system. The whiteness (W) was determined with the formula proposed by Lohman and Hartel (1994) as follows: 100 – [(100 – L*)2 + a*2 + b*2] ½.

2.8. Lipid oxidation

The lipid oxidation was evaluated by the TBARS index according to the methodology reported by Bruna et al. (2001), with some modifications. The absorbance was measured in a spectrophotometer (Beckman, Model DU-70, Muskegon, USA) at 532 nm. The results were expressed as mg of malonaldehyde (MDA)/kg of product, using a standard curve of 1, 1,3,3-tetraethoxypropane (TEP).

2.9. Texture profile analysis (TPA)

Texture profile analysis (TPA) was evaluated at room temperature (22–25 °C) in TA-xT2i texture analyzer (Texture Technologies Corp., Scarsdale, NY) according to the methodology described by Horita et al. (2014). Twelve cylinders of the samples with dimensions of 20 mm height and 22 mm diameter were submitted to two consecutive cycles of uniaxial compression at 30% of their initial height at a constant velocity of 1 mm/s, using a P-35 probe (35 mm in diameter, stainless steel). The parameters determined were hardness (N), springiness (mm), cohesiveness (dimensionless), and chewiness (N·mm).

2.10. Pressed juice

The pressed juice of sausages was determined according to the methodology described by Lucherk et al. (2017). The sausage samples were compressed in a TA-XT2i texturometer (Texture Technologies Corp., Scarsdale, USA). The percentage of fluid weight lost from the sample during compression was quantified as the pressed juice percentage.

2.11. Microstructure analysis

The microstructure of sausages was determined in the TM 3000 Tabletop scanning electron microscope (Hitachi Technologies, Japan), with a magnitude of 15 × to 30,000 × and a 15 kV acceleration voltage. A sample of approximately 0.5 cm^2 and 0.2 cm of thickness was placed into the equipment without any previous treatment. The images were obtained with a magnification of 500x.

2.12. Sensory analyses

The sensory studies were approved by the Ethics in Research Committee of the University of Campinas, SP, Brazil (protocol number – 2.809.675), and all participants signed a free and informed consent form, agreeing voluntarily to participate in the sensory tests. All tests were performed in the Sensory Analysis Laboratory (DTA/Unicamp) using individual cabins. A total of 115 consumers aged between 18 and 60 years, that regularly consumed processed meat, were recruited among students and staff of the University of Campinas (Campinas, Brazil). The color, aroma, flavor, texture, and overall acceptability were evaluated using a structured nine-point hedonic scale, with 1 being extremely disliked and 9 extremely liked (Stone & Sidel, 2004). A three-digit code has been assigned to the samples, which were evaluated by each consumer in a monadic order, following a balanced design. The check-all-that-apply (CATA) questionnaire with the 14 attributes was used to characterize the sensory profile of the sausages. The consumers were asked to check all of the terms that they considered appropriate to describe each sample (Ares et al., 2010).

2.13. Statistical analysis

The results were analyzed by analysis of variance (ANOVA) at 95% confidence level ($P < 0.05$), considering the treatments as a fixed effect and the replicates as a random effect. Previously normal distribution and variance homogeneity were tested (Shapiro-Wilk). The significant differences between treatments were analyzed by Tukey's test at the 5% level of significance using Minitab®18 software was used to conduct the data analysis. The CATA attributes were analyzed by frequency analysis of citations for each sensory term of each treatment using XLStat software (version 2019, Addinsoft, Paris, France).

3. Results and discussion

3.1. Fatty acid profile

The fatty acid profile of sausages was significantly modified by the EGs addition (Table 3). The saturated fatty acids were reduced from 40.1% (F1) to 76.9% (F4) of sausage formulations elaborated with EGs. The treatments F2 and F4 could be declared as "rich in omega 3" (>0.6 g ω3/100 g; EC, 2006, pp. 244–259), and it is credited to the canola oil, which among the vegetable oils has the highest content of unsaturated fatty acids, mainly oleic, linoleic, and linolenic acids (Welter et al., 2016), and a balanced ω6:ω3 ratio (approximately 2). These results are in agreement with Alejandre et al. (2019) and de Oliveira Fagundes et al., 2017.

