Research Article

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Assessment of emulsion gels formulated with chestnut (*Castanea sativa* M.) flour and chia (*Salvia hispanica* L) oil as partial fat replacers in pork burger formulation

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Abstract

BACKGROUND: The aim of this work was to evaluate the effect on chemical composition, physico-chemical properties, cooking characteristics, fatty acid profile, lipid oxidation, and sensory acceptability of an oil-in-water emulsion gel that was prepared with chestnut flour, chia oil, gellan gum, and water (CEG), used as a fat replacer in pork burgers. The original mixture was used as a control sample (CS). The other samples were formulated partially replacing pork backfat with 5% of CEG (CEG5%) and 10% of CEG (CEG10%).

RESULTS: Proximate analysis of samples showed several differences between samples. The CEG addition was found to be effective for improving the cooking yield while diameter reduction and thickness increase were positively affected. As regards lipid oxidation, in cooked burger, the 2-thiobarbituric acid (TBA) values for CS, CEG5% and CEG10% were 0.46, 0.57, and 0.59 mg malonaldehyde/kg sample, respectively. The linolenic and linolenic acid content of pork burger increased as CEG addition increased. Sensory properties for CS and CEG5% were similar whereas CEG10% showed the highest sensory scores.

CONCLUSIONS: A combination of chestnut flour and chia oil could be used as a novel ingredient to develop pork burgers with a better nutritional profile without diminishing their sensory and physico-chemical properties.

Keywords: chestnut flour; chia oil, fat replacer; burger, emulsion gel

INTRODUCTION

Consumer demand in the field of food production has changed considerably in the past decade. Two of the most important aspects that the current consumer looks for when purchasing food products is that they must be safe and healthy. Covering both aspects is a challenge and, at the same time, an opportunity for the food sector to develop the new products that are demanded. The meat industry is aware of this demand and the development of healthy and safe products is its current task.[1–3] Thus, one of the opportunities to innovate and transform meat is in the field of functional foods. Currently, the meat industry has three topics on which it must focus its research: (i) reducing saturated fat content, (ii) reducing nitrite content, and (iii) reducing salt content. The main strategies to do this are: the incorporation of bioactive ingredients with health beneficial effects, the elimination or reduction of ingredients with detrimental effects, and substitution of other ingredients in the meat formulation.

In the case of saturated fat content, eliminating or reducing the animal fat in meat products is not a simple task because animal fat plays an essential role in sensory characteristics such as color, taste, texture, and odor, all of which contribute to overall consumer acceptance[4] and to the technological properties of the meat because it helps to improve water-holding capacity and imparts juiciness to the meat products.[5] A possible way to reduce the animal fat content in meat products is the replacement or substitution of animal fat with vegetables oils. This has seemed to be one of the most suitable strategies to provide a healthier lipid profile to meat products.[6,7] Vegetable oils have a positive impact on nutritional aspects as a result of reduced cholesterol content increasing the polyunsaturated / saturated fatty acids ratio and lowering the ω-6/ω-3 ratio.[8] There are several vegetable oils that could be used as fat replacers, such as flaxseed, sesame, and mainly chia. The healthy reputation of chia is principally associated with its high content of unsaturated fatty acids, such as linolenic and linoleic acids. Several meat products have been formulated using this strategy.[9,10]

Traditionally, a reduction in fat and saturated fat has usually been achieved by increasing the lean meat content, or by replacing fat with water combined with a hydrophilic fat replacer.[11] However, in recent years, several studies have suggested new techniques for

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the structuring of liquid oils and, thus, the production of reformulated products with characteristics close to the formulation made with saturated fat.[12] The use of emulsion gels shows strong potential for application in the food industry in general and in the meat industry in particular, especially for the development of healthier meat products.[13] In the scientific literature there are several work where emulsion gels prepared with vegetable oils are used as fat replacers in the development of low-fat meat products.[14–16] These emulsions are prepared mainly with (i) chia oil, avocado oil, canola, olive oil or linseed oil, because these oils showed a high polyunsaturated fatty acid content in their fatty acid profile, and (ii) several flours such as oat, whey, or banana. One flour with a high potential to be used to prepared emulsions as fat replacer is chestnut flour. Chestnut flour has a good chemical composition and good physico-chemical and techno-functional properties.[17]

In cooked meat products such as Frankfurt sausage or *mortadella* there are several studies in the scientific literature where the substitution of fat by emulsion gels elaborated with vegetable oils and flours was investigated. However, there are few studies where the substitution was in fresh meat products, such as burgers. The aim of this work was therefore to evaluate the effect on chemical composition, physico-chemical properties, cooking characteristics, fatty acid profile, lipid oxidation, and sensorial acceptance of pork burger where emulsion gel prepared with chestnut flour and chia oil was used as a partial fat replacer.

MATERIALS AND METHODS

Emulsion gel elaboration

The emulsion (oil-in-water) gel elaborated with chestnut flour and chia oil was used as a partial fat replacer. Thus, chestnut emulsion gel (CEG) was made with chestnut (*Castanea sativa* M.) flour (20%), chia (*Salvia hispanica* L.) oil (30%), water (48%), and gellam gum (2%) following the methodology described by Pintado *et al.*[18] Samples of 500 g were prepared (in triplicate) by mixing the ingredients in a homogenizer (Thermomix TM 31, Madrid, Spain). To prepare CEG, the chestnut flour was first mixed with water for 30 s at high speed (approximately 5600 rpm). Then, gellam gum was added and the sample was mixed for 15 s (at approximately 5600 rpm). The final mixture was mixed at approximately 5600 rpm with gradual addition of the corresponding chia oil. The CEG were stored in a chilled room at 2 °C for 24 h. Chestnut flour had a protein content of 6.18/100 g dry matter (d.m.) and the fat and ash content was 3.74 and 1.78/100 g d.m. respectively. The total dietary fiber content was 18.57/100 g d.m with an insoluble dietary fiber amount of 10.24/100 g d.m.[17] Chestnut flour had 19.92% of saturated fatty acids (SFAs), 34.32% monounsaturated fatty acids (MUFAs), and 45.76% polyunsaturated fatty acids (PUFA), whereas chia oil showed 10.64% SFA, 8.28% MUFA, and 80.79% PUFA (Table 4).

