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Chia (*Salvia hispanica* L.) products as ingredients for reformulating frankfurters: Effects on quality properties and shelf-life

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ABSTRACT

Several strategies were examined for incorporating chia products (seeds, flour and a coproduct from cold-press oil extraction) in frankfurters. The nutritional composition, technological properties and sensory attributes of the resulting products were studied in relation to the formulation used and, lipid oxidation, pH, residual nitrite level and microbiological properties were evaluated during chilled storage. Application of these chia products (3%) was seen to enhance the nutritional composition of frankfurters, without adversely affecting the technological properties of the final product. In general, although differences were detected in the sensory attributes of the frankfurters reformulated with chia products (most of them when chia coproduct was added), all of them were judged acceptable. Besides the quality aspects, these reformulation strategies had beneficial effects on some technological properties during chilled storage: better resistance to oxidation (controlling the TBARS increase during storage) and lower residual nitrite levels than control (both effects presumably because the chia polyphenols content) and no effect on microbiological safety.

1. Introduction

Frankfurters are technologically defined as a cooked-smoked emulsion-type-sausage: structurally, a dispersion of fat particles in water held together by the action of salt-soluble, heat–coagulable proteins. Germany is the birthplace of the frankfurter and world leader in terms of the volume and number of types of frankfurters made. In addition, frankfurters-type sausages are the most widespread type of emulsified meat product in the world. Different types of frankfurters are produced all over the world (Frankfurter, Vienna and Munich white sausages among others), mainly differentiated by the seasonings used and to regional preferences (Jandásek, 2014). In America, the relevance of this meat product is mainly due to it beings the principal ingredient of the iconic American food product, the hot dog. In 1984, the American Meat Institute established the National Hot Dog and Sausage Council (NHDSC), which serves as an information resource to consumers and media on questions related to quality, safety, nutrition and preparation of hot dogs and sausages. In 2016, American consumers spent more than $2.4 billion on hot dogs in USA supermarkets (NHDSC, 2018).

On the other hand, the consumption of this type of product has been associated with some negative health concerns. A report of the World Cancer Research Fund published in 2007 described a connection between the intake of processed red meat and the risk of colorectal cancer, and recommend the intake of < 500 g cooked red meat per week (Grasso, Brunton, Lyng, Lalor, & Monahan, 2014). Although this association has not been fully clarified, excess fat, protein and iron, heat-processing compounds (heterocyclic amines) and various substances added during the technological processing (sodium chloride and nitrates) were identified as the most relevant cancer precursors in this type of product (Botez, Nistor, Andronoiu, Mocanu, & Ghinea, 2017).

The meat industry wishes to change the perception of meat products as being unhealthy by developing nutritionally improved meat products through, among other means, reformulating them. Such products can be reformulated by reducing the content of compounds perceived by some consumers to be unhealthy (fats, cholesterol, sodium chloride and nitrites) as well as by increasing the content of compounds considered to be beneficial for human health. Both strategies must take into account that reformulated meat products must meet all the expectations of consumers concerning what they look for in traditional meat products to ensure acceptability (Botez et al., 2017; Fernández-Ginés, Fernández-López, Sayas-Barberá, & Pérez-Alvarez, 2005; Olmedilla-

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Alonso, Jiménez-Colmenero, & Sánchez-Muniz, 2013). In this context, chia offers considerable potential for the development of healthier foods, and with it has been widely used as an ingredient in foods such as bread, cakes, cookies, snacks, ready-to-eat meals, beverages, etc. (Barros et al., 2018; Borneo, Aguirre, & León, 2010; Coelho & Salas-Mellado, 2015; Pintado, Herrero, Jiménez-Colmenero, & Ruiz-Capillas, 2016; Zettel, Kramer, Hecker, & Hitzmann, 2015). In most of these cases, chia has been used as the whole seed or as flour, depending on the type of product. In frankfurters, chia has been used as ground chia seed (Marín-Flores, Acevedo-Mascaruá, Cavada-Martínez, García-Romero, & Tamez-Ramírez, 2008) and as emulsion gels to replace animal fat (Herrero, Ruiz-Capillas, Pintado, Carmona, & Jimenez-Colmenero, 2017; Pintado et al., 2016). However, no references have been found in the relevant literature to the use of chia coproducts (from cold-pressing oil extraction) in food processing.

The objective of this work was to investigate the effects of different chia products (seeds, flour and a coproduct from cold-pressing oil extraction) on the processing properties of frankfurters and to evaluate their effects during chilled storage.