Table 3
Fatty acid profile of sausages formulated with pork back fat and/or pork skin-based emulsion gels (g/100 g product).

Fatty acids	Treatments						SEM
	FC1	FC2	F1	F2	F3	F4	
C14:0	0.31[a]	0.19[b]	0.21[b]	0.08[c]	0.19[b]	0.07[c]	0.02
C16:0	6.37[a]	3.93[b]	3.94[b]	2.19[d]	3.61[c]	1.85[e]	0.36
C18:0	2.81[a]	1.65[b]	1.55[c]	0.35[d]	1.54[c]	0.27[d]	0.21
∑SFA	9.50	5.77	5.70	2.62	5.34	2.19	
C16:1	0.72[b]	0.49[c]	0.52[c]	0.82[a]	0.46[d]	0.71[b]	0.03
C18:1	9.98[a]	6.39[f]	9.26[b]	9.05[c]	8.86[d]	8.66[e]	0.27
∑MUFA	10.7	6.88	9.78	9.87	9.32	9.37	
C18:2	2.37[c]	1.78[d]	3.94[a]	4.01[a]	3.74[b]	3.64[b]	0.21
C18:3	0.08[d]	0.07[d]	0.52[c]	0.90[a]	0.56[b]	0.89[a]	0.08
∑PUFA	2.45	1.85	4.46	4.91	4.30	4.53	
PUFA/SFA	0.26	0.32	0.78	1.88	0.80	2.06	
n-6/n-3	16.92	22.25	7.58	4.45	6.68	4.07	
AI	0.58	0.54	0.33	0.17	0.32	0.15	
TI	0.76	0.65	0.33	0.15	0.33	0.15	

Treatments: FC1: 20% pork back fat; FC2: 10% pork back fat; F1: 10% EG-BF; F2: 20% EG-BF; F3: 10% EG-BFI; F4: 20% EG-BFI. SFA: saturated fatty acid; MUFA: monounsaturated fatty acid; PUFA: polyunsaturated fatty acid; AI: atherogenic index; TI: thrombogenic index. SEM: standard error of the mean. Different letters in the same line indicate significant differences ($P < 0.05$).

Regarding nutritional indices, the EGs addition significantly increased ($P < 0.05$) PUFA/SFA ratio, with level near to the recommended levels of Food and Agriculture Organization of the United Nations for the human diet (0.85 FAO, 2010). The ω6/ω3 ratio was reduced at 55% (F1) to 76% (F4) when compared with control treatment FC1; further, the treatments F2 and F4 presented the ω6/ω3 ratio closed at 4. The adequate balanced ω6/ω3 ratio is an important factor for the prevention or reducing risk of various diseases, mainly cardiovascular diseases, and a ratio equal to or less than 5:1 has been recommended (Bernardi et al., 2016). Also, AI and TI decreased respectively 43% and 56% in F1 and F3 treatments and 70% and 80% in F2 and F4 treatments when compared to control FC1.

3.2. Physicochemical characterization of sausages

The physicochemical characterization of sausages is shown in Table 4. Moisture content ranged from 57.90 (FC1) to 67.88 g/100 g (FC2). The fat-reduced sausages had the highest moisture contents ($P < 0.05$) due to the strategies employed: water as a fat replacer (FC2) or addition of EGs (F1, F2, F3, and F4) that contained moisture higher than pork back fat (Table 1). Similar results were obtained by Paglarini, Furtado, et al. (2019) and Paglarini, Martini, et al. (2019). Among the reformulated sausages, F4 showed the greatest reduction in lipid intake, 30% compared to FC1 treatment. This result is consistent with the EGs compositions, which contained approximately 50 g/100 g of lipids (Table 1). The sausages F2 and F4 presented the lowest ($P < 0.05$) protein contents, however, the presented variation was little compared to the control (FC1), and it could be explained by the total substitution of fat by EGs, which presented lower protein levels than pork back fat (Table 1). The other treatments did not differ ($P > 0.05$) in the protein content. Sausage FC2 presented the lowest ($P < 0.05$) ash level due to the water added as a fat replacer, and, it was not affected in the other treatments ($P > 0.05$). The sausage F4 presented 3.93 g/100 g of dietary fiber, therefore it had claimed: "source of fibers" (3 g of fibers per 100 g; EC, 2006, pp. 244–259). Treatments F1, F2, and F3 were not considered sources of fibers, but they could contribute to the increase of the consumption of this component in the diet since a large part of the population does not consume the recommended amount of fibers (Han & Bertram, 2017).