Burger manufacture

Three independent replicates of each batch were prepared at the IPOA Research Group Pilot Plant at the Miguel Hernández University. A traditional formula was used to obtain base meat batter. This original mixture was used as the control sample, and the other burgers (two formulations) were prepared as shown in Table 1. To obtain the control sample, pork lean meat (64.58% moisture, 4.85% lipids, 29.32% protein, and 1.25% ash) and pork backfat (12.85% moisture, 72.75% lipids, 14.32% protein, and 0.35% ash) were ground through an 8 mm plate in a mincer attached to a mixer, and then the water, salt and pepper were added into the bowl and mixed with the spiral dough hook at medium speed (80 rpm) for 5 min. For each treatment, the corresponding proportions of fat (5% or 10%) were replaced by chestnut emulsion gel and then mixed again for 5 min. These mixtures were shaped using a commercial burger maker (9 cm internal Ø) to obtain patties of approximately 80 g and 1 cm thickness. Plastic packaging film was used to help maintain the shape of the patties prior to packing into PVC-lined hermetic boxes and stored at 4 °C. Five burgers from each formulation were cooked according to the methodology described by the American Meat Science Association[19] at 170 °C in a convection oven until an internal temperature of 72 °C was reached, taken in the geometrical center of each burger through a hypodermic-type thermometer.

Table 1. Formulation of pork burgers with chestnut flour and chia oil emulsion gel as partial fat replacers

	Treatments (%)		
	Control	CEG5%	CEG10%
Pork lean	65	65	65
Pork backfat	35	30	25
Chestnut emulsion gel	0	5	10
Water	5	5	5
Salt	1.5	1.5	1.5
White pepper	0.03	0.03	0.03

Percentages of non-meat ingredients are related to 100% meat.

Chemical composition

The approximate composition of the samples was analyzed by standard AOAC[20] methods to ascertain the protein (920.152), fat (963.15), ash (940.26), and moisture (925.09) content. For all parameters analyzed, three determinations per sample were made.

Physico-chemical properties

The pH was determined using a pH-meter with automatic temperature compensation and a glass-penetration electrode. The analysis was performed on five raw and cooked samples of each treatment, with three readings in each sample. Water activity (Aw) was measured in raw and cooked burgers at 25 °C using a Novasina TH-500 hygrometer (Novasina, Axair Ltd, Pfaeffikon, Switzerland). The analysis was performed in triplicate.

The color was analyzed by keeping all raw and cooked treatment samples at 18° ± 2 °C for 5 min prior to measurement using a Minolta CM-700 spectrophotometer (Minolta Camera Co., Osaka, Japan) with illuminant D_{65}, SCI mode, and an observer angle of 10°. Spectrally pure glass (CRA51, Minolta Co.) was put between the sample and the equipment. The CIEL*a*b* coordinates determined were: lightness (L*), redness (a*, red / green coordinates) and yellowness (b*, yellow / blue coordinates). Nine repeated measurements were taken for each sample, following the guidelines for meat color evaluation.[21]

Texture profile analysis was performed in cooked pork burger samples with a texture analyzer TA-XT2 (Stable Micro Systems, Farncombe, UK) following the methods for the objective measurement of meat product texture.[22] Cubic samples (1 × 1 × 1 cm) were cut from pork burger and subjected to a two-cycle compression test. Samples were compressed to 50% of their original height with a 7.5 cm diameter cylindrical probe attached to a 50 kg compression cell with a cross-head speed of 1 mm s^{-1}. The hardness (N), chewiness (N × mm), springiness (mm), and cohesiveness texture profile parameters were determined according to Bourne.[23]

Cooking characteristics

After cooking, the burgers were cooled to 21 °C for 1 h before weighting. The weight, thickness and diameter of five burgers from each batch were measured before and after cooking.

Cooking yield

The cooking yield was calculated according to Eqn (1):

$$\%\text{cooking loss} = \frac{(Raw\ weight - Cooked\ weight)}{(Raw\ weight)} \times 100 \quad (1)$$

Diameter reduction and thickness increase

The diameter reduction was calculated according to Eqn (2)

$$\text{shrinkage}\ (\%) = \frac{(raw\ diameter - cooked\ diameter)}{(raw\ diameter)} \times 100 \quad (2)$$

The thickness increase was calculated according to Eqn (3)

$$thickness\ increase\ (\%) = \frac{(Cooked\ thickness - raw\ thickness)}{(cooked\ thickness)} \times 100 \quad (3)$$

Fat and moisture retention

To estimate the amount of fat and moisture retained in the samples, Eqns 4 and 5 were used.

$$\%fat\ retention = \frac{(cooked\ sample\ weight\ x\ \%fat\ in\ cooked\ sample}{(raw\ sample\ weight\ x\ \%fat\ in\ raw\ sample)} \times 100 \quad (4)$$

$$\%moisture\ retention = \frac{(cooked\ sample\ weight\ x\ \%moisture\ in\ cooked\ sample)}{(raw\ sample\ weight\ x\ \%moisture\ in\ raw\ sample)} \times 100 \quad (5)$$

Fatty acid composition

Lipid extraction of pork burger was carried out by the procedure described by Bligh and Dyer,[24] using chloroform : methanol (2:1 v/v). Before fatty acid methylation, the solvent was removed from lipid extracts in a water bath at 35 °C under a nitrogen atmosphere. Lipid extracts were transmethylated in the presence of boron trichloride. The fatty acid composition of fatty acid methyl esters (FAMEs) was analyzed on an auto-system gas chromatography (Agilent, model 6890) equipped with a flame ionization detector (FID) and a Suprawax-280 capillary column (30 m length, 0.25 μm film, 0.25 mm internal diameter; Teknokroma, Barcelona, Spain). The injection volume was 0.2 μL in a splitless injection. and helium was used as a carrier gas with a column inlet pressure set at 11 psi. The injector temperature was set at 250 °C and the detector was set at 270 °C. The oven temperature was kept at 60 °C for 51 min; raised to 170 °C at 10.0 °C min^{-1}, and held for 2 min; raised to 230 °C at 3 °C min^{-1}, and held for 10 min; raised to 260 °C at 2 °C min^{-1} and held for 1 min. Response factors were calculated using a reference fat (BCR-164) (Fedelco Inc., Madrid, Spain). For determination and quantification of FAMEs, tritridecanoin was used as an internal standard. All analyses were performed in triplicate, and results were expressed as mg/100 g of burger.

