LWT - Food Science and Technology 161 (2022) 113416

Contents lists available at ScienceDirect

LWT

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

# Improving the lipid profile of beef burgers added with chia oil (*Salvia hispanica* L.) or hemp oil (*Cannabis sativa* L.) gelled emulsions as partial animal fat replacers

Carmen Botella-Martínez, Aarón Gea-Quesada, Estrella Sayas-Barberá, José Ángel Pérez-Álvarez, Juana Fernández-López, Manuel Viuda-Martos *

*IPOA Research Group, Centro de Investigación e Innovación Agroalimentaria y Agroambiental CIAGRO, Miguel Hernández University, Orihuela, 03312, Alicante, Spain*

ARTICLE INFO

*Keywords:*
Hemp oil
Fat replacer
Amaranth flour
Gelled emulsions

ABSTRACT

New gelled emulsions (GE) based on amaranth flour mixed with chia or hemp oil were developed and used as partial pork back-fat replacer (25 and 50%) in beef burgers. The addition of GE decreased the fat content in the burgers between 12% and 33%. The use of GE decreased the amount of palmitic, stearic, and oleic fatty acids and increased the amount of linolenic (higher in amaranth-hemp GE) and α-linolenic (higher in amaranth-chia GE) fatty acids. Both GE improved the n-6/n-3 and PUFA/SFA nutritional ratios in burgers and the AI, TI, h/H indices related to healthy properties of lipid fractions. Color, water activity, pH, and texture were not affected by the addition of GE but cooking loss, shrinkage, and thickness changes were increased (higher in amaranth-hemp GE). Burgers containing amaranth-chia GE (both raw and cooked) resulted in more susceptibility to lipid oxidation than the others and also resulted in lower sensorial acceptability. As a general conclusion, the use of amaranth-hemp GE as pork backfat substitute improve nutritional characteristics of the burgers without affecting technological or sensory properties.

## 1. Introduction

Animal fat is an important ingredient in meat products with a high impact on their technological and sensorial properties. However, its high percentage in saturated fatty acids (SFA) which has been associated with a series of diseases like obesity, cardiovascular and chronic diseases (Food and Agriculture Organization of the United Nations FAO, 2016), is being a real problem for nowadays consumers who are really worried about their health, requesting healthier foods. A way to please this demand is by reformulating meat products with healthier lipid sources (rich in unsaturated fatty acids), especially from vegetable oils (Gómez-Estaca, Herrero, et al., 2019; Vargas-Ramella et al., 2020). The type of fat and lipid composition are not only interesting from a nutritional point of view but also have a significant role in the structure, texture, sensorial and technological properties of the final product (Barros et al., 2021; Öztürk-Kerimoğlu, Urgu-Öztürk, & Serdaroglu, 2021). For this reason, several strategies have been applied to replace animal fat with vegetable oils minimizing both, their effect on the physicochemical and sensorial properties of the final product, to ensure their acceptability by consumers, but also on their technological characteristics, to ensure their technological viability in the meat industry (de Suoza-de Souza Paglarini et al., 2019; de Carvalho et al., 2020; Tarté, Paulus, Acevedo, Prusa, & Lee, 2020). One way of doing this substitution, with minimal technological effects, could be the use of gelled emulsions (GEs) (Alejandre, Passarini, Astiasarán, & Ansorena, 2017; Pintado, Ruiz-Capillas, Jiménez-Colmenero, Carmona, & Herrero, 2015). Several vegetable oils with healthy lipid profiles (wheat germ, tiger nut, chia, flaxseed, linseed, olive, canola, and soybean oils, among others) and emulsifier or gelling agents (gelatin, alginate, chia mucilage flour, protein soy, carrageenan, chestnut flour, gums, and inulin, among others) have been successfully used in the development of these GEs (Lucas-González et al., 2020; de Souza-de Souza Paglarini et al., 2019; Vargas-Ramella et al., 2020; Barros et al., 2021; Öztürk et al., 2021). Moreover, previous studies have shown the potential of these GEs as animal fat replacers in several meat products, mainly cooked meat products (Barros et al., 2020; de Carvalho et al., 2020). Among the variety of meat products, burgers and patties seem to be a compelling choice for both fat reduction and lipid profile improvement since they

* Corresponding author. Miguel Hernández University, Spain.
*E-mail address:* mviuda@umh.es (M. Viuda-Martos).

https://doi.org/10.1016/j.lwt.2022.113416
Received 30 December 2021; Received in revised form 22 March 2022; Accepted 29 March 2022
Available online 31 March 2022

are popular products sold as ready-to-eat and fast food consumption, easy to prepare at home, and so, with a high impact in our diet.

Although GEs are been highly applied as animal fat replacers in meat products, to our knowledge, there are no published data using the combination of hemp (*Cannabis sativa* L.) oil or chia (*Salvia hispanica* L.) oil with amaranth flour to elaborate GEs for fat replacer in burgers production. Chia oil is composed of a well-balanced fatty acids profile, consisting of up in the unsaturated fatty acid fraction with 65% linolenic acid and 20% linoleic acid (Villanueva-Bermejo, Calvo, Castro-Gómez, Fornari, & Fontecha, 2019). Hemp oil is rich in polyunsaturated fatty acids, mainly linoleic acid and also contains gamma and alpha linolenic acids (Tura et al., 2022). On the other hand, amaranth is a highly nutritious pseudocereal known to be a dietary source of proteins, vitamins, minerals and dietary fiber (Tafadzwa et al., 2021). Additionally, amaranth proteins provide emulsifying and gelling properties, both highly useful for the development of gelled emulsions (Alejandre, Ansorena, Calvo, Cavero, & Astiasaran, 2019).

Therefore, the aims of this work were to evaluate the technological viability of using GEs, elaborated with hemp or chia oil with amaranth flour, as partial animal fat replacer (25% and 50%) for beef burgers production and study the effect of these two partial fat substitutions on proximate composition, lipid profile, lipid oxidation, and physicochemical, cooking, and sensory properties of reformulated beef burgers.

## 2. Materials and methods

### 2.1. Materials

For gelled emulsions (GEs) preparation the following ingredients were used: chia oil (56.61% α-linolenic acid, 17.43% linoleic acid, and 15.05% oleic acid) and hemp oil (54.44% linoleic acid, 19.95% α-linolenic acid, 8.23% oleic acid) purchase from Laboratorios Almond, S.L. (Murcia, Spain); amaranth flour was obtained from Tentorium Energy S. L. (Tarragona, Spain); gellan gum (a polysaccharide excreted by microorganism *Pseudomonas elodea*) and gelatin of animal origin (pork) named "instant gel" were obtained from Sosa Ingredients S.L. (Barcelona, Spain). Meat ingredients [beef meat (74.02% moisture, 24.51% protein, 2.88% lipids, and 1.01% ash) and pork backfat (84.05% lipids, 3.18% proteins, 12.51% moisture, and 0.26% ash)] were purchased from a local supermarket.

### 2.2. Preparation of oil in water gelled emulsions

The gelled emulsions were elaborated as described by Botella-Martínez Pérez-Álvarez, Sayas-Barberá, Fernández-López, and Viuda-Martos (2021). Thus, for each type of GE, first the gelling agent was mixed in a homogenizer (Thermomix 31, Vorwerk-España, Spain) with water for 2 min at 60 °C at high speed. Then, the flour was added and mixed for 1 min at medium speed. In the next step, the temperature was turned down to 37 °C and gellan gum was added and mixed for 2.5 min at 250 rpm. In the last step, the mixture was mixed with the gradual addition of the appropriate amount of oil for 5 min, at 37 °C and 1100 rpm. The elaborated GE were placed in metal containers and stored at 4 °C until use. The chemical composition of GE elaborated with amaranth flour and chia oil was 45.76% moisture, 42.82% fats, 2.50% proteins, 8.49% carbohydrates, and 0.43% ashes while the chemical composition of GE elaborated with amaranth flour and hemp oil was 46.07% moisture, 42.56% fats, 2.52% protein, 8.41% carbohydrates, and 0.44% ashes.

### 2.3. Processing of burgers containing gelled emulsions

Burgers (twelve for each formulation) were made according to the traditional formula. This original formula was used as a formula control whereas the other four formulations, where different proportions of pork backfat (25 or 50%) fat (50 or 100%) were replaced by gelled emulsion made with amaranth flour and chia oil (BCh) or amaranth flour and hemp oil (BH), were elaborated as shown in Table 1.

Beef burgers were elaborated following the procedure described by Botella-Martinez et al., (2021). Beef meat and pork backfat were ground through 8 mm plate in a mincer. Then the mixer, water, salt and pepper were added into a bowl and mixed with the spiral dough hook at 80 rpm for 5 min. For each formulation, the corresponding proportions of fat (25% or 50%) were replaced by gelled emulsion elaborated with amaranth/chia oil or gelled emulsion elaborated with amaranth/hemp oil and mixed again for 5 min. The samples were shaped using a commercial burger maker to obtain burgers of approximately 1 cm thickness and 80 g. Burgers were packed into bags and storage at 4 °C until analysis (Raw burgers). Six burgers from each formulation were cooked in a griddle until reaching an internal temperature of 72 °C, approximately 4 min for each side (Cooked burgers).

### 2.4. Evaluation of beef burgers

#### 2.4.1. Proximate analysis

Proximate analysis (moisture, protein, fat and ash content) were evaluated by AOAC (2010) in raw and cooked burgers.

#### 2.4.2. Lipid profile and nutritional parameters

Lipid extraction from the samples was conducted according to Folch, Less and Sloane (1957). The lipid phase was methylated according to method 969.33 of AOAC (2010). The fatty acids methylated (FAMEs) were determined according to the chromatographic conditions described by Pellegrini et al. (2018). Results were expressed as g fatty acid/100 g of fat.

Using equations developed by Ulbricht and Southgate (1991), the atherogenic index (AI) and thrombogenic index (TI) were calculated (Eq. (1) and Eq. (2)), respectively.

$$AI = \frac{C12:0 + (4xC14:0) + C16:0}{\sum MUFA + \sum n-6 + \sum n-3} \tag{1}$$

$$TI = \frac{C14:0 + C16:0 + C18:0}{(0,5x\sum MUFA) + (0,5x\sum n-6) + (3x\sum n-3) + \left(\frac{\sum n-3}{\sum n-6}\right)} \tag{2}$$

The hypocholesterolemic/hypercholesterolemic ratio (h/H) was calculated using equation (3), as described by Fernández et al. (2007).

$$h/H = \frac{C18:1n9 + C18:1n7 + \sum PUFA}{C14:0 + C16:0} \tag{3}$$

#### 2.4.3. Physicochemical properties

The pH values of raw and cooked burgers were measured using a penetration probe, at different sites of the sample, connected to a pH-meter Crison model 510 (Barcelona, Spain).