The meat emulsion stability (ES) is the main important factor to indicate the success of reformulation because it is directly associated to process yield. The sausage FC2 exhibited the lowest ($P < 0.05$) ES, which

Table 4
Physicochemical characterization of sausages formulated with pork back fat and pork skin-based emulsion gels.

Parameters	Treatments						SEM
	FC1	FC2	F1	F2	F3	F4	
Proximate composition (g/100g)							
Moisture	57.90^{e}	67.88^{a}	60.78^{d}	63.77^{b}	60.80^{d}	63.09^{c}	0.58
Lipid	23.70^{a}	15.01^{e}	20.57^{b}	18.08^{cd}	19.74^{bc}	16.57^{de}	0.70
Protein	15.77^{a}	14.81^{ab}	15.05^{a}	13.54^{c}	14.98^{a}	13.82^{bc}	0.21
Ash	2.62^{a}	2.30^{b}	2.59^{a}	2.62^{a}	2.54^{ab}	2.61^{a}	0.04
Dietary fiber*	nd	nd	1.00	2.00	1.93	3.93	–
Physicochemical parameters							
ES (%)	97.25^{ab}	93.93^{e}	96.00^{d}	96.98^{bc}	96.26^{dc}	97.98^{a}	0.22
pH	5.97^{b}	6.03^{a}	5.97^{b}	5.98^{b}	5.99^{b}	5.99^{b}	< 0.01
a_w	0.982	0.980	0.978	0.980	0.982	0.980	< 0.01
TBARS (mg MDA/kg)	0.043^{b}	0.050^{b}	0.057^{b}	0.047^{b}	0.087^{a}	0.080^{a}	< 0.01
Pressed juice (%)	10.49^{b}	13.69^{a}	8.63^{c}	9.92^{bc}	9.79^{bc}	9.44^{bc}	0.32
Color parameters							
L*	60.80^{d}	60.90^{d}	63.42^{bc}	65.08^{a}	63.00^{c}	64.10^{b}	0.30
a*	10.24^{a}	10.40^{a}	9.65^{b}	9.18^{c}	9.85^{b}	9.64^{b}	0.09
b*	13.18^{a}	12.53^{c}	12.84^{b}	13.11^{a}	12.87^{b}	13.16^{a}	0.05
W	57.39^{c}	57.64^{c}	60.04^{b}	61.59^{a}	59.60^{b}	60.56^{b}	0.29
Texture parameters							
Hardness (N)	11.41^{a}	7.99^{b}	12.18^{a}	12.70^{a}	11.94^{a}	13.44^{a}	0.28
Springiness (mm)	0.89	0.90	0.90	0.90	0.89	0.91	< 0.01
Cohesiveness	0.81	0.82	0.81	0.81	0.82	0.82	< 0.01
Chewiness (N·mm)	8.22^{b}	5.87^{c}	8.89^{ab}	9.26^{ab}	8.71^{ab}	9.94^{a}	0.27

Treatments: FC1: 20% pork back fat; FC2: 10% pork back fat; F1: 10% EG-BF; F2: 20% EG-BF; F3: 10% EG-BFI; F4: 20% EG-BFI.
*The fiber content was estimated according to the formulation and purity of inulin (96.5%) and bamboo fiber (99.6%); nd: not detected. SEM: standard error of the mean. Different letters in the same line indicate significant differences ($P < 0.05$).