The atherogenicity (AI) and thrombogenicity (TI) indexes were calculated as reported by Ulbricht and Southgate,[25] according to Eqns (6) and (7), respectively:

$$AI = \frac{C12:0 + (4xC14:0) + C16:0}{\sum MUFA + \sum n6 + \sum n3} \quad (6)$$

$$TI = \frac{C14:0 + C16:0 + C18:0}{(0.5\ x \sum MUFA) + (0.5\ x \sum n6) + (3\ x \sum n3) + \left(\frac{\sum n3}{\sum n6}\right)} \quad (7)$$

The hypocholesterolemic/hypercholesterolemic ratio (Eqn (8)) was calculated following Fernandez *et al.*:[26]

$$\frac{h}{H} = \frac{C18:1n9 + C18:1n7 + \sum PUFA}{C14:0 + C16:0} \quad (8)$$

Lipid oxidation

Lipid oxidation of raw and cooked burgers was assessed by the 2-thiobarbituric acid (TBA) method following the recommendations of Rosmini *et al.*[27] The thiobarbituric acid reactive substances (TBARS) values were calculated from a standard curve of malonaldehyde (MA) and expressed as mg MA/kg sample.

Sensorial analysis of burgers

Inexperienced panelists (25) were recruited from the staff and students of the Miguel Hernández University (Orihuela, Spain). Protocols for sensory analysis were approved by the local ethics committee for clinical research (ECCR) (Vega Baja Hospital, Orihuela, Spain). All sensory work was carried out in the sensory laboratory at the university, which fulfils requirements according to the international standards.[28] During evaluation the panelists were situated in private booths. Five burgers from each formulation were cooked as previously described, and maintained warm (60 °C) in an oven until testing within 3–8 min. Rectangular pieces approximately 1.5–2 cm were cut from the center of burgers and were served immediately.[29] Each panelist evaluated three replicates of all the formulae; the sample presentation order was randomized for each panelist. Tap water was provided between samples to cleanse the palate. The attributes measured and their descriptors were as follows: for 'external evaluation': color intensity (from extremely light to extremely dark), and brightness (from dull to bright); for 'taste': fattiness, flavor and taste intensity (from imperceptible to extremely intense); for 'texture': chewiness (from imperceptible to extremely chew), granularity (from imperceptible to extremely grainy), and juiciness (from extremely dry to extremely moist). At the end of the test, panelists were asked to give a score for overall acceptability of the product from 1 to 7.

Statistical analysis

Data obtained for proximate composition, physico-chemical analysis, cooking characteristics, sensory analysis, fatty acids profile, and lipid oxidation were analyzed by means of a one-way analysis of variance (ANOVA) test. All statistical analyses were performed using the Number Cruncher Statistical Systems 2007 software (NCSS, Kaysville, UT, USA). Tukey's *post hoc* test was applied

Table 2. Chemical composition of raw and cooked pork burgers with chestnut flour and chia oil emulsion gel as partial fat replacers

	Raw			Cooked		
	Control	CEG5%	CEG10%	Control	CEG5%	CEG10%
Proteins	19.84 ± 0.16^{a}	19.62 ± 0.34^{a}	18.14 ± 0.31^{b}	25.81 ± 0.15^{a}	24.73 ± 0.14^{b}	22.91 ± 0.57^{c}
Fat	14.86 ± 0.05^{a}	13.58 ± 0.01^{b}	13.09 ± 0.04^{c}	14.66 ± 0.17^{b}	15.87 ± 0.12^{a}	15.74 ± 0.15^{a}
Moisture	61.34 ± 0.83^{a}	60.13 ± 0.67^{a}	60.79 ± 1.02^{a}	54.14 ± 0.69^{a}	54.05 ± 1.03^{a}	54.68 ± 0.55^{a}
Ash	2.39 ± 0.14^{a}	2.32 ± 0.18^{a}	2.33 ± 0.13^{a}	2.67 ± 0.16^{a}	2.76 ± 0.20^{a}	2.68 ± 0.13^{a}

For each group (raw or cooked) values followed by the same small letter within the same row are not significantly different ($P > 0.05$) according to Tukey's multiple range test.
For the same formula, means with different capital letters for raw or cooked burgers are not significantly different ($P > 0.05$) according to Tukey's multiple range test.

for comparison of means, while differences were considered significant at $P < 0.05$.

RESULTS AND DISCUSSION

Chemical composition

Table 2 showed the proximal composition of all raw and cooked pork burgers formulated with chestnut flour and chia oil emulsion gels as partial fat replacers. With regard to raw burgers, in samples where pork backfat was replace by CEG5% and CEG10% there no was modification ($P > 0.05$) in the moisture and ash content; however, a slight decrease was observed when compared with the control. In the same way, no statistical differences ($P > 0.05$) were found in the protein content among control and CEG5%. CEG10% had the lowest ($P < 0.05$) protein content. The fat content of control sample, which had the highest added fat in the formulation, was higher ($P < 0.05$) compared with burgers formulated with CEG5% and CEG10%. In agreement with these findings, Alejandre *et al.*[30] reported a fat reduction (70%) in beef patties reformulated with gelled emulsion containing algae oil.