2. Materials and methods

2.1. Preparation of frankfurters

Frankfurters were manufactured according to a traditional formula (only meat percentages add up to 100% and percentages of others ingredients are related to meat): pork lean meat (70%) and pork backfat (30%), 15% water (ice form w/w), 3% potato starch (*w*/w), 2% sodium chloride (w/w), 300 mg/kg sodium tripolyphosphate, 150 mg/kg sodium nitrite, casein 1.5%, 0.2 ml/kg liquid smoke and spices (mixture of white pepper, mace and coriander). This original mixture (40 kg aprox.) was divided in four batches. Batch 1 was used as control (CON), while chia products were added to the other three batches: batch 2 (CHS) contained 3% chia seeds; batch 3 (CHF) contained 3% of chia flour; and batch 4 (CHCP) had 3% chia coproduct added. Chia seeds, chia whole flour and chia coproduct were kindly provided by the Primaria Premium Raw Materials Company (Valencia, Spain). The coproduct was obtained by milling the residue obtained after cold pressing and oil separation from the chia seeds. All chia products that have been used in this work were previously characterized by Fernández-López, Lucas-Gonzalez, Viuda-Martos, Sayas-Barberá, and Pérez-Alvarez (2018). Regarding proximal composition, chia seeds (and also chia flour because it was obtained by a direct milling of seeds) showed 5.94% moisture, 20.58% proteins, 32.33% lipids, 33.04% dietary fiber and 4.81% ash; chia coproduct showed 6.84% moisture, 27.02% proteins, 7.40% lipids, 48.2% dietary fiber and 5.95% ash. Three replications of this elaboration process were performed on three different days.

The products were prepared in the IPOA Research Group Pilot Plant at the Miguel Hernández University following an industrial processing protocol. Briefly, meat ingredients were ground in a cutter (1094-Homogeneizer, Tekator, Höganäs, Sweden) and mixed with the sodium chloride and the rest of the ingredients for 2 min (temperature below 12 °C). After homogenization, the resulting meat batter was stuffed using a piston stuffer EM-12 (Mainca, Granollers, Barcelona, Spain) into 20 mm diameter cellulose casings (Fibran, Girona, Spain). Samples were hand linked and cooked in a water bath (90 °C) to an internal temperature of 72 °C using a thermocouple probe (Omega Engineering, Inc., Stamford, CT) positioned in the geometric centre of one sample to monitor product temperature. When the endpoint temperature was achieved, the sausages were immediately chilled in ice for 5 min. Then, they were peeled by hand and vacuum packed (vacuum machine: Egarvac, Barcelona, Spain) in plastic bags (high barrier film of water vapour permeability 1.1 g/m^2/24 h at 23 °C/50%RH, nitrogen permeability 2.7 cm^3/m^2/24 h at 23 °C/50%RH, carbon dioxide permeability 23 cm^3/m^2/24 h at 23 °C/50%RH and oxygen permeability < 5 cm^3/m^2/24 h at 23 °C/50%RH from W.K. Thomas Spain S.L., Rubí, Barcelona, Spain). All samples were stored immediately after packing at 4 °C (± 1 °C) under darkness conditions. For frankfurter characterization (proximate composition, texture, water activity and sensorial analysis), all analyses were made only on day 0. Further analyses (pH, colour, lipid oxidation, residual nitrite level, and microbiological analysis) were carried out on days 0, 7, 14 and 21 to monitor the effect of storage on quality characteristics.

2.2. Proximate composition and energy value

The proximate composition was calculated according to the followings official AOAC methods (AOAC, 2005): 950.46 to determine moisture, 981.10 to determine crude protein, 920.153 to determine ash, 991.36 to determine crude fat and 991.43 to determine total dietary fiber (TDF). The energy content was calculated based on 2 kcal/g for dietary fiber; 4 kcal/g for carbohydrate and protein; 9 kcal/g for fat (EU, 2011).

2.3. Technological properties

2.3.1. pH and water activity

The pH of frankfurters was measured directly using a Crison combination electrode probe (Cat. No. 52) connected to a pH-meter (model 507 Crison, Barcelona, Spain). The measurement was taken three times, changing the location of electrode insertion.

Water activity (a_w) was measured at 25 °C using an electrolytic hygrometer (Novasina TH-500, Novasina, Axair Ltd., Pfaeffikon, Switzerland).