The water activity ($a_w$) was measured in raw burgers using an

**Table 1**
Formulation of beef burgers burgers reformulated with both amaranth-chia oil (BCh) or amaranth-hemp oil (BH) gelled emulsion used as partial animal fat replacers.

| | Treatments (%) | | | | |
|---|---|---|---|---|---|
| | CS | BCh25 | BCh50 | BH25 | BH50 |
| **Beef** | 80 | 80 | 80 | 80 | 80 |
| **Pork backfat** | 20 | 15 | 10 | 5 | 10 |
| **Water** | 5 | 5 | 5 | 5 | 5 |
| **Salt** | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 |
| **White pepper** | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| **GECW** | 0 | 5 | 10 | 5 | 10 |

Percentages of non-meat ingredients are related to 100% meat. CS: control sample. GECW: gelled emulsion elaborated with cocoa bean shell flour and walnut oil.

electrolytic hygrometer (Novasina TH-500, Novasina, Pfaeffikon, Switzerland) at 25 °C.

Texture profile analysis- TPA was performed in cooked beef burgers samples using a TA-XT2i Texture Analyzer (Stable Micro Systems, Surrey, England). Samples of 1 $cm^3$ were submitted to two-cycle compression to 75% at a constant velocity of 1 mm/s at room temperature. The parameters calculated were: Hardness (N) springiness (mm), cohesiveness, and chewiness (N x mm) (Claus, 1995).

Color measurements were performed using a CM-700 spectrophotometer (Minolta Camera Co., Osaka, Japan) with illuminant D65, observer angle 10°, SCI mode and a low reflectance glass placed between surface of samples and the equipment. For Color assessment, the CIE-L*a*b* color coordinates determined were: lightness (L*), red/green coordinate (a*) and yellow/blue coordinate (b*). The psychophysical magnitudes hue (h*) and chrome (C*) were calculated with equations (4) and (5), respectively, in both raw and cooked burgers.

$$C^* = \sqrt{a^{*2} + b^{*2}} \tag{4}$$

$$h^* = arctg(b^* / a^*) \tag{5}$$

Total color differences ($\Delta E$) of each sample reformulate with respect to control burger (BC) were also calculated with equation (6).

$$\Delta E = \sqrt{\left(L_S^* - L_{CON}^*\right)^2 + \left(a_S^* - a_{CON}^*\right)^2 + \left(b_S^* - b_{CON}^*\right)^2} \tag{6}$$

### 2.4.4. Cooking characteristics

The weight, thickness, and diameter of the beef burgers from each batch were measured at room temperature before and after cooking. To estimate the dimensional changes, the shrinkage and the thickness increases were calculated with equations (7) and (8).

$$\%\ Thickness\ increase = \frac{cooked\ thickness - raw\ thickness}{cooked\ thickness}\ x100 \tag{7}$$

$$\%\ Shrinkage = \frac{raw\ diameter - cooked\ diameter}{raw\ diameter}\ x100 \tag{8}$$

The cooking loss was calculated according to equation (9):

$$\%\ Cooking\ loss = \frac{raw\ weight - cooked\ weight}{raw\ weight}\ x100 \tag{9}$$

### 2.4.5. Lipid oxidation

The Thiobarbituric Acid Reactive substances (TBARs) values were determined according to Rosmini et al. (1996) in both, raw and cooked samples. Results, expressed as mg malondialdehyde (MDA)/kg sample.

### 2.4.6. Sensory analysis

The sensory evaluation was carried out in a sensory analysis laboratory of Miguel Hernández University (Orihuela, Spain). The sensory panel was formed by 37 members, from the staff and students. Five samples from each formulation were shown to panellist to evaluate the raw burger attributes and later the samples were cooked in a griddle and submitted on pieces of 2 $cm^3$ approximately. The sensory analysis scheme was developed for raw samples with a hedonic scale of 9 levels: color intensity (1: extremely light and 9: extremely dark), for rancid aroma (1: imperceptible and 9: extremely rancid), and visual aspect (1: dislike extremely and 9: like extremely). In the case of cooked samples, the following attributes: general acceptability, juiciness, chewiness, fat sensation and graininess, were evaluated with a hedonic scale of 9 levels being 1: dislike extremely and 9: like extremely:

## 2.5. Statistical analysis

The full process (gelled emulsion elaboration and burger manufacture) was replicated three times (three independent batches). Each replication was done on a different production day and each batch was analyzed in triplicate. Data were evaluated by one-way analysis of variance (ANOVA) and Tukey-b post-hoc test was performed at 5% significance level ($p < 0.05$) using SPSS software (version 24.0, SPSS Inc., Chicago, USA). Means and standard deviations of data are shown in corresponding tables and figures.

# 3. Results and discussion

## 3.1. Proximate composition of beef burgers

Table 2 showed the proximal composition of raw and cooked beef burgers reformulated with either amaranth-chia oil or amaranth-hemp oil gelled emulsion used as partial animal fat replacers.

In raw burger, the effect of replacing animal fat with GEs did not cause any effect ($p > 0.05$) on ash and protein content. However, the moisture values increased while the fat values decreased ($p < 0.05$) in beef burgers containing GEs, compared to control ones. The increase in moisture content was due to the water added to prepare the GEs. The same finding has been reported by several authors when used GEs as animal fat replacers in meat products (Lucas-González et al., 2020; Botella-Martínez, Viuda-Martos, Pérez-Álvarez, & Fernández-López, 2021). The reduction in fat content when the animal fat was replaced by the GEs was not influenced by the type of GE used ($p > 0.05$) but occur in a concentration-dependent manner ($p < 0.05$). When both GEs were used at 25% of fat substitution in burgers, the level of fat reduction achieved was 12%, while GEs were used at 50% of fat substitution, the level of reduction increased until 33% compared to control burgers, without differences between gelled emulsion elaborated with chia oil (GCh) and gelled emulsion elaborated with hemp oil (GH). This behavior was also observed by several authors (Alejandre et al., 2017; Barros et al., 2020; Lucas-González et al., 2020). Thus, Lucas-González et al. (2020) who replaced animal fat with chia-chestnut gelled emulsion (5 and 10%) in pork burgers reported a reduction of the fat content when

**Table 2**
Proximate composition of raw and cooked beef burgers reformulated with both amaranth-chia oil or amaranth-hemp oil gelled emulsion used as partial animal fat replacers.

| | Sample | Protein | Fat | Ash | Moisture |
|---|---|---|---|---|---|
| Raw | BC | 17.47 ± 1.78$^a$ | 14.46 ± 0.65$^a$ | 2.33 ± 0.20$^a$ | 62.39 ± 2.52$^b$ |
| | BCh25 | 18.63 ± 0.36$^a$ | 12.71 ± 5.96$^b$ | 2.24 ± 0.20$^a$ | 65.47 ± 2.48$^a$ |
| | BCh50 | 18.06 ± 0.04$^a$ | 9.18 ± 0.73$^c$ | 2.38 ± 0.03$^a$ | 65.90 ± 0.34$^a$ |
| | BH25 | 18.43 ± 0.28$^a$ | 12.64 ± 1.01$^b$ | 2.22 ± 0.02$^a$ | 65.08 ± 0.89$^a$ |
| | BH50 | 18.50 ± 1.41$^a$ | 9.91 ± 0.49$^c$ | 2.27 ± 0.04$^a$ | 65.72 ± 0.64$^a$ |
| Cooked | BC | 23.98 ± 0.06$^v$ | 16.13 ± 0.16$^v$ | 2.79 ± 0.07$^v$ | 55.90 ± 0.23$^v$ |
| | BCh25 | 24.42 ± 0.07$^v$ | 13.51 ± 0.44$^w$ | 2.77 ± 0.01$^v$ | 57.70 ± 0.20$^w$ |
| | BCh50 | 24.45 ± 0.51$^v$ | 9.32 ± 0.32$^x$ | 2.82 ± 0.02$^v$ | 57.68 ± 0.00$^w$ |
| | BH25 | 24.43 ± 0.12$^v$ | 13.81 ± 0.68$^w$ | 2.84 ± 0.05$^v$ | 57.17 ± 0.29$^w$ |
| | BH50 | 25.05 ± 0.52$^v$ | 10.05 ± 0.38$^x$ | 2.73 ± 0.03$^v$ | 57.41 ± 0.15$^w$ |

Values expressed in g/100 g of sample. For each parameter, results followed by same letter are not significantly different according to Tukey's HSD post-hoc test ($p > 0.05$). Data are presented as mean ± standard deviation.
BC: control burgers with a traditional formula; BCh25: sample with 25% animal fat replaced by GE with chia oil and amaranth flour; BCh50: sample with 50% animal fat replaced by GE with chia oil and amaranth flour. BH25: sample with 25% animal fat replaced by GE with hemp oil and amaranth flour as fat replacer. BH50: sample with 50% animal fat replaced by GE with hemp oil and amaranth flour. A lower-case letter refers to the comparison of the same parameter between the different raw samples (a-e) and for cooked samples (v-z).

substitution level increased. Similarly, Regarding nutritional claims, only burgers with the highest GEs substitution level (BCh50 and Bh50) can be considered as “reduced fat content” (at least 30% reduction compared to the original product (European Parliament, 2006).

In cooked burger, again no statistical differences ($p > 0.05$) were found among the control sample and reformulated samples for protein and ash content while in the case of fat and moisture content the same behavior than raw burger was observed.