In cooked burger, for moisture and ash content, again no statistical differences were found among the control sample and burgers with CEG5% or CEG10% as fat replacer. The protein content fell with the use of CEG5% or CEG10% as partial fat replacer with statistical differences ($P > 0.05$) between samples, and it occurs in a concentration-dependent manner. With regard to the fat content, the samples with CEG5% or CEG10%, as partial fat-replacers, had higher values ($P < 0.05$) than the control sample. However, no statistical differences ($P > 0.05$) were found between them. The increase in the fat content of samples with CEG5% and CEG10% as fat replacers with respect to the control sample may be due to the fact that the emulsion gel, elaborated with chestnut flour, maintains the chia oil in its structure, avoiding its loss during the thermal treatment. These results are similar to those reported by Selani *et al.*,[31] who reported a fat content increase in low-fat beef burgers where pineapple byproducts and canola oil were used as fat replacers.

Physico-chemical properties

The physico-chemical properties of raw and cooked pork burgers formulated with chestnut flour and chia oil emulsion gels as partial fat replacers are shown in Table 3. For pH and Aw, in raw pork burger, no statistical differences ($P > 0.05$) were found between the burgers with CEG5%, CEG10%, and control samples. In the same way, in cooked pork burger, no statistical differences ($P > 0.05$) were found between the burgers with CEG5% and CEG10% and control samples. The values obtained from both Aw and pH are within the typical values for this type of product,[7,32] which indicates that the replacement of the fat by the emulsion of chestnut and chia oil does not have an important effect on the parameters analyzed. With regard to the color values (Table 3), in raw pork burger, lightness (L*) increased when pork backfat was replace by CEG5% or CEG10%. Thus, statistical differences were found ($P < 0.05$) between the treated pork burger and the control sample. For the red-green coordinate (a*), the values obtained showed that the use of CEG5% or CEG10% as fat replacers decrease the value of this coordinate over the control but with no statistical differences ($P > 0.05$). For the yellow-blue coordinate (b*) the substitution of pork backfat by CEG5% and CEG10% showed an increase in this parameter ($P < 0.05$) compared to the control sample but with

Table 3. Physico-chemical properties of pork burgers (raw and cooked) formulated with chestnut flour and chia oil emulsion gels as partially fat-replacers

				Color parameters			
		pH	Aw	L*	a*	b*	ΔE
Raw	Control	5.52 ± 0.02^{a}	0.964 ± 0.001^{a}	57.81 ± 1.26^{c}	5.16 ± 0.48^{a}	14.91 ± 0.24^{b}	-
	CEG5%	5.53 ± 0.02^{a}	0.967 ± 0.001^{a}	60.79 ± 1.68^{b}	4.94 ± 0.35^{a}	16.41 ± 0.31^{a}	3.42 ± 0.23^{b}
	CEG10%	5.51 ± 0.01^{a}	0.966 ± 0.002^{a}	65.13 ± 1.32^{a}	4.87 ± 0.31^{a}	15.99 ± 0.24^{a}	7.42 ± 0.72^{a}
Cooked	Control	5.80 ± 0.02^{a}	0.965 ± 0.001^{a}	55.81 ± 1.65^{a}	7.03 ± 0.14^{b}	21.64 ± 0.16^{a}	-
	CEG5%	5.80 ± 0.04^{a}	0.966 ± 0.002^{a}	54.79 ± 1.44^{a}	8.55 ± 0.18^{a}	21.76 ± 0.19^{a}	4.97 ± 0.51^{a}
	CEG10%	5.75 ± 0.03^{a}	0.967 ± 0.001^{a}	50.96 ± 1.51^{b}	8.08 ± 0.32^{a}	21.87 ± 0.19^{a}	1.14 ± 0.47^{b}

For each group (raw or cooked), values followed by the same small letter within the same row are not significantly different ($P > 0.05$) according to Tukey's multiple range test.

Table 4. Cooking characteristics and textural properties of pork burgers with chestnut flour and chia oil emulsion gel as partial fat replacers

	Control	CEG5%	CEG10%
Textural properties			
Hardness (N)	45.30 ± 1.47a	39.02 ± 2.32b	34.47 ± 2.08c
Springiness (mm)	0.36 ± 0.02a	0.32 ± 0.03a	0.33 ± 0.01a
Cohesiveness	0.38 ± 0.06a	0.41 ± 0.03a	0.36 ± 0.02a
Chewiness (N × mm)	6.21 ± 0.45a	5.16 ± 0.43b	4.08 ± 0.52c
Cooking characteristics			
Cooking loss (%)	21.12 ± 0.14a	21.10 ± 0.55a	18.16 ± 0.83b
Shrinkage (%)	18.56 ± 0.48a	17.40 ± 0.14b	16.30 ± 0.24c
Increase in thickness (%)	8.89 ± 0.25a	7.56 ± 0.18b	7.09 ± 0.12c
Fat retention (%)	62.19 ± 2.65a	66.47 ± 1.86b	70.02 ± 1.93c
Moisture retention (%)	42.71 ± 1.56a	41.96 ± 2.43b	44.52 ± 1.52a

Values followed by the same small letter within the same row are not significantly different ($P > 0.05$) according to Tukey's multiple range test.