2.3.2. Colour

A colorimetric analysis was performed directly on frankfurters cross-sections using a CM-2600d colorimeter (Minolta Camera Co., Osaka, Japan), with the following settings (illuminant D65, observer 10°, SCI mode, 11 mm aperture for illumination and 8 mm for measurement). The following CIELAB colour coordinates were determined: lightness (L*), redness (a*, ± red-green) and yellowness (b*, ± yellow-blue). Total colour differences (Δ*E*) of each sample (S) respect to control sausage (CON) were also calculated as: $\Delta E = \sqrt{(L_S^* - L_{CON}^*)^2 + (a_S^* - a_{CON}^*)^2 + (b_S^* - b_{CON}^*)^2}$. Nine determinations per sample were carried out [(three measures on the same inner face of three slices (2 cm height)].

2.3.3. Textural properties

Texture profile analysis was performed with a Texture Analyzer TA-XT2i (Stable Micro Systems, Surrey, England). Sausage sections (2 cm height, placed in horizontal orientation relative to their length) were subjected to a 2-cycle compression to 75% of their original height with a speed of 1 mm/s and at 20–25 °C and the corresponding force-time deformation curves were obtained. From these curves, the following attributes were calculated (Bourne, 1978): hardness (N), springiness (mm), cohesiveness and chewiness (N x mm). Six determinations per sample were made.

2.3.4. Residual nitrite level

Residual nitrite level (mg $NaNO_2$/kg sample) was determined according to standards ISO/DIS 2918.26 (ISO, 1975).

2.3.5. Lipid oxidation

Lipid oxidation was evaluated as a function of changes in thiobarbituric acid-reactive substances (TBARs) following the method of Rosmini et al. (1996). Briefly, sample extracts (sample + TBA solution + trichloroacetic solution) were heated and centrifuged to obtain the supernatant which absorbance was measured at 532 nm.

2.4. Microbiological analysis

Samples were prepared in a vertical laminar-flow cabinet (model AV 30/70, Telstar, Madrid, Spain). Microbiological analysis of frankfurters was carried out by duplicate as follows: for each sample, 10 g was taken and placed in a sterile plastic bag (Sterilin, Stone, Staffordshire, UK) with 90 ml of peptone water (0.1%). After 1 min in a stomacher blender (Colworth 400, Seward, London, UK), appropriate decimal dilutions were pour plated on the following media: plate count agar (Merck, Germany) for the total viable count (TVC) (37 °C for 48 h); De Man, Rogosa, Sharp Agar (Merck, Germany) for lactic acid bacteria (LAB) (37 °C for 48 h); and Violet Red Bile Glucose Agar (Merck, Germany) with a double layer for Enterobacteriaceae (37 °C for 24 h). Results are expressed as logarithms of colony forming units per gram (log cfu/g).

2.5. Sensory evaluation

A 30-member sensory panel (10 males and 20 females) aged 18–55 years and with no specific training in the sensory analysis of frankfurter, were recruited from the staff and students of the Miguel Hernández University. Protocols for sensory analysis were approved by the Project Evaluation Office of the Miguel Hernández University (OEP, UMH, Elche, Alicante, Spain). This analysis was performed under white fluorescent lights in individual booths. Pieces of approximately 2.0 cm (4 pieces, one from each bath) were cut from the frankfurter and served at room temperature. Unsalted crackers and mineral water (room temperature) were provided to clean the palate between samples. The hedonic scale consisted of 9 levels (1: dislike extremely and 9: like extremely), in which the panelists evaluated the following attributes: colour, taste, aroma, texture and general acceptability.

2.6. Statistical analysis

One way analysis of variance (ANOVA) was performed to evaluate the statistical significance ($P < .05$) of the effect of sample formulation (product characterization) and two-way ANOVA as a function of formulation and storage time (product shelf-life) using the SPSS program v. 27 for Windows (IBM, Chicago, USA). Formulation and storage time were assigned as fixed effects and replication as a random effect. For sensory evaluation, panelists were considered random factors. The results in the tables are expressed as mean values and standard deviation. Tukey's post hoc test was applied for comparisons of means and differences were considered significant at $P < .05$.

3. Results and discussion

3.1. Composition and energy value

The compositional analysis of the frankfurters is presented in Table 1. Of the chemical composition, only moisture, fat and TDF content showed differences ($P < .05$) between samples from the different batches. No differences were observed in the protein and ash contents irrespective of the formulation used (Table 1). The addition of 3% chia (in any of its presentations: seeds, flour or coproduct) decreased the moisture content and increased TDF in frankfurters. However, a significant increase in fat content ($P < .05$) was observed only when chia was added as flour (CHF) or as seeds (CHS). In any case, the increase in the fat content in CHF and CHS samples would come from chia oil, which could improve the fatty acid profile of these frankfurters (Muñoz, Cobos, Díaz, & Aguilera, 2013; Pintado et al., 2016). The fat content is also responsible for the energy value differences between samples; the higher the fat content, the higher the energy value. However, protein provided > 30% of the energy value in all the samples.