had a reduction of 50% fat and the addition of the same water content (10%) in the sausage in according to Pintado et al. (2018) who have found a similar result. The sausages F2 and F4 did not differ (P > 0.05) of control formulation FC1, which can be attributed to the fibers content, mainly bamboo fiber, responsible for improving its water holding capacity. The treatments F1 and F3 showed the same ES (P > 0.05), but it was slightly lower (P < 0.05) than the control FC1. The use of pork skin combined with dietary fibers or vegetable oil showed very efficiently to improve emulsion stability and reduced the cooking loss in meat products (Alves et al., 2016; Choe et al., 2013; de Oliveira Fagundes et al., 2017; Faria et al., 2015). In the present work, the sausages with EGs showed high emulsion stability, and they were comparable to control treatment.

The EGs showed lower pH than pork back fat (Table 1). However, the pH of sausages formulated with EGs did not (P > 0.05) differ from the control treatment FC1. The a_w was not affected by the formulations (P > 0.05), suggesting that the dietary fibers and collagen did not increase the bound water content in the sausages. Alves et al. (2016) reported that pork skin/green banana flour gel used as a fat replacer in Bologna sausages did not influence the a_w.

Regarding the lipid oxidation, all treatments presented low TBARS levels, less than 0.087 mg MDA/kg (Table 4). The presence of the antioxidants added to the formulations (sodium erythorbate and sodium nitrite), refrigeration, vacuum packaging, and absence of light retarded the oxidative processes during the cooking and stored until analysis. TBARS levels were higher (P < 0.05) in treatments F3 and F4 than treatments F1 and F2. However, these treatments presented similar fatty acid compositions. Thus, it could be due to the interference of inulin present in EG-BFI: inulin can be hydrolyzed in reducing sugar in an acid environment pH ≤ 4, and TBARS reaction occurs in acidic conditions. As reported by Guillén-Sans and Guzmán-Chozas (1998), sugars are one of the substances reactive to thiobarbituric acid, which possibly contributed to the higher TBARS levels observed in the treatments F3 and F4. Other studies reported an increase in TBARS values with the incorporation of inulin: Cava et al. (2012) attribute this observation to impurities from the inulin, such as metal transitions; Latoch et al. (2016) attributed this behavior possibly due to the reaction of inulin with TBA reagent.

The pressed juice was measured by the amount of liquid lost by sausages when the compression force was applying to simulate the release of liquid during chewing. As expected, the sausage FC2 presented higher (P < 0.05) pressed juice due to the highest water unretained to the meat matrix in this formulation (Table 2). It is not a positive outcome since this treatment showed the lowest emulsion stability, texture parameters (hardness and chewiness), and sensory related-texture score. The other treatments presented similar moisture content, and in this case, the pressed juice could be correlated more assertively with the water holding ability of the fibers. As observed, the pressed juice of the treatments F2, F3, and F4 did not differ (P > 0.05) from the FC1 control treatment. It indicated that the fibers contributed to the water holding since the treatments containing the EGs presented superior moisture content to the treatment FC1, which may contribute to the succulence perception in the sausages.

The color parameters of sausages were affected (P < 0.05) by EGs addition (Table 4). EGs caused an increase (P < 0.05) in lightness (L*) values, and it was proportional to EGs content in the sausage formulations. The redness (a*) values decreased (P < 0.05) with EGs addition. These results were similar to those reported by Paglarini, Furtado, et al. (2019), according to them, the increase of L* could be due to the greater light reflection caused by the smaller diameter of the oil droplets relative to the droplets produced with animal fat. The yellowness (b*) was barely affected by EGs. Some works that used pork skin combined with green banana flour (Alves et al., 2016) and canola oil (de Oliveira Fagundes et al., 2017) in meat products did not see any difference in L* values among the treatments. The whiteness (W) value, which correlates the coordinates L*, a* and b* was calculated to see the overall effect on color, it indicates the bleaching of the sample. The EGs increased the W values (P < 0.05) of the sausages when compared to the treatments formulated with only pork back fat (FC1 and FC2). Comparable outcome was obtained by Faria et al. (2015) with the incorporation of pork skin/amorphous cellulose gel as a fat replacer in Bologna sausage. Despite these results, color difference was not noticed in treatments FC1, F1, and F3 in the sensory analysis (Fig. 2a), which demonstrates a negligible effect caused by EGs.