### 3.2. Fatty acids profile and health parameters of beef burgers

#### 3.2.1. Fatty acids profile

Table 3 shows the fatty acids profile of beef burgers (raw and cooked). Regarding raw burgers, as expected, significant differences ($p < 0.05$) were detected in the fatty acid profile of burgers depending on both, the type of fat used (animal fat, GCh or GH) and the level of pork fat replacement (25 or 50%). From the total of fatty acids identified in control burgers, oleic (C18:1), palmitic (C16:0), linoleic (C18:2), stearic (C18:0), and palmitoleic (C16:1) fatty acids make up 91% of total fatty acids. To reach this level, in the case of reformulated burgers, the contribution of the α-linolenic fatty acid (C18:3) must be considered. In general, it could say that the use of GE as partial animal fat replacer in burgers decreased the amount of palmitic (C16:0), stearic (C18:0) and oleic (C18:1) fatty acids and increased the amount of linolenic (C18:2) and α-linolenic (C18:3) fatty acids ($p < 0.05$). The most evident difference between burgers due to the type of GE used was the amount of linolenic (C18:2) and α-linolenic (C18:3) fatty acids. Burgers with amaranth-chia GE showed the highest amount of α-linolenic (C18:3) fatty acid while burgers with amaranth-hemp GE showed the highest ($p < 0.05$) amount of linolenic (C18:2) fatty acid. This is in accordance with the fatty acid composition of the corresponding vegetable oils. According to European Association, raw and cooked BCh50 and cooked BCh25 could be labeled with the nutritional claim as “high n-3 fatty acids”, since they contained more than 0.6 g α-linolenic acid per 100 g of the product (European Parliament, 2006).

For the cooked samples, the trend is very similar regarding the influence of the percentage of substitution and the gelled emulsion used. Some small variations in the values and so in the statistical significance in cooked sample respect to obtained in raw samples could be attributed to the loss of fat and water during cooking. Among the saturated fatty acids (SFA), in all burgers, the largest proportions ($p < 0.05$) were palmitic (C16:0), stearic (C18:0), and myristic (C14:0) fatty acids. The replacement of animal fat by GE in burgers decreased the SFA content ($p < 0.05$) depending on both, the substitution level (higher decrease at 50% substitution level) and type of GE used (higher decrease when amaranth-hemp oil GE was used). This fact has also been reported by other authors in the case of replacement of animal fat by vegetable or marine oils in several meat products (Domínguez et al., 2017; Heck et al., 2019; Pires, dos Santos, Barros, & Trindade, 2019; Tarté et al., 2020; Vargas-Ramella et al., 2020). Control burgers (raw and cooked) showed the highest amount of SFA, (35.89% and 36.20% respectively), therefore BH50 (raw and cooked) showed the lowest, with a decrease of 17% and 12.5% respectively, with respect to control ones.

In the case of monounsaturated fatty acid (MUFA) content, a reduction was also reported due to the use of GE, showing control samples (raw and cooked) the highest content ($p < 0.05$). It is important to notice that MUFA was the predominant fraction in all burgers (raw and cooked) being oleic acid (C18:1) the predominant. On the contrary, polyunsaturated fatty acid (PUFA) fraction increased in reformulated burgers, compared to control ones, being this increase higher at higher GE replacement level and also when amaranth-hemp GE was used ($p < 0.05$). Linoleic (C18:2) and α-linolenic (C18:3) fatty acids are responsible (in a high way) for this increase.

#### 3.2.2. Health indices of burgers

Table 4 shows the health indices of cooked beef burgers (control and reformulated burgers). In relation to the PUFA/SFA ratio, it is observed an increase when animal fat is replaced by GE, due to both, the decrease in SFA and the increase in PUFA contents. This increase depends on both, substitution level (higher at 50% than at 25% replacement level) and type of GE (higher when amaranth-hemp GE was used) ($p < 0.05$). All reformulated burgers are in accordance with the recommendations of the PUFA/SFA ratio that should be above than 0.4 (Wood et al., 2008). Regarding the n-6/n-3 index, all reformulated burgers, except BH25 are in accordance with the recommended value which must be less than 4 (Simopoulos, 2004). As can be seen in Table 4, this index was widely improved (decreased) ($p < 0.05$) by the use of GE with respect to control burgers.

The indices TI, AI and h/H have been proposed as good indicators of healthy food products and have been widely calculated and discussed to address the healthy characteristics of fats in meat products (Botella-Martínez, Lucas-González, et al., 2021; de Souza-de Souza Paglarini et al., 2019; Pintado et al., 2015). Regarding that, TI and AI should be as low as possible and h/H ratio the other way around, as higher as possible. In view of that, the influence of pork back fat replacement by GE in burgers was positive considering that TI and AI indices decreased ($p < 0.05$) and h/H ratio increased ($p < 0.05$). All these changes observed are directly related to the percentage of pork backfat replace: the most positive values in the three indices were shown in burgers with 50% substitution (BCh50 and BH50). Several authors have used these indices to highlight the healthy properties of using vegetable oils (added in different ways) in substitution of animal fats in meat products (Barros et al., 2021; Botella-Martínez, Lucas-González, et al., 2021; Pires et al., 2019).

### 3.3. Physicochemical characteristics of beef burgers

The physicochemical properties of raw and cooked beef burgers formulated with amaranth flour and chia or hemp oil gelled emulsions as partial pork backfat replacers were shown in Table 5. Regarding raw burgers, the main values of pH and Aw were not affected ($p > 0.05$) by addition of GEs in burgers as partial substitute of pork backfat. Similarly, Lucas-González et al. (2020) found no differences on pH and Aw values in burgers when emulsion gels formulated with chestnut flour and chia oil were used as a substitute of pork backfat. Lightness (L*), yellowness (b*) and hue (h*) of burgers were not influenced ($p > 0.05$) by the used of gelled emulsions. Quite the opposite, redness (a*) and chroma (C*) were significantly affected by this replacement although their variation was not quantitatively relevant. In fact, redness values ranged from 4.06 (control burger) to 5.72 (BCh25). Similarly, Barros et al. (2021) found no differences in the color parameters of the beef burgers added with oil emulsions. On the contrary, several authors (Lucas-González et al., 2020; de Souza-de Souza Paglarini et al., 2019; Barros et al., 2020) reported that the addition of gelled emulsions, in different meat products, were able to affect all color parameters. All these differences could be due to the different oil characteristics and composition, as well as the emulsion properties and the rest of ingredients used in the meat product formulation. In addition, taking into account that color differences (ΔE*) lower than 3 units cannot be detected by human eye (Martínez, Melgosa, Pérez, Hita, & Negueruela, 2001), only burgers formulated with gelled emulsion elaborated with chia oil as partial fat replacement (BCh25 and BCh50) could be detected as different from control burgers.

In reference to cooked burgers, the cooking process resulted in a slight pH increase (ranging from 6.27 to 6.38) respect to the corresponding raw samples, but without differences ($p > 0.05$) between samples.

As regards to color properties, during heating of meat products several reactions occur, including the Maillard reaction, protein denaturation, and fat and water loss and these reactions are responsible for color and taste development of cooked products (Fennema, Damodaran, & Parkin, 2017). In this case, some of the color changes detected in raw burgers due to the addition of gelled emulsions have not been noted after

**Table 3**
Lipid profile of raw and cooked beef burgers reformulated with both amaranth/chia oil or amaranth/hemp oil gelled emulsion used as partial animal fat replacers.