3.2. Technological properties

3.2.1. pH and water activity

Neither the *pH* of frankfurters nor the *water activity* (at day 0) were modified by the addition of any chia product. All sausages showed a similar pH value of 6.14 ± 0.03 (Table 2) and Aw value of 0.984 ± 0.005 ($P > .05$). In other words, the addition of chia (in any of its presentation forms) did not have any positive or negative effect on pH or Aw changes for frankfurters at day 0.

The pH decreased in all the samples during storage (Table 2). During the first 7 days of storage, the pH behaved similarly in all the samples but at 14 and 21 days differences were noted between the pH of the control frankfurters and those with added chia products (CHS, CHF and CHCP) ($P < .05$). The decreasing trend in pH could be due to a substantial increase in LAB during storage (Table 5). The carbohydrates present in the frankfurter formulations might promote such growth even in vacuum-packaged products stored under refrigeration. At the end of storage, some basic compounds released during proteolysis may counteract the pH decrease. Similar data have been reported by others authors in several cooked meat products (Fernández-Ginés, Fernández-López, Sayas-Barbera, Sendra, & Pérez-Álvarez, 2004; Pintado, Herrero, Jiménez-Colmenero, Pasqualin-Cavalheiro, & Ruiz-Capillas, 2018; Viuda-Martos, Ruíz-Navajas, Fernández-López, & Pérez-Alvarez, 2010).

3.2.2. Colour

Colour plays an important role in both quality and consumer preference in meat products. Generally, the formation of metmyoglobin (fresh meats) or nitrosohemichrome (in cured meats) and lipid oxidation lead to the discolouration of meat and fade in cured meat. The colour parameters of frankfurters are shown in Table 2.

At day 0, lightness and yellowness were affected ($P < .05$) only when chia coproduct was added (CHCP), these samples showing the lowest L* values and the highest b* values. Several authors have reported that L* values in meat products are highly related with the moisture and fat content (mainly due to the water and fat free in the surface that affects light reflection) because both factors make the product lighter-colored. When chia products were added, water and fat are retained due chia water and oil holding capacities (Fernández-López et al., 2018). The slight increases in b* values following the addition of

Table 1
Proximate analysis and energy value of frankfurters (day 0).

Proximate composition	CON	CHS	CHF	CHCP
Moisture (%)	65.67 ± 0.14a	62.94 ± 0.16b	62.00 ± 0.15b	62.42 ± 0.40b
Protein (%)	15.55 ± 0.57a	16.24 ± 0.46a	15.61 ± 0.23a	16.05 ± 0.31a
Fat (%)	14.39 ± 0.51b	16.04 ± 0.74a	16.15 ± 0.52a	14.93 ± 0.16b
Ash (%)	2.03 ± 0.01a	2.05 ± 0.02a	2.15 ± 0.02a	2.17 ± 0.02a
TDF (%)	–	1.42 ± 0.65a	1.21 ± 0.32a	1.81 ± 0.40a
Energy value (kcal/100 g)	191.71	209.32	207.79	198.57

mean ± sd; TDF: total dietary fiber.
CON: control frankfurter; CHS: frankfurter + 3% chia seeds; CHF: frankfurter + 3% chia flour; CHCP: frankfurter + 3% chia coproduct.
Different letters in the same row indicate significant differences ($P < .05$).

Table 2
Evolution of pH, CIELAB colour coordinates (L*, a* and b*) and colour differences (ΔE*) respect to control sample, during storage of the frankfurters.