no statistical differences ($P > 0.05$) between CEG5% and CEG10%. The results obtained were in agreement with those reported by Rodríguez-Carpena *et al.*[33] and Zhuang *et al.*[34] These authors mentioned that burgers treated with vegetable oils as partial fat replacers showed significantly higher L*-values, significantly lower a*-values, and significantly higher b*-values than control samples. The effect of thermal treatment on the color properties of burgers showed that lightness (L*) decreased ($P < 0.05$) in the treatments where CEG5% and CEG10% were used as fat replacers with no statistically significant differences ($P > 0.05$) among them. Some authors reported that the reduction of L* during the cooking treatment in meat products may be related to the changes in the myoglobin states and also to the release of water.[20] For the redness coordinate, the cooking process led to an increase ($P < 0.05$) in the values obtained for samples with CEG5% and CEG10% when compared with the control burger. On the other hand, for the yellowness coordinate, no statistical differences ($P > 0.05$) were found between the burgers with CEG5% and CEG10% and control samples. ΔE* is the difference between two colors in an L* a* b* color space. Martínez *et al.*[35] reported that only ΔE* higher than 3 CIELAB units would be distinguished by an observer. With regard to the differences in color (ΔE*) between pork burgers where pork backfat was replace by CEG5% or CEG10% compared with the control samples, in raw burgers, all samples clearly differed from the control. In cooked burgers, the only sample that clearly did not differ from the control was the CEG10% sample. Table 4 showed the textural properties of cooked pork burgers where chestnut flour and chia oil emulsion gel were used as partial fat replacers. Hardness and chewiness were significantly ($P < 0.05$) affected by the substitution of pork backfat by CEG5% and CEG10%. In reference to hardness, 13.80 and 23.90% hardness reduction occurred with the CEG5% and CEG10% treatments compared with the control sample. In the scientific literature, contradictory results have been reported on hardness, depending on the concentration and types of ingredient used as fat replacers. Afshari *et al.*[36] reported that the use of an emulsion formed by canola / olive oil, soy protein, inulin and β-glucan to replace the fat in beef burgers significantly reduced hardness of samples, decreasing it by 50.2% in comparison with control burgers. On the other hand, Heck *et al.*[16] reported that hydrogelled emulsions from vegetables oils used as fat replacer to produce healthier low-fat beef burgers, increase burger hardness compared with the control samples and it occurs in a concentration-dependent manner. For the chewiness, as occurs with hardness, the substitution of pork backfat by chestnut flour and chia oil emulsion gel at 5% and 10% produced a reduction in this parameter ($P < 0.05$) when compared with the control sample. For cohesiveness and springiness, no statistically significant differences ($P > 0.05$) were found between the control and the samples with CEG5% and CEG10%. These results agreed with those reported by Rodríguez-Carpena *et al.*[33] who found that cooked burger patties manufactured using avocado, sunflower and olive oils as replacers of pork back-fat had no effect on cohesiveness and springiness when compared with a control sample. A reduction in the hardness and chewiness values can be considered as good by the consumer because these changes can be associated with a better quality of the meat used to make the hamburger.

Cooking characteristics

The cooking characteristics (cooking loss, diameter reduction, thickness increase, fat retention, and moisture retention) of cooked pork burgers where chestnut flour and chia oil emulsion gel were used as partial fat replacers are shown in Table 4. As regards the cooking loss, no statistical differences ($P > 0.05$) were found between the control sample and CEG5% whereas CEG10% had the lowest ($P < 0.05$) cooking loss. Cooking loss occurred during the thermal treatment mainly due to moisture evaporation and dripping of melted fat.[31,37] With regard to shrinkage (Table 4), the control sample showed the highest ($P < 0.05$) value followed by the CEG5% sample. The lowest shrinkage value (16.30%) was obtained for the CEG10% sample. Cooking shrinkage, which is considered one of the most important physical quality changes that occurs in burgers during the cooking process, is due to protein denaturation and releasing of fat and water from burger patties.[38] Serdaroglu and Degirmencioglu[39] reported that the reduction in fat level led to a reduction in burger shrinkage. These results are supported by the findings of Heck *et al.*[16] who reported that hydrogelled emulsions from vegetables oils used as fat replacers to produce healthier low-fat beef burgers also reduced shrinkage during cooking. Regarding the thickness increase (Table 4), compared with control samples, the burgers formulated with CEG5% and CEG10% showed a reduction in thickness increase ($P < 0.05$) and it occurred in a concentration dependent manner. This may be attributed to the binding and stabilizing properties of CEG, which could reduce distortion of the product during the thermal treatment.

The water retention and fat retention parameters are related to the capacity of the protein matrix, to retain both water and fat in its structure. The control sample showed the lowest fat retention ($P < 0.05$) values followed by the CEG5% burger. The highest ($P < 0.05$) fat retention values were achieved in the CEG10% burger. This increase in the fat retention may be due to the ability of the chestnut flour to retain oil in its structure and also to protect it during the cooking process, avoiding its loss. These results were consistent with those reported by Selani *et al.*[31] who reported a fat retention increase in low-fat beef burgers where pineapple byproducts and canola oil were used as fat replacers. As regards moisture retention, no statistical differences were found ($P > 0.05$) between the control sample and burgers containing CEG5% and CEG10% of chestnut flour and chia oil emulsion gels.

Fatty acid profile

Table 4 shows the fatty acid profile of raw and cooked burger formulated with chestnut flour and chia oil emulsion gels as partial

Table 5. Fatty acid profile of chestnut flour, chia oil and pork burgers (raw and cooked) formulated with chestnut flour and chia oil emulsion gels as partially fat-replacers