| | Raw | | | | | Cooked | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *% Fatty acids* | BC | BCh25 | BCh50 | BH25 | BH50 | BC | BCh25 | BCh50 | BH25 | BH50 |
| *C10:0* | 0.05 ± 0.00$^{aM}$ | 0.05 ± 0.00$^{aM}$ | 0.04 ± 0.00$^{bJ}$ | 0.05 ± 0.00$^{aH}$ | 0.04 ± 0.00$^{bK}$ | 0.05 ± 0.00$^{vJ}$ | 0.05 ± 0.00$^{vL}$ | 0.04 ± 0.00$^{wK}$ | 0.05 ± 0.00$^{vM}$ | 0.04 ± 0.00$^{wN}$ |
| *C12:0* | 0.05 ± 0.00$^{bM}$ | 0.06 ± 0.00$^{aM}$ | 0.05 ± 0.00$^{bJ}$ | 0.05 ± 0.00$^{bH}$ | 0.05 ± 0.00$^{bK}$ | 0.06 ± 0.00$^{vJ}$ | 0.05 ± 0.00$^{wL}$ | 0.05 ± 0.00$^{wK}$ | 0.05 ± 0.00$^{wM}$ | 0.05 ± 0.00$^{wN}$ |
| *C14:0* | 1.16 ± 0.03$^{aE}$ | 1.09 ± 0.02$^{bG}$ | 0.93 ± 0.04$^{eF}$ | 1.02 ± 0.02$^{cD}$ | 0.96 ± 0.03$^{dF}$ | 1.17 ± 0.07$^{vD}$ | 1.09 ± 0.06$^{wE}$ | 1.03 ± 0.02$^{xD}$ | 1.09 ± 0.03$^{wF}$ | 1.03 ± 0.09$^{xG}$ |
| *C4:1 cis* | 0.05 ± 0.00$^{bM}$ | 0.05 ± 0.00$^{bM}$ | 0.03 ± 0.00$^{cJ}$ | 0.03 ± 0.00$^{cH}$ | 0.07 ± 0.00$^{aJ}$ | 0.05 ± 0.00$^{wJ}$ | 0.02 ± 0.00$^{yH}$ | 0.04 ± 0.00$^{xK}$ | 0.04 ± 0.00$^{xM}$ | 0.08 ± 0.00$^{vM}$ |
| *C15:0* | 0.09 ± 0.00$^{cL}$ | 0.10 ± 0.02$^{bL}$ | 0.08 ± 0.00$^{dI}$ | 0.08 ± 0.00$^{dG}$ | 0.13 ± 0.02$^{aI}$ | 0.10 ± 0.02$^{xI}$ | 0.11 ± 0.02$^{wJ}$ | 0.14 ± 0.02$^{vI}$ | 0.11 ± 0.02$^{wL}$ | 0.14 ± 0.02$^{vK}$ |
| *C15:1* | 0.08 ± 0.00$^{cL}$ | 0.10 ± 0.03$^{bL}$ | 0.02 ± 0.00$^{dJ}$ | 0.02 ± 0.00$^{dH}$ | 0.16 ± 0.07$^{aI}$ | 0.03 ± 0.00$^{zK}$ | 0.17 ± 0.02$^{xI}$ | 0.12 ± 0.05$^{yI}$ | 0.18 ± 0.02$^{wK}$ | 0.19 ± 0.01$^{vK}$ |
| *C16:0* | 21.86 ± 0.08$^{aB}$ | 20.68 ± 0.04$^{bB}$ | 18.83 ± 0.02$^{dB}$ | 19.95 ± 0.10$^{cB}$ | 17.47 ± 0.11$^{eB}$ | 21.86 ± 0.05$^{vB}$ | 20.50 ± 0.07$^{wB}$ | 19.04 ± 0.03$^{xB}$ | 20.39 ± 0.11$^{wB}$ | 18.46 ± 0.08$^{yC}$ |
| *C16:1 trans* | 0.48 ± 0.03$^{aH}$ | 0.43 ± 0.07$^{bJ}$ | 0.38 ± 0.02$^{dH}$ | 0.41 ± 0.05$^{cE}$ | 0.31 ± 0.02$^{eH}$ | 0.46 ± 0.00$^{vG}$ | 0.41 ± 0.00$^{wGH}$ | 0.35 ± 0.00$^{yG}$ | 0.40 ± 0.00$^{xI}$ | 0.32 ± 0.00$^{zJ}$ |
| *C16:1 cis* | 2.07 ± 0.02$^{aD}$ | 1.95 ± 0.04$^{bF}$ | 1.66 ± 0.09$^{dE}$ | 1.78 ± 0.12$^{cD}$ | 1.51 ± 0.07$^{eE}$ | 2.04 ± 0.02$^{vD}$ | 1.80 ± 0.02$^{xE}$ | 1.67 ± 0.02$^{yD}$ | 1.89 ± 0.02$^{wF}$ | 1.63 ± 0.02$^{eF}$ |
| *C17:0* | 0.39 ± 0.02$^{abI}$ | 0.37 ± 0.01$^{abJ}$ | 0.32 ± 0.01$^{bH}$ | 0.34 ± 0.02$^{abF}$ | 0.40 ± 0.01$^{aG}$ | 0.41 ± 0.00$^{x}$ | 0.40 ± 0.00$^{yG}$ | 0.43 ± 0.00$^{vF}$ | 0.40 ± 0.00$^{yI}$ | 0.42 ± 0.00$^{wI}$ |
| *C17:1* | 0.35 ± 0.01$^{aI}$ | 0.34 ± 0.01$^{bJ}$ | 0.28 ± 0.01$^{dH}$ | 0.31 ± 0.01$^{cF}$ | 0.28 ± 0.01$^{dH}$ | 0.35 ± 0.01$^{vH}$ | 0.32 ± 0.01$^{xH}$ | 0.32 ± 0.01$^{xG}$ | 0.33 ± 0.01$^{wJ}$ | 0.30 ± 0.01$^{yJ}$ |
| *C18:0* | 12.44 ± 0.02$^{aC}$ | 11.36 ± 0.06$^{bD}$ | 10.22 ± 0.01$^{dD}$ | 10.55 ± 0.02$^{cC}$ | 10.25 ± 0.06$^{dC}$ | 12.12 ± 0.00$^{vC}$ | 12.04 ± 0.00$^{vwC}$ | 11.30 ± 0.00$^{xC}$ | 11.49 ± 0.00$^{wxD}$ | 10.92 ± 0.00$^{wD}$ |
| *C18:1cis* | 43.15 ± 0.09$^{aA}$ | 42.89 ± 0.08$^{bA}$ | 38.40 ± 0.07$^{dA}$ | 40.07 ± 0.10$^{cA}$ | 32.55 ± 0.11$^{eA}$ | 45.22 ± 0.02$^{vA}$ | 40.07 ± 0.02$^{xA}$ | 37.15 ± 0.01$^{yA}$ | 41.97 ± 0.01$^{wA}$ | 35.82 ± 0.01$^{zA}$ |
| *C18:2 (n-6)* | 12.59 ± 0.02$^{dC}$ | 12.63 ± 0.04$^{dC}$ | 13.60 ± 0.02$^{cC}$ | 17.39 ± 0.06$^{bB}$ | 23.72 ± 0.08$^{aB}$ | 12.15 ± 0.01$^{zC}$ | 12.51 ± 0.02$^{vyC}$ | 12.94 ± 0.09$^{xC}$ | 15.68 ± 0.12$^{wC}$ | 21.32 ± 0.02$^{vB}$ |
| *C18:2 (n-3)* | 0.07 ± 0.00$^{cM}$ | 0.07 ± 0.00$^{cM}$ | 0.06 ± 0.00$^{cJ}$ | 0.55 ± 0.01$^{bE}$ | 1.26 ± 0.02$^{aE}$ | 0.07 ± 0.00$^{xJ}$ | 0.07 ± 0.00$^{xK}$ | 0.08 ± 0.00$^{xK}$ | 0.41 ± 0.02$^{wI}$ | 1.06 ± 0.02$^{vG}$ |
| *C18:3 (n-3)* | 0.67 ± 0.02$^{eG}$ | 3.89 ± 0.02$^{cE}$ | 8.62 ± 0.02$^{aE}$ | 2.83 ± 0.02$^{dD}$ | 5.92 ± 0.02$^{bD}$ | 0.70 ± 0.02$^{zE}$ | 5.67 ± 0.03$^{wD}$ | 12.79 ± 0.04$^{vC}$ | 2.36 ± 0.02$^{yE}$ | 5.08 ± 0.03$^{xE}$ |
| *C18:3 (n-6)* | 0.11 ± 0.00$^{dK}$ | 0.13 ± 0.01$^{cL}$ | 0.09 ± 0.00$^{eI}$ | 0.17 ± 0.01$^{bF}$ | 0.43 ± 0.01$^{aG}$ | 0.13 ± 0.00$^{wI}$ | 0.14 ± 0.00$^{vI}$ | 0.14 ± 0.00$^{vI}$ | 0.13 ± 0.00$^{w}$ | 0.14 ± 0.00$^{vK}$ |
| *C20:0* | 0.21 ± 0.00$^{eJ}$ | 0.22 ± 0.00$^{dK}$ | 0.23 ± 0.00$^{cH}$ | 0.31 ± 0.00$^{bF}$ | 0.45 ± 0.01$^{aG}$ | 0.23 ± 0.02$^{yH}$ | 0.24 ± 0.02$^{yH}$ | 0.24 ± 0.02$^{xH}$ | 0.29 ± 0.02$^{wJ}$ | 0.40 ± 0.02$^{vI}$ |
| *C20:1* | 0.96 ± 0.01$^{bF}$ | 0.96 ± 0.01$^{bH}$ | 0.89 ± 0.01$^{cE}$ | 0.99 ± 0.01$^{aD}$ | 0.72 ± 0.01$^{dF}$ | 1.05 ± 0.01$^{vD}$ | 0.85 ± 0.01$^{wF}$ | 0.67 ± 0.01$^{yE}$ | 0.87 ± 0.01$^{wG}$ | 0.77 ± 0.01$^{xH}$ |
| *C20:2 (n-11)* | 0.60 ± 0.01$^{aG}$ | 0.59 ± 0.01$^{abI}$ | 0.53 ± 0.01$^{cG}$ | 0.58 ± 0.01$^{bE}$ | 0.43 ± 0.01$^{dG}$ | 0.58 ± 0.01$^{vF}$ | 0.53 ± 0.01$^{wG}$ | 0.41 ± 0.01$^{xF}$ | 0.54 ± 0.01$^{wH}$ | 0.41 ± 0.01$^{xI}$ |
| *C20:3 (n-8)* | 0.12 ± 0.01$^{aK}$ | 0.14 ± 0.01$^{aL}$ | 0.10 ± 0.01$^{bI}$ | 0.11 ± 0.01$^{bG}$ | 0.13 ± 0.01$^{aI}$ | 0.13 ± 0.00$^{xI}$ | 0.15 ± 0.00$^{vI}$ | 0.13 ± 0.00$^{xI}$ | 0.15 ± 0.00$^{vK}$ | 0.14 ± 0.00$^{wK}$ |
| *C20:3 (n-11)* | 0.30 ± 0.01$^{bI}$ | 0.40 ± 0.01$^{aJ}$ | 0.29 ± 0.01$^{cH}$ | 0.29 ± 0.01$^{cF}$ | 0.40 ± 0.01$^{aG}$ | 0.39 ± 0.02$^{yG}$ | 0.48 ± 0.02$^{vG}$ | 0.41 ± 0.02$^{xF}$ | 0.48 ± 0.02$^{vH}$ | 0.46 ± 0.02$^{wI}$ |
| *C20:4* | 0.09 ± 0.01$^{abL}$ | 0.10 ± 0.01$^{aL}$ | 0.09 ± 0.01$^{abI}$ | 0.09 ± 0.00$^{bG}$ | 0.08 ± 0.00$^{cJ}$ | 0.09 ± 0.00$^{vI}$ | 0.09 ± 0.00$^{vJ}$ | 0.06 ± 0.00$^{yJ}$ | 0.08 ± 0.00$^{wL}$ | 0.07 ± 0.00$^{xM}$ |
| *C20:5* | 0.01 ± 0.00$^{eN}$ | 0.02 ± 0.00$^{dN}$ | 0.03 ± 0.00$^{cJ}$ | 0.06 ± 0.00$^{bG}$ | 0.14 ± 0.02$^{aI}$ | 0.02 ± 0.00$^{yK}$ | 0.03 ± 0.00$^{xL}$ | 0.06 ± 0.00$^{wJ}$ | 0.06 ± 0.00$^{wM}$ | 0.11 ± 0.00$^{vL}$ |
| *C23:0* | 0.15 ± 0.02$^{aK}$ | 0.10 ± 0.02$^{bL}$ | 0.08 ± 0.00$^{cI}$ | 0.08 ± 0.00$^{cG}$ | 0.07 ± 0.00$^{dJ}$ | 0.10 ± 0.00$^{wI}$ | 0.11 ± 0.00$^{vJ}$ | 0.08 ± 0.00$^{xJ}$ | 0.10 ± 0.00$^{wL}$ | 0.08 ± 0.00$^{xM}$ |
| *C 24:0* | 0.10 ± 0.02$^{aKL}$ | 0.09 ± 0.02$^{bL}$ | 0.07 ± 0.00$^{dI}$ | 0.07 ± 0.00$^{dG}$ | 0.08 ± 0.00$^{cJ}$ | 0.09 ± 0.01$^{xI}$ | 0.11 ± 0.00$^{wJ}$ | 0.12 ± 0.00$^{vI}$ | 0.11 ± 0.00$^{wL}$ | 0.11 ± 0.00$^{wL}$ |
| *∑SFA* | 35.89 ± 0.13$^{a}$ | 33.19 ± 0.07$^{b}$ | 30.85 ± 0.03$^{d}$ | 32.50 ± 0.02$^{c}$ | 29.90 ± 0.02$^{e}$ | 36.20 ± 0.03$^{v}$ | 34.71 ± 0.05$^{w}$ | 32.46 ± 0.03$^{y}$ | 34.09 ± 0.01$^{x}$ | 31.65 ± 0.01$^{z}$ |
| *∑MUFA* | 49.51 ± 0.17$^{a}$ | 46.84 ± 0.05$^{b}$ | 41.73 ± 0.07$^{d}$ | 45.44 ± 0.04$^{c}$ | 37.59 ± 0.06$^{e}$ | 49.31 ± 0.10$^{v}$ | 45.38 ± 0.04$^{x}$ | 40.44 ± 0.02$^{y}$ | 45.80 ± 0.08$^{w}$ | 39.23 ± 0.07$^{z}$ |
| *∑PUFA* | 14.56 ± 0.17$^{e}$ | 17.96 ± 0.06$^{d}$ | 27.41 ± 0.08$^{b}$ | 22.07 ± 0.03$^{c}$ | 32.52 ± 0.06$^{a}$ | 14.28 ± 0.01$^{y}$ | 19.67 ± 0.16$^{x}$ | 27.03 ± 0.08$^{w}$ | 19.89 ± 0.13$^{x}$ | 28.80 ± 0.06$^{v}$ |
| *∑n3* | 0.74 ± 0.04$^{e}$ | 3.96 ± 0.03$^{c}$ | 12.68 ± 0.06$^{a}$ | 3.39 ± 0.02$^{d}$ | 7.18 ± 0.03$^{b}$ | 0.77 ± 0.04$^{z}$ | 5.75 ± 0.05$^{x}$ | 12.87 ± 0.08$^{v}$ | 2.78 ± 0.02$^{y}$ | 6.14 ± 0.02$^{w}$ |
| *∑n6* | 12.69 ± 0.02$^{d}$ | 12.76 ± 0.05$^{d}$ | 13.69 ± 0.03$^{c}$ | 17.56 ± 0.02$^{b}$ | 24.16 ± 0.05$^{a}$ | 12.28 ± 0.02$^{y}$ | 12.65 ± 0.03$^{y}$ | 13.08 ± 0.04$^{x}$ | 15.81 ± 0.02$^{w}$ | 21.47 ± 0.06$^{v}$ |