TPA parameters are presented in Table 4. As expected, the partial substitution of pork back fat by water decreased (P < 0.05) the hardness, chewiness, and cohesiveness of sausage FC2. The addition of the EGs slightly affected the texture parameters of the sausages. The hardness did not ($P > 0.05$) differ between the sausages with EGs and the control formulation FC1. However, the chewiness was slightly higher ($P < 0.05$) in treatment F4 than the control FC1, which indicates that the work during chewing will be slightly greater in sausage F4, and it could be attributed to the highest amount of fiber (3.93 g/100 g) of this treatment, also reported by Paglarini, Furtado, et al. (2019) and Paglarini, Martini, et al. (2019) in frankfurters reformulated with emulsion gels. The springiness and cohesiveness did not differ between sausages formulated with EGs and traditional sausage FC1 ($P > 0.05$). The texture is an important attribute to consumer acceptance, and EG systems showed high similarity to pork back fat, which demonstrates the potential of the EGs to replace this ingredient.

3.3. Microstructure

The SEM images of the sausages are shown in Fig. 1. The sausages containing the EGs (F1, F2, F3 and, F4) presented similar topographies characterized by dense structure, where the bamboo fiber chains were entrapped. Barretto et al. (2015) also demonstrated that insoluble fibers could be observed by SEM images in emulsified meat products. In F3 and F4 treatments, the microstructures were more compact, with smaller pores than other treatments, probably due to both inulin binder effect on the components of the meat emulsion and the water holding capacity of bamboo fiber. This result was more evidenced in F4 treatment, which carried the highest fibers content (3.93 g/100 g) and corroborating its better meat emulsion stability showed. According to Zhuang et al. (2018), the insoluble fibers are physically retained in the myofibrillar gel network, and they can absorb the water lost during cooking, which results in a lower incidence of water channels and contributes to producing a more homogeneous and compact protein network. Inulin also contributes to producing a denser microstructure in emulsified meat products due to its viscous properties Felisberto et al. (2015).

3.4. Sensory evaluation

The sensory acceptance of sausages is presented in Fig. 2a. The sausages F1 and F3, which contained 50% of the EGs in substitution of pork back fat, did not differ ($P > 0.05$) from the traditional sausage FC1