			Raw			Cooked		
	Chestnut flour	Chia oil	Control	CEG5%	CEG10%	Control	CEG5%	CEG10%
C12:0	N.D.	N.D.	12.63 ± 1.05^{bL}	9.85 ± 0.48^{cL}	19.96 ± 0.46^{aI}	13.93 ± 1.04^{aO}	13.49 ± 0.82^{bN}	13.38 ± 0.11^{bO}
C14:0	N.D.	0.03 ± 0.01^{H}	274.39 ± 8.41^{aG}	155.49 ± 2.88^{bF}	142.68 ± 0.02^{cG}	211.84 ± 1.09^{bF}	216.63 ± 1.18^{aG}	177.08 ± 1.22^{cG}
C14:1	N.D.	N.D.	5.94 ± 0.53^{cM}	8.83 ± 0.96^{aL}	6.87 ± 0.45^{bL}	0.00 ± 0.00	7.14 ± 0.15^{aP}	0.00 ± 0.00
C15:0	N.D.	N.D.	14.12 ± 1.05^{aL}	6.11 ± 0.94^{bM}	5.24 ± 0.09^{cM}	9.53 ± 1.07b	13.49 ± 0.19^{aN}	8.66 ± 0.63^{bP}
C15:1	N.D.	N.D.	24.52 ± 3.15^{aK}	9.51 ± 1.92^{cL}	17.67 ± 0.93^{bJ}	24.92 ± 2.08^{aN}	11.90 ± 0.26^{cO}	16.53 ± 0.98^{bN}
C16:0	18.41 ± 0.13^{C}	6.88 ± 0.07^{D}	3512.60 ± 3.15^{aB}	2785.94 ± 4.80^{bB}	1992.30 ± 1.85^{cC}	3361.54 ± 6.22^{bB}	3483.47 ± 4.49^{aB}	3245.59 ± 2.23^{cB}
C16:1	0.43 ± 0.04^{F}	0.05 ± 0.01^{H}	382.12 ± 5.25^{aF}	295.37 ± 2.88^{bE}	199.30 ± 0.46^{cE}	356.97 ± 1.05^{bE}	419.76 ± 3.37^{aF}	316.37 ± 2.57^{F}
C17:0	N.D.	N.D.	70.59 ± 5.25^{aI}	35.99 ± 0.96^{bJ}	24.54 ± 0.49^{cH}	57.17 ± 2.08^{aK}	52.37 ± 2.24^{bK}	45.65 ± 0.98^{cK}
C17:1	N.D.	N.D.	41.61 ± 2.10^{aJ}	29.88 ± 1.92^{bK}	15.71 ± 0.02^{cK}	48.38 ± 4.15^{aL}	42.85 ± 0.25^{bL}	37.78 ± 0.68^{cM}
C18:0	1.39 ± 0.07^{E}	3.60 ± 0.05^{E}	1969.69 ± 3.5^{aC}	1475.47 ± 2.88^{b}	580.87 ± 2.31^{cF}	1811.98 ± 2.03^{bC}	1881.39 ± 3.37^{aD}	1758.16 ± 4.58^{cD}
C18:1n9c	33.89 ± 0.15^{B}	8.00 ± 0.07^{C}	6567.07 ± 8.41^{aA}	5393.30 ± 2.96^{bA}	5088.74 ± 2.78^{cA}	6547.89 ± 3.11^{bA}	6655.08 ± 3.48^{aA}	6211.79 ± 9.65^{cA}
C18:2n6c	40.77 ± 0.17^{A}	19.18 ± 0.09^{B}	1665.50 ± 1.05^{cD}	1836.70 ± 2.81^{bC}	3640.98 ± 0.93^{aB}	1777.53 ± 1.05^{cD}	1946.46 ± 3.40^{bC}	2135.92 ± 8.98^{aC}
C18:3n3	4.99 ± 0.06^{D}	61.61 ± 0.10^{A}	72.55 ± 1.30^{aE}	1285.35 ± 4.80^{bD}	1314.89 ± 2.76^{cD}	93.09 ± 3.19^{aH}	827.62 ± 1.09^{bE}	1452.80 ± 6.68^{cE}
C20:0	N.D.	0.28 ± 0.02^{F}	23.03 ± 1.46^{cK}	29.88 ± 1.92^{aK}	25.20 ± 0.46^{bH}	38.12 ± 2.03^{bM}	34.12 ± 1.12^{cM}	41.71 ± 0.87^{aL}
C20:1	N.D.	0.13 ± 0.01^{G}	111.45 ± 4.20^{aH}	105.92 ± 3.84^{bG}	15.05 ± 0.93^{cK}	135.61 ± 1.02^{aG}	126.96 ± 2.25^{bH}	136.15 ± 3.65^{aH}
C20:2	N.D.	N.D.	70.59 ± 1.05^{aI}	68.58 ± 0.96^{aH}	0.00 ± 0.00	87.23 ± 1.08^{aI}	78.56 ± 1.09^{bI}	77.13 ± 0.68^{bI}
C20:3n11c	N.D.	N.D.	41.21 ± 2.30^{bJ}	47.53 ± 1.36^{aI}	0.00 ± 0.00	84.30 ± 1.06^{aJ}	58.72 ± 2.28^{cJ}	65.32 ± 0.34^{bJ}
ΣSFA	19.92 ± 0.13	10.79 ± 0.10	5877.04 ± 10.56^{a}	4498.71 ± 9.68^{b}	2790.73 ± 7.42^{c}	5504.10 ± 8.91^{b}	5694.95 ± 7.56^{a}	5290.21 ± 7.85^{c}
ΣMUFA	34.32 ± 0.17	8.32 ± 0.06	7132.71 ± 12.65^{a}	5842.80 ± 10.52^{b}	5343.34 ± 8.12^{c}	7113.77 ± 6.98^{b}	7263.70 ± 6.91^{a}	6718.62 ± 8.70^{c}
ΣPUFA	45.76 ± 0.17	80.89 ± 0.05	1850.24 ± 8.63^{c}	3238.15 ± 9.56^{b}	4955.87 ± 7.89^{a}	2042.14 ± 8.96^{c}	2911.35 ± 9.65^{b}	3731.17 ± 8.95^{a}
PUFA/SFA	2.29 ± 0.08	7.59 ± 0.09	0.31 ± 0.03^{c}	0.72 ± 0.05^{b}	1.79 ± 0.06^{a}	0.37 ± 0.04^{c}	0.51 ± 0.04^{b}	0.71 ± 0.06^{a}
n6/n3	8.17 ± 0.01	0.31 ± 0.03	22.96 ± 0.08^{a}	1.43 ± 0.09^{c}	2.77 ± 0.10^{b}	19.09 ± 0.10^{a}	2.35 ± 0.11^{b}	1.47 ± 0.13^{c}
AI	0.23 ± 0.02	0.08 ± 0.01	0.51 ± 0.05^{a}	0.38 ± 0.04^{b}	0.25 ± 0.06^{c}	0.46 ± 0.02^{a}	0.43 ± 0.02^{a}	0.38 ± 0.02^{b}
TI	0.13 ± 0.03	0.11 ± 0.02	0.67 ± 0.06^{a}	0.49 ± 0.03^{b}	0.19 ± 0.04^{c}	0.60 ± 0.06^{a}	0.56 ± 0.03^{a}	0.49 ± 0.02^{b}
h/H	4.33 ± 0.09	13.04 ± 0.10	2.22 ± 0.09^{c}	2.93 ± 0.07^{b}	4.70 ± 0.03^{a}	2.40 ± 0.05^{c}	2.59 ± 0.11^{b}	2.91 ± 0.09^{a}