Results are expressed as g/100g. Data are presented as mean ± standard deviation. BC: control burgers with a traditional formula; BCh25: sample with 25% animal fat replaced by GE with chia oil and amaranth flour; BCh50: sample with 50% animal fat replaced by GE with chia oil and amaranth flour. BH25: sample with 25% animal fat replaced by GE with hemp oil and amaranth flour as fat replacer. BH50: sample with 50% animal fat replaced by GE with hemp oil and amaranth flour. SFA: saturated fatty acids; UFA: unsaturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: Polyunsaturated fatty acids. For each parameter, results followedby same letter are not significantly different according to Tukey's HSD post-hoc test ($p > 0.05$). A lower-case letters refers to the comparison of the same fatty acid or parameters between the different raw samples (a-e) and for cooked samples (v-z), while an upper-case letter (A-N) refers to the comparison of the different fatty acids in the same sample.

**Table 4**
Health indices cooked beef burgers reformulated with both amaranth/chia oil or amaranth/hemp oil gelled emulsion used as partial animal fat replacers.

| Sample | ∑PUFA/∑SFA | n6/n3 | AI | TI | h/H |
|---|---|---|---|---|---|
| *BC* | 0.39 ± 0.02$^{x}$ | 15.89 ± 0.04$^{y}$ | 0.43 ± 0.01$^{v}$ | 1.06 ± 0.03$^{v}$ | 2.59 ± 0.02$^{y}$ |
| *BCh25* | 0.57 ± 0.02$^{w}$ | 2.20 ± 0.02$^{x}$ | 0.39 ± 0.01$^{w}$ | 0.72 ± 0.03$^{x}$ | 2.85 ± 0.02$^{x}$ |
| *BCh50* | 0.83 ± 0.04$^{v}$ | 1.02 ± 0.02$^{v}$ | 0.35 ± 0.01$^{x}$ | 0.47 ± 0.02$^{z}$ | 3.20 ± 0.01$^{w}$ |
| *BH25* | 0.58 ± 0.02$^{w}$ | 5.69 ± 0.02$^{w}$ | 0.38 ± 0.01$^{w}$ | 0.84 ± 0.03$^{w}$ | 2.89 ± 0.02$^{x}$ |
| *BH50* | 0.91 ± 0.05$^{v}$ | 3.50 ± 0.04$^{v}$ | 0.34 ± 0.01$^{y}$ | 0.62 ± 0.02$^{y}$ | 3.32 ± 0.01$^{v}$ |

For each parameter, results followed by same letter are not significantly different according to Tukey's HSD post-hoc test ($p > 0.05$). Data were presented as mean ± standard deviation.
BC: control burgers with a traditional formula; BCh25: sample with 25% animal fat replaced by GE with chia oil and amaranth flour; BCh50: sample with 50% animal fat replaced by GE with chia oil and amaranth flour. BH25: sample with 25% animal fat replaced by GE with hemp oil and amaranth flour as fat replacer. BH50: sample with 50% animal fat replaced by GE with hemp oil and amaranth flour. AI:atherogenic index; TI: thrombogenic index; h/H: hypocholesterolemic/hypercholesterolemic index. A lower-case letter refers to the comparison of the same parameter between the different cooked samples (v-z).

cooking. It could be said that cooking has masked these changes, resulting in similar values for all burgers in all color parameters. These results were in agreement than those reported by Lucas-González et al. (2020) and Summo, De Angelis, Difonzo, Caponio, and Pasqualone (2020) who observed that the color differences were higher in raw burger than in cooked burgers where the fat was partially replace by gelled emulsions. It is important to notice that, after cooking, all values for color differences (ΔE*) were lower than 3 units and so they could not be detected by the human eye (Martínez et al., 2001).

The texture properties of cooked burgers were shown in Table 6. There were no significant differences ($p > 0.05$) for hardness, springiness, and chewiness between all samples analyzed. Cohesiveness was the only parameter that significantly varied between samples ($p < 0.05$). Cohesiveness differences were mainly influenced by the fat replacement level (25% or 50%) and not by the type of GE used; the higher the fat replacement level, the lower cohesiveness values. However, it must be noted that burgers with the highest fat substitution levels (BCh50 and BH50) showed cohesiveness values similar to control burgers ($p > 0.05$). This trend could indicate that if these GE were used at higher fat substitution levels, burgers cohesiveness will be expected to be significantly reduced. In the scientific literature, contradictory results have been reported on textural properties, depending on the concentration and types of emulsions used as fat replacers in burgers (Afshari, Hosseini, Khaneghah & Khaksar, 2017; Barros et al., 2021; Cittadini et al., 2021; Heck et al., 2019; Lucas-González et al., 2020). For example, in the study carried out by Cittadini et al. (2021) where 100% of pork fat was replaced by two hydrogels (avocado-algal oil mixed and pumpkin seed-algal oil mixed) in foal burgers, no differences ($p > 0.05$) in hardness or springiness were found compared to control burgers, but cohesiveness and chewiness were significantly reduced ($p < 0.05$). On the contrary, Afshari et al. (2017) reported that the use of an emulsion (canola/olive oil, soy protein, inulin and β-glucan) to replace the animal fat in burgers significantly reduced hardness of samples in comparison with control ones. On the other hand, Alejandre, et a. (2019), de Souza-de Souza Paglarini et al. (2019), Barros et al. (2020) and Vargas-Ramella et al. (2020) informed that there were no differences in textural properties of reformulated meat products with oil emulsions used as fat replacers. These differences could be attributed to the different physicochemical characteristics between animal fat and gelled emulsions and their interaction with meat.

### 3.4. Cooking characteristics

Cooking loss, shrinkage and increase in thickness of beef burgers

**Table 6**
Texture profile (TPA) of cooked beef burgers reformulated with both amaranth/chia oil or amaranth/hemp oil gelled emulsion used as partial animal fat replacers.

| Sample | *Hardness (N)* | *Springiness (mm)* | Cohesiveness | *Chewiness (N* x *mm)* |
|---|---|---|---|---|
| *BC* | 13.00 ± 4.55$^{a}$ | 0.23 ± 0.08$^{a}$ | 0.59 ± 0.15$^{ab}$ | 1.69 ± 0.77$^{a}$ |
| *BCh25* | 11.45 ± 4.23$^{a}$ | 0.22 ± 0.02$^{a}$ | 0.65 ± 0.11$^{a}$ | 1.39 ± 0.91$^{a}$ |
| *BCh50* | 9.40 ± 4.34$^{a}$ | 0.18 ± 0.04$^{a}$ | 0.40 ± 0.03$^{b}$ | 1.15 ± 0.79$^{a}$ |
| *BH25* | 8.71 ± 2.33$^{a}$ | 0.21 ± 0.03$^{a}$ | 0.65 ± 0.10$^{a}$ | 1.16 ± 0.37$^{a}$ |
| *BH50* | 8.36 ± 3.25$^{a}$ | 0.26 ± 0.04$^{a}$ | 0.47 ± 0.06$^{ab}$ | 1.02 ± 0.65$^{a}$ |

For each parameter, results followed by same letter are not significantly different according to Tukey's HSD post-hoc test ($p > 0.05$).
Data are presented as mean ± standard deviation.
BC: control burgers with a traditional formula; BCh25: sample with 25% animal fat replaced by GE with chia oil and amaranth flour; BCh50: sample with 50% animal fat replaced by GE with chia oil and amaranth flour. BH25: sample with 25% animal fat replaced by GE with hemp oil and amaranth flour as fat replacer. BH50: sample with 50% animal fat replaced by GE with hemp oil and amaranth flour.