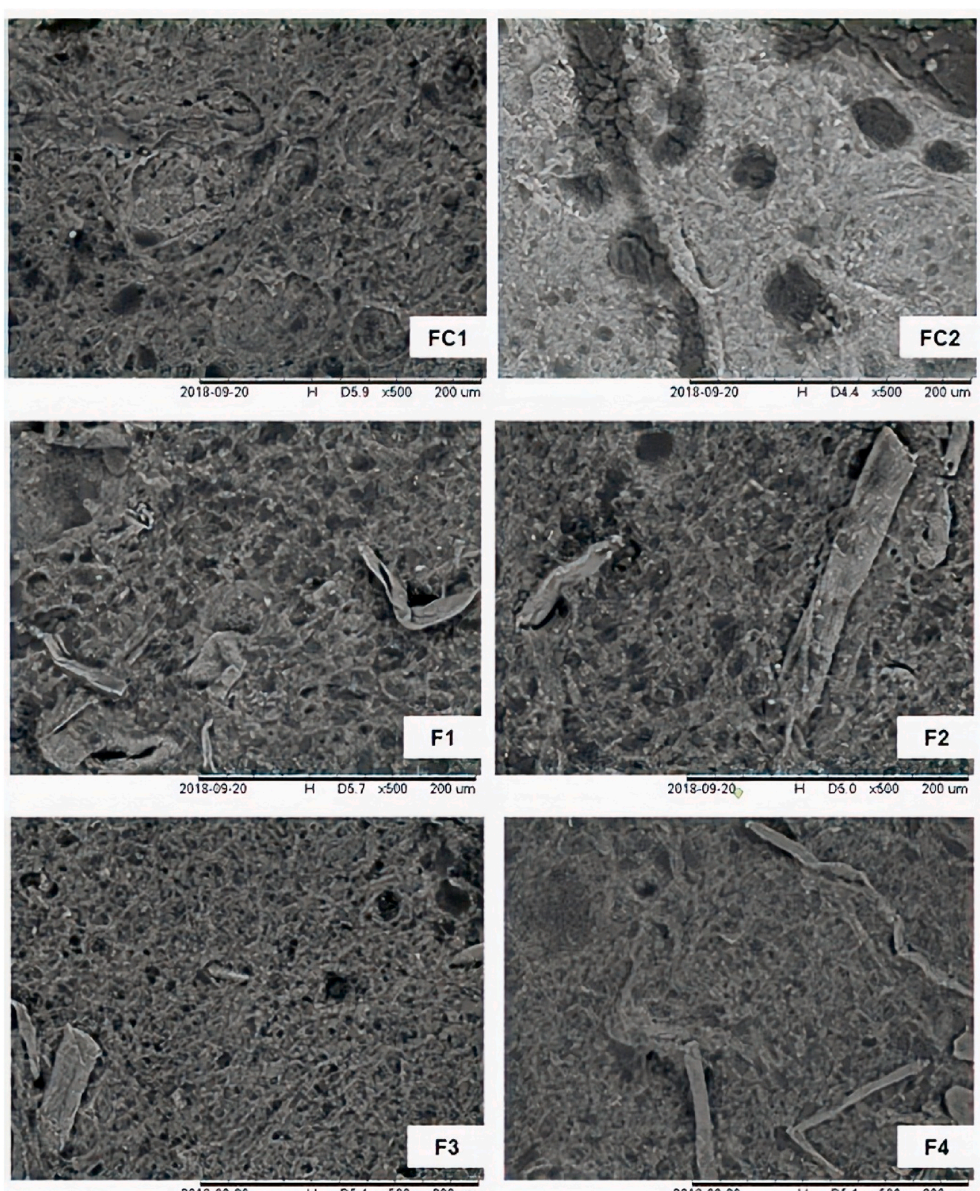

Fig. 1. SEM images of sausages formulated with pork back fat and pork skin-based emulsion gels (500 × magnification, 200 μm scale).

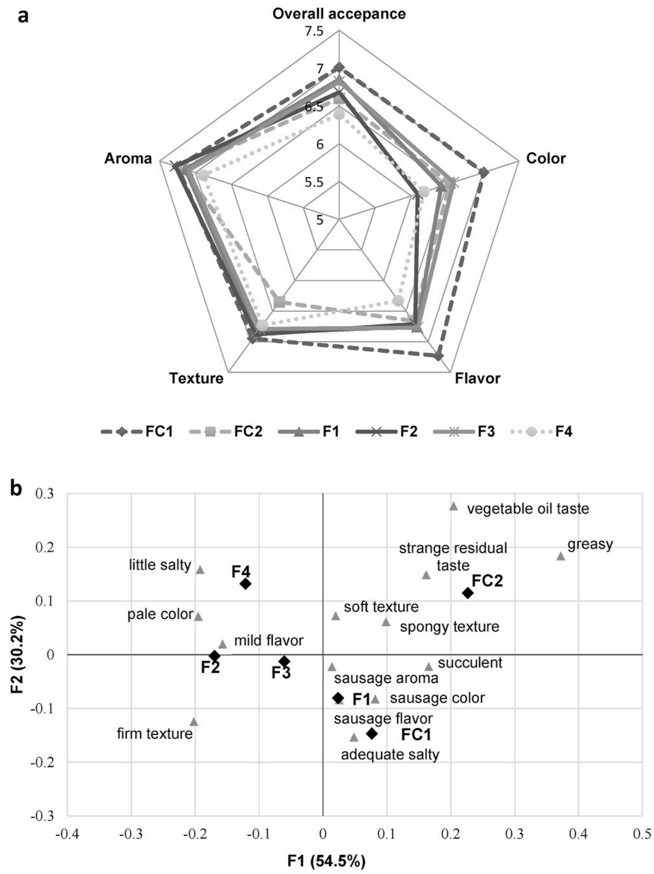

Fig. 2. Sensory acceptance (a) and CATA test (b) of sausages formulated with pork back fat and pork skin-based emulsion gels.