N.D., not detected.
Chestnut flour and chia oil: values expressed as g/100 g sample.
SFA: saturated fatty acid; MUFA: monounsaturated fatty acid; PUFA: polyunsaturated fatty acid.
AI: Atherogenicity index; TI: and thrombogenicity index; h/H: hypocholesterolemic/hypercholesterolemic ratio.
For each group (raw or cooked) values followed by the same small letter within the same row are not significantly different ($P > 0.05$) according to Tukey's multiple range test.
For the same formula, means with different capital letters for chestnut flour, chia oil, raw or cooked burgers are not significantly different ($P > 0.05$) according to Tukey's multiple range test.

fat replacers. In raw burgers, the partial substitution of pork backfat by CEG5% and CEG10% produced burgers with a higher nutritional value than control burgers, due to the increase in PUFAs, which include essential fatty acids and the decrease in SFA content. The increase ($P < 0.05$) in PUFAs in the CEG5% and CEG10% samples compared to the control was 75.59% and 167.84%, respectively while the decrease ($P < 0.05$) in SFA in CEG5% and CEG10% samples compared to the control was 23.45% and 52.51% respectively. The decrease in SFA content in CEG5% and CEG10% was mainly due to the decrease in the myristic, palmitic, and stearic acid content, whereas the increase in PUFA was due mainly to linoleic (C18:2ω6) and linolenic acids (C18:3ω3), which are the main fatty acids found in chia oil.[40] It is important to notice that control sample had the highest content ($P < 0.05$) in MUFA followed by CEG5% and finally CEG10%. This decrease in MUFAs was mainly due to a decrease in oleic acid.

In raw burger (Table 4) the partial substitution of pork backfat by CEG5% and CEG10% had statistical effects ($P < 05$) in the atherogenicity index, thrombogenicity indexes, hypocholesterolemic / hypercholesterolemic ratio, PUFA/SFA ratio, and the $\omega6/\omega3$ ratio. Thus, the results obtained for burgers formulated with CEG5% and CEG10% showed lower ($P < 05$) atherogenicity and thrombogenicity indexes than the control sample, significantly improving the healthy properties of the new burgers. Similarly, the the hypocholesterolemic / hypercholesterolemic ratio and the PUFA/SFA ratio were significantly ($P < 0.05$) affected by the partial substitution of pork backfat by CEG5% and CEG10%. Both ratios increase in these samples compared with the control sample. These results agree with those reported by Heck *et al.*[16] who showed that hydrogelled emulsions from vegetables oils used as fat replacer to produce low-fat beef burgers decreased the atherogenicity and thrombogenicity indexes and increased the PUFA/SFA ratio compared with the control sample. Similarly, Salcedo-Sandoval *et al.*[41] reported that pork burger where pork backfat (49%) was replace with a healthier oil combination (olive, fish and linseed) stabilized in a konjac-based oil bulking system, the atherogenicity and thrombogenicity indexes decreased 25.4% and 41.10%, respectively, while the PUFA/SFA ratio increased by 70.60% compared with the control sample.

In cooked burgers (Table 4), the same behavior was observed as in the raw burgers. The PUFA content increased in samples where pork backfat was partially replaced by CEG5% and CEG10% due to the increase in linoleic and linolenic acids while the SFA content decreased. In the same way, cooked burgers (Table 4) maintained the same trend as raw burgers in the calculated indexes. Control burgers therefore had lower ($P < 0.05$) hypocholesterolemic / hypercholesterolemic and higher ($P < 0.05$) atherogenicity and thrombogenicity values than CEG5% and CEG10% samples. The PUFA/SFA ratio increase ($P < 0.05$) in these samples (CEG5% and CEG10%), compared with the control sample, occurred in a concentration-dependent manner. These results were in concordance with those reported by Afshari *et al.*[36] who showed that the use of emulsions formed by canola / olive oil and soy protein or canola / olive oil and soy protein, inulin and β-glucan to replace the fat in cooked beef burgers significantly impacted in the atherogenicity and thrombogenicity indexes, decreasing theses indexes by 68.86–70.14% and 78.68–79.23% in comparison with control burgers. Likewise, Mancini *et al.*[42] carried out a research to determine the capacity of ginger powder (1% and 2%) to affect the fatty acid profile and the hypocholesterolemic / hypercholesterolemic ratio as well as the atherogenicity and the thrombogenicity indexes in burgers formulated with rabbit meat. These authors reported that fatty acid profile was improved in cooked samples leading to decreased atherogenicity and thrombogenicity indexes and increased the hypocholesterolemic / hypercholesterolemic index (Table 5).

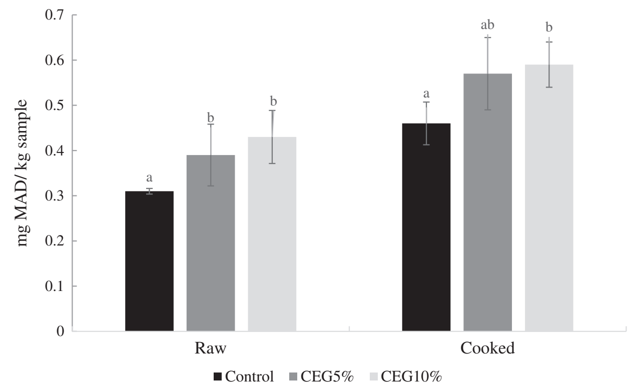

Figure 1. 2-Thiobarbituric acid values of pork burgers (raw and cooked) formulated with chestnut flour and chia oil emulsion gels as partial fat replacers.