**Table 5**
Physico-chemical parameters of raw and cooked beef burgers reformulated with both amaranth/chia oil or amaranth/hemp oil gelled emulsion used as partial animal fat replacers.

| | Sample | pH | Aw | L* | a* | b* | C* | h | ΔE |
|---|---|---|---|---|---|---|---|---|---|
| *Raw* | BC | 6.20 ± 0.03$^{a}$ | 0.887 ± 0.01$^{a}$ | 47.38 ± 4.29$^{a}$ | 4.06 ± 1.40$^{b}$ | 7.76 ± 1.87$^{a}$ | 8.90 ± 1.75$^{b}$ | 61.85 ± 9.27$^{a}$ | – |
| | BCh25 | 6.15 ± 0.03$^{a}$ | 0.889 ± 0.01$^{a}$ | 47.53 ± 2.73$^{a}$ | 5.72 ± 1.23$^{a}$ | 9.08 ± 1.87$^{a}$ | 10.81 ± 1.81$^{a}$ | 57.45 ± 6.72$^{a}$ | 3.60 ± 2.02 |
| | BCh50 | 6.18 ± 0.03$^{a}$ | 0.889 ± 0.01$^{a}$ | 47.06 ± 3.86$^{a}$ | 5.10 ± 1.27$^{ab}$ | 8.69 ± 1.41$^{a}$ | 10.17 ± 1.32$^{ab}$ | 59.43 ± 7.41$^{a}$ | 4.01 ± 2.11 |
| | BH25 | 6.16 ± 0.03$^{a}$ | 0.888 ± 0.00$^{a}$ | 46.55 ± 1.91$^{a}$ | 5.17 ± 1.14$^{ab}$ | 8.95 ± 1.21$^{a}$ | 10.36 ± 1.53$^{ab}$ | 60.30 ± 3.84$^{a}$ | 2.95 ± 1.02 |
| | BH50 | 6.17 ± 0.03$^{a}$ | 0.889 ± 0.00$^{a}$ | 47.83 ± 2.36$^{a}$ | 4.36 ± 0.73$^{ab}$ | 9.41 ± 1.40$^{a}$ | 10.41 ± 1.31$^{ab}$ | 64.87 ± 4.64$^{a}$ | 2.79 ± 1.82 |
| *Cooked* | BC | 6.38 ± 0.02$^{v}$ | – | 44.17 ± 1.78$^{v}$ | 3.96 ± 0.52$^{v}$ | 9.06 ± 0.98$^{v}$ | 10.01 ± 0.98$^{v}$ | 65.82 ± 2.9$^{v}$ | – |
| | BCh25 | 6.33 ± 0.02$^{v}$ | – | 43.02 ± 3.13$^{v}$ | 4.19 ± 1.06$^{v}$ | 8.64 ± 1.26$^{v}$ | 9.90 ± 1.53$^{v}$ | 65.11 ± 3.42$^{vw}$ | 2.98 ± 1.84$^{v}$ |
| | BCh50 | 6.34 ± 0.01$^{v}$ | – | 44.67 ± 2.20$^{v}$ | 4.11 ± 0.59$^{v}$ | 8.22 ± 0.77$^{v}$ | 9.20 ± 0.85$^{v}$ | 66.47 ± 2.83$^{vwx}$ | 2.44 ± 1.13$^{v}$ |
| | BH25 | 6.28 ± 0.02$^{w}$ | – | 43.44 ± 2.40$^{v}$ | 4.34 ± 0.66$^{v}$ | 8.59 ± 0.70$^{v}$ | 9.33 ± 0.76$^{v}$ | 64.57 ± 3.97$^{x}$ | 2.92 ± 1.73$^{v}$ |
| | BH50 | 6.27 ± 0.01$^{w}$ | – | 43.49 ± 3.07$^{v}$ | 4.33 ± 0.88$^{v}$ | 8.66 ± 2.25$^{v}$ | 9.38 ± 2.20$^{v}$ | 61.21 ± 6.28$^{wx}$ | 2.83 ± 2.23$^{v}$ |

For each parameter, results followed by same letter are not significantly different according to Tukey's HSD post-hoc test ($p > 0.05$). Data are presented as mean ± standard deviation.
BC: control burgers with a traditional formula; BCh25: sample with 25% animal fat replaced by GE with chia oil and amaranth flour; BCh50: sample with 50% animal fat replaced by GE with chia oil and amaranth flour. BH25: sample with 25% animal fat replaced by GE with hemp oil and amaranth flour as fat replacer. BH50: sample with 50% animal fat replaced by GE with hemp oil and amaranth flour. A lower-case letter refers to the comparison of the same parameter between the different raw samples (a-e) and for cooked samples (v-z).

(control and reformulated) were shown in Table 7. The use of gelled emulsions affected all cooking properties ($p < 0.05$) in different ways. In general, the burgers reformulation with GEs increased cooking loss, shrinkage and thickness increase ($p < 0.05$), being this effect higher when GE elaborated with hemp oil were used. Burgers with hemp oil (BH25 and BH50) showed the highest cooking loss, shrinkage and thickness increase, without differences ($p > 0.05$), between the levels of replacement applied. The cooking process leads to water evaporation and lipid migration in samples, and the intensity of these changes affects product acceptance (Fernández-López et al., 2019; Lucas-González et al., 2020). In the scientific literature, there is not a clear trend in the behavior of this parameter in reformulated burgers with vegetable oils added with gelled emulsions: increase (Dias et al., 2021), decrease (Heck et al., 2017; Lucas-González et al., 2020) and not modifications (Barros et al., 2021; Heck et al., 2019). In most the cases, these modifications although significant compared to control burgers does not seem to be quantitatively very important (2–10%). These variations could be attributed to the specific behavior of the ingredients used for the GE preparation (type and percentage of oil, flour, emulsion agent, and gelling agent), their stability, and their interrelation with the meat matrix. Regarding that, the higher cooking loss found in burgers with GE with hemp oil (BH25 and BH50) compared to burgers with GE with chia oil (BCh25 and BCh50) could be related to the lower emulsion stability and firmness reported for these GE with hemp oil (Botella-Martínez, Pérez-Álvarez, Sayas-Barberá, Fernández-López, & Viuda-Martos, 2021) which would allow lower water and oil retention capacity into the emulsion structure.

Reformulated burgers with the highest cooking loss (BH25 and BH50) showed also the highest shrinkage ($p < 0.05$) and the reasons would seem to be the same as reported for cooking loss. Cooking shrinkage has been mainly attributed to meat protein denaturation, giving off water and fat from meat batter (Pathare & Roskilly, 2016). It has been reported that the most important physical change occurs during meat product grilling (Tabarestani & Tehrani, 2014).

### 3.5. *Lipid oxidation of beef burgers (TBARS)*

Lipid oxidation is the main process responsible for the quality deterioration of meat and meat products. This process affects color, texture, nutritional value, taste, and aroma leading to rancidity, which are important reasons for consumer rejection (Lima, Rangel, Urbano, Mitzi, & Moreno, 2013).

In order to monitor the effects of reformulation and heating treatment on the lipid oxidation of beef burgers, lipid oxidation was measured in all samples, before and after cooking (Fig. 1). Significant differences ($p < 0.05$) were obtained with the addition of GEs, in both

**Table 7**
Cooking properties of cooked beef burgers reformulated with both amaranth/chia oil or amaranth/hemp oil gelled emulsion used as partial animal fat replacers.

| Sample | *Cooking loss (%)* | *Shrinkage (%)* | *Thickness increase (%)* |
|---|---|---|---|
| *BC* | $19.34 \pm 0.30^{c}$ | $19.55 \pm 0.96^{c}$ | $8.13 \pm 0.53^{c}$ |
| *BCh25* | $21.63 \pm 0.47^{bc}$ | $21.64 \pm 1.78^{b}$ | $12.92 \pm 0.42^{b}$ |
| *BCh50* | $24.26 \pm 0.56^{ab}$ | $21.41 \pm 0.45^{b}$ | $11.07 \pm 0.90^{b}$ |
| *BH25* | $27.13 \pm 0.32^{a}$ | $25.75 \pm 1.81^{a}$ | $13.02 \pm 0.20^{a}$ |
| *BH50* | $25.09 \pm 0.95^{a}$ | $24.19 \pm 1.67^{a}$ | $13.81 \pm 0.69^{a}$ |

For each parameter, results followed by same letter are not significantly different according to Tukey's HSD post-hoc test ($p > 0.05$). Data are presented as mean ± standard deviation.
BC: control burgers with a traditional formula; BCh25: sample with 25% animal fat replaced by GE with chia oil and amaranth flour; BCh50: sample with 50% animal fat replaced by GE with chia oil and amaranth flour. BH25: sample with 25% animal fat replaced by GE with hemp oil and amaranth flour as fat replacer. BH50: sample with 50% animal fat replaced by GE with hemp oil and amaranth flour.

raw and cooked samples. In raw samples, burgers reformulated with chia oil (BCh25 and BCh50) registered higher TBARS values ($p < 0.05$) than the control sample, being burgers with the highest replacement level (BCh50) which showed the highest ($p < 0.05$) TBARs values (1.13 mg MDA/kg of sample). In fact, BCh50 samples showed 3.5 times more oxidation than the control sample. Burgers reformulated with GE with hemp oil (BH25 and BH50) showed similar TBARs values (0.42 and 0.47 mg MDA/kg of sample, respectively) ($p > 0.05$) than control (0.32 mg MDA/kg of sample).

The TBARs values of cooked samples was higher ($p < 0.05$) in burgers with GCh (52% and 58% for BCh25 and BCh50, respectively) than GH (21% and 31% for BH25 and BH50, respectively). This fact was in concordance with several authors who reported that the use of GE elaborated with vegetable oils as animal fat replacement in meat products might be complex due to the high oxidation susceptibility of these unsaturated oils (Lucas-González et al., 2020; Moghtadaei, Soltanizadeh, Goli, & Sharifimehr, 2021). The differences in the lipid profile of the oils, the content of polyunsaturated fatty acids, and the temperature used to generate oleogels or gelled emulsions could affect the MDA levels (Gómez-Estaca et al., 2019).

It must be noticed that TBARS values in burgers reformulated with GE elaborated with amaranth flour and hemp oil (both raw and cooked) as well as the burgers reformulated (both raw and cooked) with GE elaborated chia oil (25%) were below the malonaldehyde limit for acceptability reported by Trindade, Mancini-Filho, and Villavicencio (2009) (2 mg MDA/kg) for loss of sensory attributes and perception of oxidation by consumers. However, it is important to highlight that cooked burgers reformulated with GE elaborated with amaranth flour and chia oil showed values above the threshold limit for consumer acceptability.

### 3.6. *Sensorial analysis*

The influence of the addition of GEs on sensory attributes of raw beef burgers is shown in Table 8. Relevant parameters affecting consumer purchase were measured, such as "color", "rancid aroma" and "product appearance" (mainly influenced by the product's optical properties, its physical form and its mode of presentation). Panelists did not detect differences between control and reformulated burgers ($p > 0.05$) for any of the three evaluated parameters. This result agreed with the instrumental color parameters, where L*, b* and h* values had no differences ($p > 0.05$) between samples and the rest of color parameters (a* and C*) showed small differences which were statistically significant but without practical significance (<3 units).