Parameter	Sample	Storage time (days)			
		0	7	14	21
pH	CON	6.13 ± 0.03av	6.03 ± 0.03aw	6.00 ± 0.03aw	5.94 ± 0.02aw
	CHS	6.13 ± 0.03av	5.99 ± 0.03aw	5.85 ± 0.03bx	5.81 ± 0.03bw
	CHF	6.15 ± 0.04av	6.01 ± 0.01aw	5.90 ± 0.01bx	5.85 ± 0.04bx
	CHCP	6.15 ± 0.02av	5.99 ± 0.02aw	5.92 ± 0.02bx	5.89 ± 0.02by
L*	CON	64.27 ± 1.35av	67.43 ± 1.36aw	68.56 ± 1.56aw	65.55 ± 1.78av
	CHS	62.95 ± 1.35av	63.49 ± 1.23bv	65.16 ± 1.85bw	62.78 ± 1.88bv
	CHF	62.52 ± 2.44av	65.03 ± 1.45bw	60.93 ± 1.66cx	59.79 ± 1.45cy
	CHCP	58.55 ± 1.02bv	60.85 ± 1.55cw	60.23 ± 1.52cw	58.95 ± 1.96cv
a*	CON	4.30 ± 0.36av	5.35 ± 0.11aw	6.49 ± 0.09ax	4.95 ± 0.08av
	CHS	3.58 ± 0.57av	4.40 ± 0.09bw	5.29 ± 0.04bx	3.89 ± 0.06bv
	CHF	3.32 ± 0.43av	3.30 ± 0.06cv	4.99 ± 0.04bw	3.51 ± 0.04bv
	CHCP	3.33 ± 0.10av	3.18 ± 0.03cv	4.37 ± 0.03bw	3.18 ± 0.06bv
b*	CON	9.55 ± 0.28av	8.41 ± 0.35aw	9.80 ± 0.26av	10.15 ± 0.65av
	CHS	9.84 ± 0.74av	7.89 ± 0.42bw	8.64 ± 0.33aw	9.96 ± 0.56av
	CHF	10.32 ± 0.96bv	7.35 ± 0.22bx	9.04 ± 0.48aw	10.06 ± 0.35av
	CHCP	11.77 ± 0.38bv	8.56 ± 0.45ax	9.92 ± 0.25aw	10.83 ± 0.77av
ΔE*	CON	–	–	–	–
	CHS	1.53 ± 0.12bv	4.08 ± 0.11bx	3.78 ± 0.11bx	3.05 ± 0.09bw
	CHF	1.76 ± 0.96bv	3.32 ± 0.99bw	7.81 ± 0.66ax	5.93 ± 0.65ay
	CHCP	6.21 ± 0.22av	6.93 ± 0.74av	8.59 ± 0.59aw	6.86 ± 0.39av

mean ± sd.
CON: control frankfurter; CHS: frankfurter + 3% chia seeds; CHF: frankfurter + 3% chia flour; CHCP: frankfurter + 3% chia coproduct.
Different letters (a,b,c) in the same column, for the same parameter, indicate significant differences ($P < .05$).
Different letters (v,w,x,y) in the same row indicate significant differences ($P < .05$).

chia coproduct could be related with the yellow components present in this coproduct (Fernández-López et al., 2018). The addition of chia products (in any of its presentations) did not modify the redness of frankfurters. Nevertheless, taking into consideration the differences in colour (ΔE*) between all the frankfurters with added chia (CHS, CHF and CHCP) with respect to the control samples (at day 0; freshly prepared samples), the only sample that clearly differed from the control was the CHCP sample. ΔE* is the difference between two colours in an L* a* b* colour space. Martínez, Melgosa, Pérez, Hita, and Negueruela (2001) reported that only ΔE* higher than 3 CIELAB units would be distinguished by an observer.

Throughout the storage period, control frankfurters were lighter and redder ($P < .05$) than samples with added chia products (Table 2). In the case of L* and a* both values increased during the first days of storage but were similar to initial values at the end of the storage, except in CHF, in which the samples were darker at the end of storage than at the beginning. By contrast, b* values decreased ($P < .05$) during the first days of storage in all samples, but yellowness was the same at the end of the storage period as at the beginning and even some differences in b* values detected between samples at the beginning of the storage period, were not detected at the end.

Usually, a* values have been related to meat red components (haemopigments) and their interconversions, and also to oxidation processes that can affect both the haemopigments and fat. Similar data for the storage period were provided by Choe, Kim, Lee, Kim, and Kim (2013) and Ranucci et al. (2018) in frankfurters with non-meat ingredients added. During storage period, all the colour differences respect to control sample were increasing, being all of them higher than 3 CIELAB units.