Lipid oxidation (TBARs)

Lipid oxidation can have negative effects on the quality of meat and meat products due to modifications in sensory attributes such as color, texture, odor, taste, or flavor, and changes in nutritional composition.[43] The lipid oxidation values of raw and cooked pork burgers formulated with chestnut flour and chia oil emulsion gels as partial fat replacers are shown in Fig. 1. In raw burger the partial substitution of pork backfat by CEG5% and CEG10%, increased the lipid oxidation values ($P < 0.05$). Nevertheless, the TBAR values of samples containing 5% and 10% of chestnut flour and chia oil emulsion gels did not show statistical differences ($P > 0.05$). In cooked burger (Fig. 1), again the control sample showed the lowest lipid oxidation values with no statistical differences ($P > 0.05$) from the sample with CEG5%. The sample with CEG10% showed the higher ($P < 0.05$) lipid oxidation values (0.59 mg MA/kg sample).

The results obtained showed that the substitution of pork backfat by chestnut flour and chia oil emulsion gels had a negative effect on the oxidative stability of both raw and cooked pork burger. A possible explanation for this phenomenon would be the replacement of saturated fatty acids, present in animal fat, which are more stable to oxidation as they do not have double bonds, with unsaturated fatty acids present in vegetable oils, which are more susceptible to lipid oxidation. However, it should be borne in mind that the lipid oxidation values obtained for both raw and cooked burgers are below the malonaldehyde limit for acceptability because Trindade *et al.*[44] reported that the value of 2 mg malonaldehyde/kg is a limit that can indicate loss of sensory attributes and perception of oxidation by consumers, whereas Georgantelis *et al.*[45] reported that a rancid flavor is detected in meat products with TBARS values higher than 0.6 malonaldehyde/kg sample. The results obtained in this work agreed with those reported by Selani *et al.*,[46] who described lower malonaldehyde values in control raw and cooked beef burgers (with no added vegetal fat) than those of the samples where pineapple by-products and canola oil were used as partial fat replacers. Similarly, Moghtadaei *et al.*[47] analyzed the production of sesame oil oleogels and its application as partial substitutes of animal fat in beef burger. These authors reported that the lipid oxidation

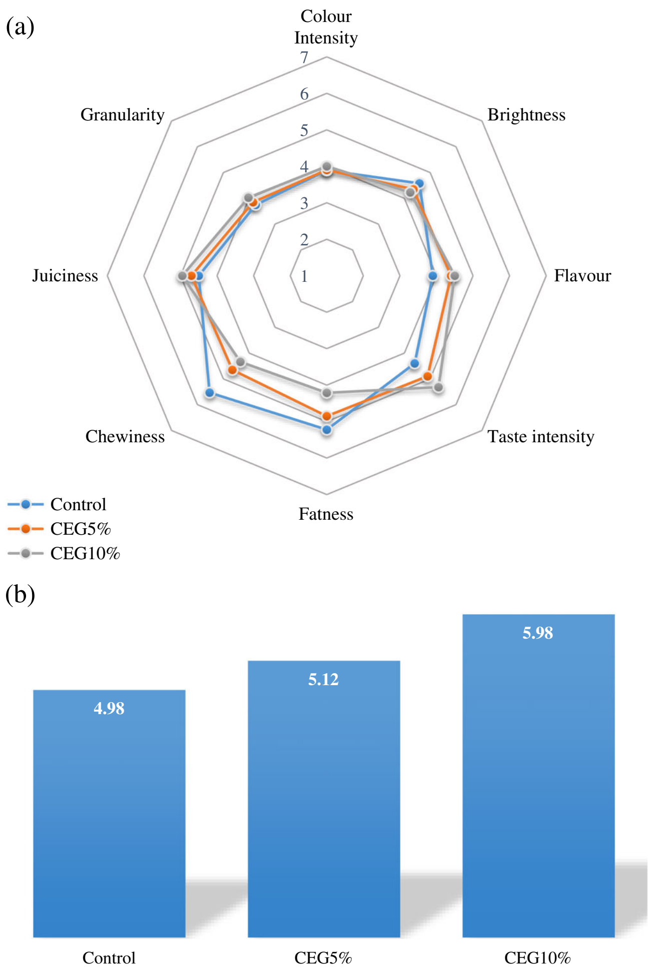

Figure 2. Results for sensorial analysis (a) and general acceptance (b) of cooked pork burgers with chestnut flour and chia oil emulsion gel as partial fat replacers.

of beef burger was significantly affected by the concentration of sesame oil oleogels used as partial substitutes for animal fat. Thus, the lipid oxidation significantly increased with the addition of sesame oil oleogels and this occurs in a concentration-dependent manner.

Sensorial analysis

Figure 2 showed the results obtained for the sensorial analysis carried out in cooked pork burgers formulated with CEG5% and CEG10% as partial fat replacers. There were no differences ($P > 0.05$) between the control burgers and the burgers formulated with CEG5% and CEG10% in color intensity, brightness, juiciness, and granularity. For flavor and taste intensity, burgers formulated with CEG5% and CEG10% showed higher ($P < 0.05$) scores than control samples with no statistical differences between them. Regarding the fatness, it is important to note that there is a discrepancy between the fat values measured in an instrumental way and the values obtained for this parameter in the sensory analysis. Thus, the panelist indicated that there were statistical differences ($P < 0.05$) between the samples (the burger control presenting the highest value) while instrumentally no significant differences were observed among them. For chewiness, the control burger had the highest ($P < 0.05$) scores followed by CEG5% and CEG10% with no statistical differences between them ($P > 0.05$). These results were in agreement with the instrumental analysis. As regard general acceptance (Fig. 2(b)), the lowest values were obtained for CEG5% and the control sample, with no statistical differences ($P < 0.05$) between them. On the other hand, among the cooked pork burgers studied, the most acceptable sample ($P < 0.05$) was CEG10%.

CONCLUSION

The substitution of pork backfat by an oil-in-water emulsion prepared with chestnut flour and chia oil had no negative effects on the chemical composition and physico-chemical properties of pork burgers. The cooking characteristics and the fatty acid profile were improved in samples where chestnut emulsion gel was used as fat replacer. A combination of chestnut flour and chia oil could therefore be used as a novel ingredient to develop pork burgers with a better nutritional profile without harming their sensory and physico-chemical properties.

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