In the case of cooked samples, juiciness, chewiness, fat sensation, graininess and general acceptability were evaluated (Fig. 2). The only attribute that showed differences ($p < 0.05$) between samples was graininess: BCh25 and BH25 showed the highest ($p < 0.05$) score (6.60 and 6.50, respectively) without statistical differences between them ($p > 0.05$), while control sample had the lowest (5.00). These results agreed with the instrumental analysis since textural analysis revealed only differences in cohesiveness between some samples. For the preference test, control sample (6.70) and BH50 (5.90) were the most chosen. It has to be mentioned that the information about the nutritional improvement (healthier lipid profile) achieved in reformulated burgers was not communicated to panellists and that could be relevant and affect their sensory attractiveness (Siegrist, 2008).

## 4. Conclusions

This study suggests that the reformulation of beef burgers using gelled emulsion (based on amaranth-chia oil or amaranth-hemp oil) as a partial (up to 50%) pork back-fat substitute is feasible and can be seen as a viable alternative for improving nutritional composition without adversely affecting either the physicochemical properties (color, pH and texture) or the typical appearance of the resulting burgers. A reduction

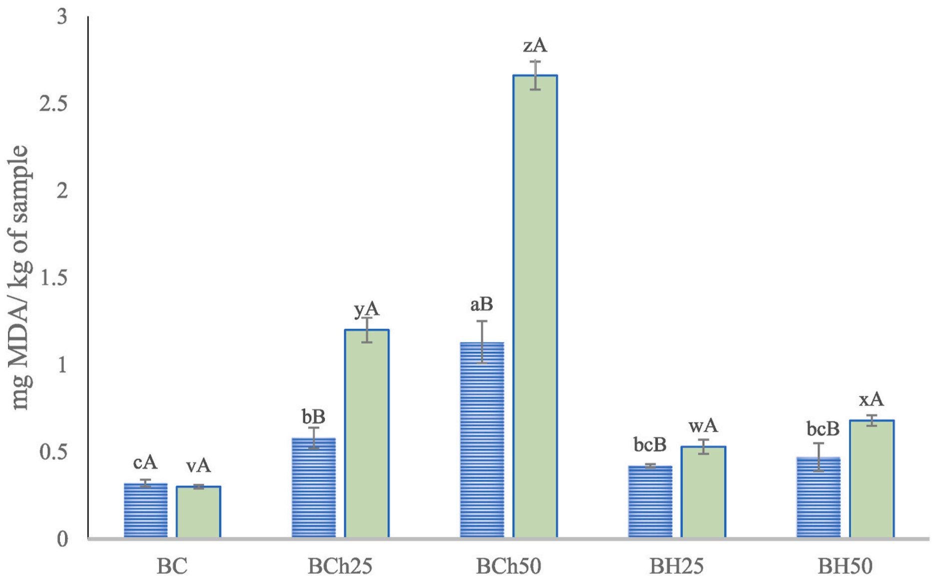


**Fig. 1.** Lipid oxidation (TBARS values) of raw and cooked beef burgers reformulated with both amaranth/chia oil or amaranth/hemp oil gelled emulsion used as partial animal fat replacers.
For each parameter, results followed by same letter are not significantly different according to Tukey's HSD post-hoc test ($p > 0.05$). Data are presented as mean ± standard deviation. A lower-case letter refers to the comparison of the same treatment between the different samples (a–e) for raw samples and (v–z) for cooked samples, while an upper-case letter (A–B) refers to the comparison of the different TBARs values in the same sample depending on treatment (raw or cooked). BC: control burgers with a traditional formula; BCh25: sample with 25% animal fat replaced by GE with chia oil and amaranth flour; BCh50: sample with 50% animal fat replaced by GE with chia oil and amaranth flour. BH25: sample with 25% animal fat replaced by GE with hemp oil and amaranth flour as fat replacer. BH50: sample with 50% animal fat replaced by GE with hemp oil and amaranth flour. Blue histogram is for raw beef burgers reformulated with both amaranth/chia oil or amaranth/hemp oil gelled emulsion. Green histogram is for cooked beef burgers reformulated with both amaranth/chia oil or amaranth/hemp oil gelled emulsion. . (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

**Table 8**
Sensory analysis of raw cooked beef burgers reformulated with both amaranth/chia oil or amaranth/hemp oil gelled emulsion used as partial animal fat replacers.

| Sample | Color | Rancid aroma | Product appearance |
|---|---|---|---|
| *BC* | 5.62 ± 1.32[a] | 4.94 ± 2.30[a] | 3.66 ± 2.31[a] |
| *BCh25* | 6.44 ± 1.61[a] | 4.95 ± 2.40[a] | 4.27 ± 1.72[a] |
| *BCh50* | 5.83 ± 0.73[a] | 5.36 ± 2.01[a] | 3.74 ± 2.41[a] |
| *BH25* | 5.11 ± 1.61[a] | 3.93 ± 1.62[a] | 3.75 ± 2.32[a] |
| *BH50* | 6.55 ± 1.02[a] | 4.41 ± 2.30[a] | 4.57 ± 2.61[a] |

For each parameter, results followed by same letter are not significantly different according to Tukey's HSD post-hoc test ($p > 0.05$). Data are presented as mean ± standard deviation.
BC: control burgers with a traditional formula; BCh25: sample with 25% animal fat replaced by GE with chia oil and amaranth flour; BCh50: sample with 50% animal fat replaced by GE with chia oil and amaranth flour. BH25: sample with 25% animal fat replaced by GE with hemp oil and amaranth flour as fat replacer. BH50: sample with 50% animal fat replaced by GE with hemp oil and amaranth flour.

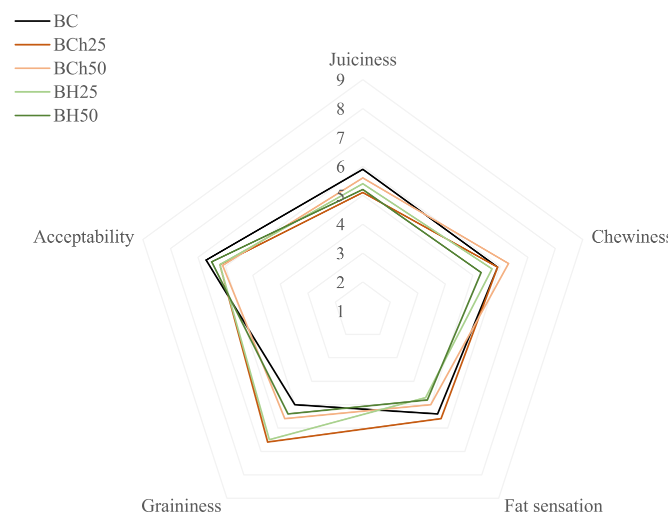


**Fig. 2.** Sensory analysis of cooked beef burgers reformulated with both amaranth/chia oil or amaranth/hemp oil gelled emulsion used as partial animal fat replacers.
BC: control burgers with a traditional formula; BCh25: sample with 25% animal fat replaced by GE with chia oil and amaranth flour; BCh50: sample with 50% animal fat replaced by GE with chia oil and amaranth flour. BH25: sample with 25% animal fat replaced by GE with hemp oil and amaranth flour as fat replacer. BH50: sample with 50% animal fat replaced by GE with hemp oil and amaranth flour.

of 12–33% of total fat was achieved with an improved lipid profile (lower saturated fatty acids and higher polyunsaturated fatty acids than control). Burgers with amaranth-hemp gelled emulsion were especially rich in linolenic fatty acid while burgers with amaranth-chia gelled emulsion was in α-linolenic fatty acid. These last burgers (with amaranth-chia gelled emulsion) were more susceptible to lipid oxidation than control and amaranth-hemp gelled emulsions (despite the use of hemp oil which was expected more susceptible to oxidation). Panelists did not detect differences in color, rancid aroma, or appearance in raw burgers but when they were cooked, control and burgers with amaranth-hemp gelled emulsions received the highest score.

## CRediT authorship contribution statement

**Carmen Botella-Martínez:** Investigation, Writing – original draft. **Aarón Gea-Quesada:** Investigation. **Estrella Sayas-Barberá:** Formal analysis, Data curation. **José Ángel Pérez-Álvarez:** Data curation, Supervision. **Juana Fernández-López:** Formal analysis, Writing – review & editing. **Manuel Viuda-Martos:** Conceptualization, Writing – review & editing.

## Declaration of competing interest

The authors declared that they have no conflicts of interest to this work.

## Acknowledgements

This work was supported by the grant of Carmen Botella-Martínez from Miguel Hernandez University, Spain. IPOA researchers are members of the HealthyMeat network, funded by CYTED (ref. 119RT0568).

## References


Afshari, R., Hosseini, H., Khaneghah, A. M., & Khaksar, R. (2017). Physico-chemical properties of functional low-fat beef burgers: Fatty acids profile modification. *LWT-Food Science and Technology, 78*, 325–331.

Alejandre, M., Ansorena, D., Calvo, M. I., Cavero, R. Y., & Astiasaran, I. (2019). Influence of a gel emulsion containing microalgal oil and a blackthorn (*Prunus spinosa* L.) branch extract on the antioxidant capacity and acceptability of reduced-fat beef patties. *Meat Science, 148*, 219–222.

Alejandre, M., Passarini, D., Astiasarán, I., & Ansorena, D. (2017). The effect of low-fat beef patties formulated with a low-energy fat analogue enriched in long-chain polyunsaturated fatty acids on lipid oxidation and sensory attributes. *Meat Science, 134*, 7–13.

AOAC. (2010). *Official methods of analysis of AOAC international* (18th ed.). Rockville, MD, USA: Association of Official Analytical Chemistry.

Barros, J. C., Munekata, P. E. S., de Carvalho, F. A. L., Domínguez, R., Trindade, M. A., Pateiro, M., et al. (2021). Healthy beef burgers: Effect of animal fat replacement by algal and wheat germ oil emulsions. *Meat Science, 10*(11), 2706.

Barros, J. C., Munekata, P. E. S., de Carvalho, F. A. L., Pateiro, M., Barba, F. J., Domínguez, R., et al. (2020). Use of tiger nut (*Cyperus esculentus* L.) oil emulsion as animal fat replacement in beef burgers. *Foods, 9*(1), 44.