3.2.3. Texture analysis

Table 3 shows the effect of chia products on the textural properties of frankfurters. For the four textural parameters analysed, the control samples and those with chia coproducts added (CHCP) showed similar values ($P > .05$). This indicates that the addition of 3% chia coproduct to frankfurters did not have any effect on its textural properties. When chia was added as seeds, the only textural parameter affected ($P < .05$) was hardness, the frankfurters containing chia seeds (CHS) being softer than the others, while CON and CHCP samples showed similar hardness values. This textural behaviour could be explained by the technological properties of chia (Fernández-López et al., 2018; Olivos-Lugo, Valdivia-López, & Tecante, 2010; Pintado et al., 2016), whose emulsifying activity is probably sufficient to provide high emulsion stability and gelling properties, contributing to maintaining the protein network and the continuous phase in the meat emulsion. Several chia proteins, mainly globulins, albumins, glutelins and prolamins have been identified as gelling agents and so promote frankfurter gelling (Olivos-Lugo et al., 2010; Sandoval-Oliveros & Paredes-López, 2013). However, these technological properties attributed to chia proteins did not show when chia was added as seeds (CHS) because all the chia compounds were retained in the seed. The most evident changes in textural properties were observed in frankfurters when chia was added as flour (CHF), resulting in frankfurters less hard, chewy and springy than control samples ($P < .05$). Springiness is a measurement of elastic recovery after deforming force is removes. Chewiness is a measure of the energy required to chew a solid food to the point that it is adequate for swallowing, therefore, the decrease of chewiness showed in frankfurters with chia flour added (CHF) could mean the product is easier to chew. This decrease in frankfurter springiness and chewiness due to the addition of chia flour has also been reported by other authors in meat products containing chia flour and others vegetable flours (Barros et al., 2018; Lucas-González, Pellegrini, Viuda-Martos, Pérez-Alvarez, & Fernández-López, 2019; Pellegrini et al., 2018).

3.2.4. Residual nitrite level

The use of nitrate/nitrite in meat processing has important effects in terms of colour development, fat oxidation, flavour, and microbiological safety, although the health concerns relating to its use have led to a tendency toward decreased usage to alleviate the potential risk of the formation of carcinogenic, teratogenic, and mutagenic nitroso compounds (Viuda-Martos et al., 2009). It must remembered that as soon as nitrite is added to the meat formulation, it starts to disappear since the nitrite is reduced to nitric oxide (NO) which reacts with myoglobin to form nitric oxide myoglobin. Several previous studies have reported that the level of added nitrite in processed meat products decreases over time, from the moment of addition to the point of

Table 3
Texture profile analysis (TPA) parameters of frankfurters (day 0).

	CON	CHS	CHF	CHCP
Hardness (N)	12.71 ± 0.34a	9.75 ± 2.15b	10.90 ± 1.57b	13.08 ± 0.34a
Cohesiveness	0.80 ± 0.01a	0.87 ± 0.04a	0.90 ± 0.04a	0.87 ± 0.04a
Springiness (mm)	0.90 ± 0.03a	0.94 ± 0.02a	0.38 ± 0.02b	0.81 ± 0.17a
Chewiness (N mm)	9.11 ± 0.26a	8.31 ± 2.40a	5.96 ± 1.43b	9.09 ± 1.69a

mean ± sd;
CON: control frankfurter; CHS: frankfurter + 3% chia seeds; CHF: frankfurter + 3% chia flour; CHCP: frankfurter + 3% chia coproduct.
nd = not detectable.
Different letters in the same row indicate significant differences ($P < .05$).

Table 4
Evolution of lipid oxidation (TBARS values, expressed as mg MA/kg) and residual nitrite level (mg/kg) during storage of the frankfurters.

	Storage time (days)			
	0	7	14	21
TBARS (mg MA/kg)				
CON	0.26 ± 0.02bv	0.43 ± 0.02aw	0.58 ± 0.02ax	0.64 ± 0.03ay
CHS	0.28 ± 0.01bv	0.35 ± 0.01cw	0.41 ± 0.02bx	0.42 ± 0.02bx
CHF	0.39 ± 0.02av	0.41 ± 0.03bv	0.41 ± 0.02bw	0.41 ± 0.02bw
CHCP	0.29 ± 0.03bv	0.31 ± 0.01dw	0.35 ± 0.02cx	0.42 ± 0.03by
Residual nitrite level (mg/kg)				
CON	23.88 ± 0.57av	22.54 ± 0.17av	19.20 ± 0.25aw	8.37 ± 0.11ax
CHS	20.54 ± 0.47av	18.31 ± 0.15bv	12.50 ± 0.61cw	2.22 ± 0.61bx
CHF	20.37 ± 0.59av	15.97 ± 0.34cw	6.39 ± 0.04dx	2.05 ± 0.02by
CHCP	22.60 ± 0.16av	21.60 ± 0.35av	13.23 ± 0.55bw	2.07 ± 0.45bx