in all sensorial attributes. The sausage F2 exhibited a slightly lower ($P < 0.05$) score to the color parameter when compared with the control treatment FC1. The sausage F4 presented the highest fiber content, which probably contributed to lower sensory acceptance ($P < 0.05$) regarding the flavor, color, and aroma attributes. Alves et al. (2016) found a similar result; they reported lower acceptance of Bologna sausages formulated with more than 80% of pork skin/green banana flour gel. Faria et al. (2015) also related that sensory acceptance, salty text, and texture lowered as pork skin/amorphous cellulose gel raised in Bologna sausage. On the other hand, Choe et al. (2013) reported no sensory difference of Frankfurters incorporated with up to 20% pork skin/wheat fiber gel. The FC2 sausage was the least ($P < 0.05$) accepted to texture due to the higher water content present in this formulation, which corroborated the lowest hardness and chewiness founded to FC2 sausage.

The CATA test is presented in Fig. 2b. The first and second components explained 84.67% of the variations presented and, therefore, were considered sufficient to relate the CATA attributes and the different sausage formulations. The treatments FC1 and F1 were related to positive attributes, such as sausage flavor, aroma and color, succulence, and adequate salty. The F1 treatment presented the highest similarity to the FC1 treatment due to the lowest content of dietary fiber (1%) among the treatments containing the EGs. The treatments F2 and F3 were related to the firm texture, possibly due to the performance of the fibers in the meat matrix, although this result was not corroborated to the instrumental texture analysis (Table 4). The F4 treatment was correlated to the negative attributes, such as little salt, mild flavor, and pale color. This result may be related to the high fibers content (3.93 g/100 g) in this formulation that could mask the salty and flavor perceptions by consumers. Similar results were reported by Faria et al. (2015) in meat products with added dietary fiber. The FC2 treatment was related to the most negative attributes, such as greasy, vegetable oil flavor, strange residual flavor, spongy texture, and soft texture, suggesting that the pork back fat substitution by water is not an adequate strategy in the sensorial aspect.

4. Conclusion

In the present study, pork back fat was replaced by pork skin-based EGs in hot-dog sausages made with a high content of MDCM. Most physicochemical parameters were not affected by EGs. Regarding the nutritional aspects, the EGs improved ω3-PUFA and dietary fiber contents and decreased the SFAs content and ω6/ω3 ratio of the sausages. Thus, we concluded that both EG formulations proposed in this work are suitable ingredients to substitute up to 50% of pork back fat in low-cost cooked sausages with better nutritional appeal and no change in sensory parameters.

CRediT authorship contribution statement

Mirian dos Santos: Conceptualization, Investigation, Formal analysis, Methodology, Visualization, Data curation, Writing - original draft, Writing - review & editing. **Paulo E.S. Munekata:** Methodology, Investigation, Visualization, Writing - review & editing. **Mirian Pateiro:** Methodology, Visualization, Writing - review & editing. **Giseli Carvalho Magalhães:** Formal analysis, Methodology. **Andrea Carla Silva Barretto:** Methodology, Visualization, Writing - review & editing. **José Manuel Lorenzo:** Methodology, Visualization, Writing - review & editing. **Marise Aparecida Rodrigues Pollonio:** Conceptualization, Methodology, Validation, Resources, Writing - review & editing, Project administration, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors are grateful to the Scientific and Technological Development Council (CNPq) for financial support (131994/2017-4), and to companies Nutrassim, Beneo, Cooperativa Holambra, BRF S.A., Kerry do Brasil and New Max Industrial for donating the ingredients. This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001. Jose M. Lorenzo is a member of Healthy Meat network (CYTED 119RT0568). Paulo E. S. Munekata acknowledges the Postdoctoral Fellowship "Juan de la Cierva" Program (FJCI-2016-29486) of the Ministry of Economy and Competitiveness (MINECO, Spain).

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