Botella-Martínez, C., Lucas-González, R., Lorenzo, J. M., Santos, E. M., Rosmini, M., Sepúlveda, N., et al. (2021b). Cocoa coproducts-based and walnut oil gelled emulsion as animal fat replacer and healthy bioactive source in beef burgers. *Foods, 10*(11), 2706. https://doi.org/10.3390/foods10112706

Botella-Martínez, C., Pérez-Álvarez, J.Á., Sayas-Barberá, E., Fernández-López, J., & Viuda-Martos, M. (2021a). Assessment of chemical, physicochemical, and lipid stability properties of gelled emulsions elaborated with different oils chia (*Salvia hispanica* L.) or hemp (*Cannabis sativa* L.) and pseudocereals. *Foods, 10*, 1463.

Botella-Martínez, C., Viuda-Martos, M., Pérez-Álvarez, J. A., & Fernández-López, J. (2021c). Total and partial fat replacement by gelled emulsion (hemp oil and buckwheat flour) and its impact on the chemical, technological and sensory properties of Frankfurters. *Foods, 10*, 1681.

de Carvalho, F. A. L., Munekata, P. E. S., Pateiro, M., Campagnol, P. C. B., Domínguez, R., Trindade, M. A., et al. (2020). Effect of replacing backfat with vegetable oils during the shelf-life of cooked lamb sausages. *LWT-Food Science and Technology, 122*, 109052.

Cittadini, A., Munekata, P. E. S., Pateiro, M., Sarriés, M. V., Domínguez, R., & Lorenzo, J. M. (2021). Physicochemical composition and nutritional properties of foal burgers enhanced with healthy oil emulsion hydrogels. *International Journal of Food Science and Technology, 56*, 6182–6191.

Claus, J. R. (1995). Methods for the objective measurement of meat product texture. In *Proceeding of 48th reciprocal meat conference* (pp. 96–101). San Antonio, TX, USA: Reciprocal Meat Conference Proceeding.

Dias, M. F., Guimarães, A. S., Benevenuto, A. A., Jr., Silva, V. R. O., Fontes, P. R., Ramos, A.d. L. S., et al. (2021). Canola and olive oil gelled emulsions as pork fat replacers in beef burgers. *British Food Journal, 124*(1), 50–60. https://doi.org/10.1108/bfj-02-2021-0119. ahead of print.

European Parliament. (2006). Regulation 1924/2006 of the European Parliament and of the council of 20 December 2006 on nutrition and health claims made on foods. *Official Journal European Union, L12*, 3–8. OJ.

Fennema, O. R., Damodaran, S., & Parkin, K. L. (2017). Introduction to food chemistry. In *Fennema's food chemistry* (pp. 1–16). CRC Press.

Fernández-López, J., Lucas-González, R., Viuda-Martos, M., Sayas-Barberá, E., Navarro, C., Haros, C. M., et al. (2019). Chia (*Salvia hispanica* L.) products as ingredients for reformulating frankfurters: Effects on quality properties and shelf-life. *Meat Science, 156*, 139–145.

Fernández, M., Ordoñez, J. A., Cambero, I., Santos, C., Pin, C., & Hoz, L. (2007). Fatty acids compositions of selected varieties of Spanish dry ham related to their nutritional implications. *Food Chemistry, 101*, 107–112.

Folch, J., Less, M., & Sloane, G. H. (1957). A simple method for the isolation and purification of total lipids from animal tissues. *Journal of Biological Chemistry, 226*, 497–509.

Food and Agriculture Organization of the United Nations FAO. (2016). *Influencing food environments for healthy diets*. Rome, 2016.

Gómez-Estaca, J., Herrero, A. M., Herranz, B., Álvarez, M. D., Jiménez-Colmenero, F., & Cofrades, S. (2019a). Characterization of ethyl cellulose and beeswax oleogels and their suitability as fat replacers in healthier lipid pâtés development. *Food Hydrocolloids, 87*, 960–969.

Gómez-Estaca, J., Pintado, T., Jiménez-Colmenero, F., & Cofrades, S. (2019b). Assessment of a healthy oil combination structured in ethyl cellulose and beeswax oleogels as animal fat replacers in low-fat. PUFA-enriched pork burgers. *Food and Bioprocess Technology, 12*(6), 1068–1081.

Heck, R. T., Fagundes, M. B., Cichoski, A. J., de Menezes, C. R., Barin, J. S., Lorenzo, J. M., et al. (2019). Volatile compounds and sensory profile of burgers with 50% fat replacement by microparticles of chia oil enriched with rosemary. *Meat Science, 148*, 164–170.

Heck, R. T., Vendruscolo, R. G., de Araújo Etchepare, M., Cichoski, A. J., de Menezes, C. R., Barin, J. S., et al. (2017). Is it possible to produce a low-fat burger with a healthy n-6/n-3 PUFA ratio without affecting the technological and sensory properties? *Meat Science, 130*, 16–25.

Lima, D. M., Rangel, A., Urbano, S., Mitzi, G., & Moreno, G. M. (2013). Oxidação lipídica da carne ovina. *Acta Veterinaria Brasilica, 7*(1), 14–28.

Lucas-González, R., Roldán-Verdu, A., Sayas-Barberá, E., Fernández-López, J., Pérez-Álvarez, J. A., & Viuda-Martos, M. (2020). 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. *Journal of the Science of Food and Agriculture, 100*(3), 1265–1273.

Martínez, J. A., Melgosa, M., Pérez, M., Hita, E., & Negueruela, A. I. (2001). Visual and instrumental color evaluation in red wine. *Food Science and Technology International, 7*, 439–444.

Moghtadaei, M., Soltanizadeh, N., Goli, S. A. H., & Sharifimehr, S. (2021). Physicochemical properties of beef burger after partial incorporation of ethylcellulose oleogel instead of animal fat. *Journal of Food Science & Technology, 58*, 4775–4784.

Öztürk-Kerimoğlu, B., Urgu-Öztürk, M., & Serdaroglu, M. (2021). A new inverse olive oil emulsion plus carrot powder to replace animal fat in model meat batters. *LWT-Food Science and Technology, 135*, 110044.

Pathare, P. B., & Roskilly, A. P. (2016). Quality and energy evaluation in meat cooking. *Food Engineering Review, 8*, 435–447.

Pellegrini, M., Lucas-Gonzales, R., Ricci, A., Fontecha, J., Fernández-López, J., Pérez-Álvarez, J. A., et al. (2018). Chemical, fatty acid, polyphenolic profile, techno-functional and antioxidant properties of flours obtained from quinoa (*Chenopodium quinoa* Willd) seeds. *Industrial Crops and Products, 111*, 38–46.

Pintado, T., Ruiz-Capillas, C., Jiménez-Colmenero, F., Carmona, P., & Herrero, A. M. (2015). Oil-in-water emulsion gels stabilized with chia (*Salvia hispanica* L.) and cold gelling agents: Technological and infrared spectroscopic characterization. *Food Chemistry, 185*(8), 470–478.

Pires, M. A., dos Santos, L. R., Barros, J. C., & Trindade, M. A. (2019). Effect of replacing pork backfat with Echium oil on technological and sensory characteristics of bologna sausages with reduced sodium content. *LWT-Food Science and Technology, 109*, 47–54.

Rosmini, M., Perlo, F., Pérez-Álvarez, J. A., Pagán-Moreno, M., Gago-Gago, M., López-Santoveña, F., et al. (1996). TBA test by an extractive method applied to pate. *Meat Science, 42*, 103–110.

Siegrist, M. (2008). Factors influencing public acceptance of innovative food technologies and products. *Trends in Food Science & Technology, 19*(11), 606–608.

Simopoulos, A. P. (2004). Omega-6/omega-3 essential fatty acid ratio and chronic diseases. *Food Reviews International, 20*, 77–90.

de Souza Paglarini, C., de Figueiredo Furtado, G., Honório, A. R., Mokarzel, L., da Silva Vidal, V. A., Ribeiro, A. P. B., et al. (2019). Functional emulsion gels as pork back fat replacers in Bologna sausage. *Food Structure, 20*, 100105.

Summo, C., De Angelis, D., Difonzo, G., Caponio, F., & Pasqualone, A. (2020). Effectiveness of oat-hull-based ingredient as fat replacer to produce low fat burger with high beta-glucans content. *Foods, 9*(8), 1057.

Tabarestani, H. S., & Tehrani, M. M. (2014). Optimization of physicochemical properties of low-fat hamburger formulation using blend of soy flour, split-pea flour and wheat starch as part of fat replacer system. *Journal of food process preservation, 38*, 278–288.

Tafadzwa, M. J., Zvamaziva, J. T., Charles, M., Amiel, M., Pepukai, M., & Shepherd, M. (2021). Proximate, physico-chemical, functional and sensory properties of quinoa and amaranth flour as potential binders in beef sausages. *Food Chemistry, 365*, 130619.

Tarté, R., Paulus, J. S., Acevedo, N. C., Prusa, K. J., & Lee, S. L. (2020). High-oleic and conventional soybean oil oleogels structured with rice bran wax as alternatives to pork fat in mechanically separated chicken-based bologna sausage. *LWT-Food Science and technology, 131*, 109659.

Trindade, R. A., Mancini-Filho, J., & Villavicencio, A. L. C. H. (2009). Effect of natural antioxidants on the lipid profile of electron beam-irradiated beef burgers. *European Journal of Lipid Science and Technology, 111*, 1161–1168.

Tura, M., Mandrioli, M., Valli, E., Rubino, R. C., Parentela, D., & Toschi, T. G. (2022). Changes in the composition of a cold-pressed hemp seed oil during three months of storage. *Journal of Food Composition and Analysis, 106*, 104270.

Ulbricht, T., & Southgate, D. (1991). Coronary heart disease: Seven dietary factors. *Lancet, 338*, 985–992.

Vargas-Ramella, M., Munekata, P. E. S., Pateiro, M., Franco, D., Campagnol, P. C. B., Tomasevic, I., et al. (2020). Physicochemical composition and nutritional properties of deer burger enhanced with healthier oils. *Foods, 9*(5), 571.

Villanueva-Bermejo, D., Calvo, M. V., Castro-Gómez, P., Fornari, T., & Fontecha, J. (2019). Production of omega 3-rich oils from underutilized chia seeds. Comparison between supercritical fluid and pressurized liquid extraction methods. *Food Research International, 115*, 400–407.

Wood, J. D., Enser, M., Fisher, A. V., Nute, G. R., Sheard, P. R., Richardson, R. I., et al. (2008). Fat deposition, fatty acid composition and meat quality: A review. *Meat Science, 78*(4), 343–358.