CON: control frankfurter; CHS: frankfurter + 3% chia seeds; CHF: frankfurter + 3% chia flour; CHCP: frankfurter + 3% chia coproduct.
Different letters (a-b) in the same column, for the same parameter, indicate significant differences ($P < .05$).
Different letters (v,w,x,y) in the same row indicate significant differences ($P < .05$).

consumption (Hill, Webb, Moncol, & Adams, 1973; Pérez-Rodríguez, Bosch-Bosch, & Garciá-Mata, 1996). The rate of depletion is dependent upon various factors, such as pH, initial nitrite concentration, processing and storage temperatures, meat-to-water ratio, and the presence of reductants (Merino, Darnerud, Toldrá, & Ilbäck, 2016). Therefore, any residual nitrite levels will correspond to nitrite that has not reacted with myoglobin and it is available for other reactions in the organism (Fernández-López et al., 2007).

The evolution of residual nitrite levels during storage is shown in Table 4. In the present study, at day 0, residual nitrite levels in all the frankfurters were similar ($P > .05$), irrespective of formulation, and all were in the range considered normal for cooked cured meat products (Hill et al., 1973; Pérez-Rodríguez et al., 1996).

As can be seen, residual nitrite levels decreased ($P < .05$) during storage in all the samples, but with differences between samples. Control samples showed the highest ($P < .05$) residual nitrite levels at all measurements time during the storage period and by the end of storage showed a reduction of 65%. In the case of frankfurters with added chia (CHS, CHF and CHCP) reductions were greater (reaching approximately 90%). Differences in the degree of reduction for the residual nitrite level between control samples and samples with chia products added could be attributed to the polyphenolic compounds present in chia products (Fernández-López et al., 2018; Pellegrini et al., 2018) because some authors have reported that nitrite can react with bioactive compounds especially with polyphenolic compounds (Garrote, Cruz, Moure, Domínguez, & Parajó, 2004; Krishnaswamy, 2001).

3.2.5. Lipid oxidation

TBARS values (as indicators of lipid oxidation) are presented in Table 4. TBARs values in all the samples were below the level of incipient rancidity (≥1.0) throughout the storage period (Ockerman, 1976). At day 0, frankfurters containing chia flour (CHF) showed the highest TBARs value ($P < .05$), while there were no differences between the other samples (CON, CHS and CHCP). The chia content in highly unsaturated fatty acids (Muñoz et al., 2013) might have contributed to the higher degree of lipid oxidation observed when chia was added as flour. In the case of chia added as seeds, most of these fatty acids are containing within the seeds and so are not affected by oxidation, at the moment. In the case of CHCP samples, as the chia coproduct had a lower fat content, the TBARs values were similar to the control values. In this study, the TBARs values of the frankfurters were slightly higher than mentioned by Pintado et al. (2016) but comparable to those of Ranucci et al. (2018).

There was a significant increase ($P < .05$) in the TBARS values during storage in all the samples but with different intensities. The CON samples showed the greatest increase (59%), while the CHF samples, which had the highest TBARs values at the beginning of storage, showed the lowest increase (19%). CHS and CHCP samples showed similar increases during storage (37%). Taking into account that chia products contain highly unsaturated fatty acids, which are very susceptible to lipid oxidation, a higher oxidation rate in the frankfurters containing chia products was to be expected. This pattern of lipid oxidation could be related to the presence of antioxidant compounds in chia products (Fernández-López et al., 2018; Pellegrini, Lucas-Gonzalez, et al., 2018).

3.3. Microbiological analyses during storage

The microbiological stability of cooked meat products depends on intrinsic factors, such as their composition, and extrinsic factors, especially the packaging and storage temperature, bearing in mind that neither the pH (Table 2) nor Aw of the products is able to limit microbial growth. In this case, TVC and LAB counts (Table 5) increased during storage in all the samples, as previously described in several cooked meat products during storage (Ranucci et al., 2018; Viuda-Martos et al., 2010). Although some slight differences in the TVC and LAB counts were detected between samples during storage, all the

Table 5
Evolution of microbial load (total viable count) and lactic acid bacteria (log10 cfu/g) during storage of the frankfurters.

	Storage time (days)			
	0	7	14	21
Total viable count				
CON	2.63 ± 0.07av	3.32 ± 0.06aw	3.85 ± 0.07ax	4.60 ± 0.05ay
CHS	2.52 ± 0.03av	3.22 ± 0.05aw	3.62 ± 0.05ax	4.55 ± 0.04ay
CHF	2.85 ± 0.06bv	3.86 ± 0.03bw	4.02 ± 0.05bx	4.63 ± 0.06ay
CHCP	2.95 ± 0.05bv	3.65 ± 0.04bw	4.22 ± 0.03bx	4.69 ± 0.03ay
Lactic acid bacteria				
CON	2.41 ± 0.02av	2.85 ± 0.04aw	3.55 ± 0.03ax	4.45 ± 0.04ay
CHS	2.39 ± 0.06av	2.92 ± 0.06aw	3.63 ± 0.04ax	4.52 ± 0.06ay
CHF	2.55 ± 0.05av	2.99 ± 0.04aw	3.89 ± 0.06bx	4.46 ± 0.03ay
CHCP	2.64 ± 0.02av	3.2 ± 0.05aw	4.05 ± 0.04bx	4.55 ± 0.05ay

CON: control frankfurter; CHS: frankfurter + 3% chia seeds; CHF: frankfurter + 3% chia flour; CHCP: frankfurter + 3% chia coproduct.
Different letters (a-b) in the same column, for the same parameter, indicate significant differences ($P < .05$).
Different letters (v,w,x,y) in the same row indicate significant differences ($P < .05$).

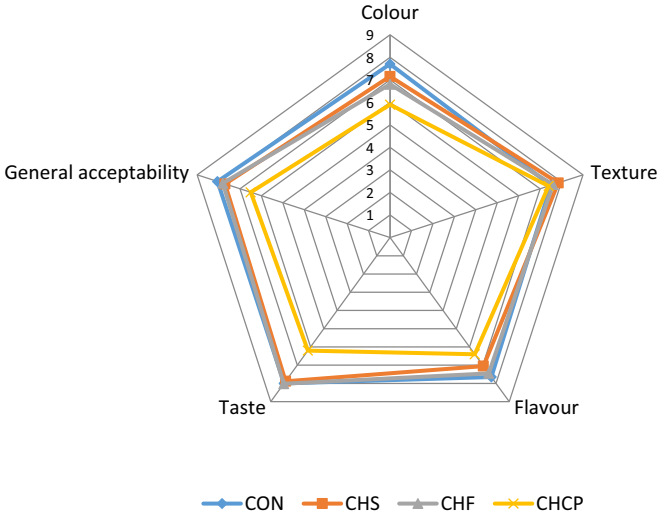

Fig. 1. Sensory evaluation of frankfurters.
CON: control frankfurter; CHS: frankfurter + 3% chia seeds; CHF: frankfurter + 3% chia flour; CHCP: frankfurter + 3% chia coproduct.

samples showed similar counts at the end of storage. All counts at the end of the experiment were below 5.0 log cfu/g, a level considered insufficient to promote the characteristic of a degraded product (slime production, colour changes, off-flavours).

Enterobacteriaceae were only detected in frankfurters at day 14 of storage, counts remaining below 2.0 log cfu/g throughout, with no differences among samples ($P > .05$) (data not shown).

3.4. Sensory analysis

As regards the sensory analysis of the frankfurters (Fig. 1), CON, CHS and CHF samples generally scored significantly higher than CHCP for all the sensory parameters considered except texture, for which scores were similar ($P > .05$) in all the samples.

Only texture was not modified by the addition of any chia product, all the samples (CHS, CHF and CHCP) obtaining similar scores to the control. For the rest of the attributes evaluated (colour, flavour, taste and general acceptability), CHCP samples showed lower scores ($P < .05$) than CON, CHS and CHF samples. CHS and CHF showed similar scores ($P > .05$) for all the attributes evaluated, and only obtained a lower score ($P < .05$) than CON for colour. CHCP samples scored worse for general acceptability, but all samples were judged to be acceptable (> 5) by the panelists. It has previously been described that the addition of non-meat ingredients to meat products modifies their colour, flavour, texture and general acceptability attributes compared with products with no added non-meat ingredients (Barros et al., 2018; Pintado et al., 2016).

4. Conclusions

The research described herein suggests that the reformulation of frankfurters using chia products (seeds, flour or coproducts from cold-pressing chia oil extraction) is feasible and represents a viable alternative for the valorization of the coproducts. As ingredients they enhance the nutritional composition, without adversely affecting the technological properties of the final product. In general, although differences were detected in the sensory attributes of reformulated frankfurters, all of them were judged acceptable by panelists.

Besides the quality aspects, these reformulation strategies had beneficial effects on some technological properties during chilled storage, the resulting products exhibiting greater resistance to oxidation and lower residual nitrite levels than control frankfurters, without affecting microbiological safety.

Declaration of interest

None.

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