LWT - Food Science and Technology 206 (2024) 116630

Contents lists available at ScienceDirect

LWT

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

Innovative formulation in pâté using a gelled emulsion of hemp oil *(Cannabis sativa L.)* as fat replacer

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ARTICLE INFO

Keywords:
Reformulation
Fat substitution
Hemp oil
Polyunsaturated fatty acids
Pâté
Healthy meat product

ABSTRACT

The effect of the partial replacement (10 and 20%) of animal fat by a gelled emulsion based on hemp oil and buckwheat flour (hemp-GE) in a traditional pâte was assessed. For that, the nutritional composition, physicochemical properties, lipid profile, lipid oxidation and sensory properties were evaluated. Hemp-GE had a positive effect in the reduction of cholesterol and improved the n-6/n-3 and PUFA/SFA nutritional ratios which is in line with the nutritional recommendations for the development of healthier meat products. Although reformulated pâtes resulted more susceptible to lipid oxidation and some of their physicochemical properties were modified, these changes were not sufficiently intense to diminish the sensory acceptance of the new product. Structuring healthy vegetal oils employing gelled emulsions in view of using them as partial animal fat replacers in traditional meat products seems to be a useful strategy to make them healthier.

1. Introduction

Liver pâté is a highly appreciated dish that is mostly made of liver and fat and has its roots in European gastronomy heritage (Skałecki et al., 2021). Not only does it give a rich and flavourful sensation, but it also acts as a useful supply of biologically relevant proteins, along with critical vitamins such as B1, B12, folic acid, and heme iron (Brito et al., 2006; Lucas-González et al., 2019). This nutritional profile renders liver pâtés particularly attractive, especially for individuals like children and women susceptible to iron deficiency-induced anemia, a prevalent global health concern (Lucas-González et al., 2019; Sánchez-Zapata et al., 2012). The selection and quality of the primary ingredients in the formulation determine the majority of the nutritional value of pâtés. Although the nutritional value of pâte is indisputable, the innovation of the meat industry towards the incorporation of healthier raw materials of natural origin is opening up a new field of attractive research opportunities that might lead to improved product quality as well as the encouragement of healthy eating choices (Barbut et al., 2021). The high-calorie value, high-fat content (25–40%), and unfavorable fatty acid composition (mainly saturated fatty acids typical of animal fats) mean that regular use of these products may damage the health (Lucas-González et al., 2019; Skałecki et al., 2021). Therefore, the meat industry and the scientific community are concentrating on creative ways to produce healthier meat products with additional value, without compromising on textural and sensory aspects in order to increase the nutritional worth of this type of food (Cittadini et al., 2022). In this regard, has been reported that certain comminuted meat products (such as sausages and frankfurters) replace saturated animal fats with liquid vegetable oils (such as canola, olive, sunflower, peanut, fish) with or without the inclusion of hydrocolloid gums to alter the fatty acid content of the final product (Domínguez et al., 2017; Öztürk-Kerimoğlu et al., 2021).

The elaboration of a gelled emulsion using hemp seed oil (*Cannabis sativa* L.) and buckwheat flour as an emulsifying agent is the main topic of this study in view to enhance the nutritional profile of a traditional pâté and encourage the use of sustainable and alternative ingredients. The high protein, vitamin, mineral, and dietary fiber content of buckwheat flour (Zhou et al., 2015) is enhanced by the added hemp seed oil, which is known for its nutritional value and content in polyunsaturated fatty acids (PUFA), particularly long-chain n-3 PUFA, which are known to improve health in the neurological, immunological, and cardiovascular systems (Heck et al., 2022). The use of gelled emulsions, made with different vegetable oils and flours, as animal fat replacers in different meat products such as burgers and cooked sausages has been

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https://doi.org/10.1016/j.lwt.2024.116630
Received 21 May 2024; Received in revised form 3 August 2024; Accepted 10 August 2024
Available online 13 August 2024

previously studied (Botella-Martínez, Viuda-Martos, et al., 2021, 2022; Hanula et al., 2022; Nacak et al., 2021). However, the combination of hemp seed oil and buckwheat flour to obtain gelled emulsions and their application in a meat product like a pâté, as fat replacement, has not been previously reported. This combination has been carefully chosen based on factors such as technical viability, physicochemical characteristics, and fatty acid content. This study aims (i) to assess the viability of using a gelled emulsion made of hemp seed oil and buckwheat flour as partial fat replacement of pâtés, and (ii) to evaluate the impact of this substitution on the chemical composition, fatty acid profiles, physicochemical properties, lipid oxidation, and sensory attributes.

2. Materials and methods

2.1. Materials

The following ingredients were used for the elaboration of the hemp seed oil gelled emulsions (Hemp-GE): water (40%), hemp seed oil (40%), buckwheat flour (15%), and gelatine "instant gel" (5%) from pork origin. The preparation of the gelled emulsion and materials employed for this elaboration was carried out according to the procedure described by Botella-Martínez, Pérez-Álvarez, et al., 2021). Briefly, water (60 °C) was mixed with instant gel and then the flour was added and mixed again. When the temperature was turned down to 37 °C, the hemp oil was gradually added. Once the GE was obtained, it was refrigerated and stored at 4 °C until its use. The meat ingredients (pork liver, dewlap, and pork fat) were purchased from a local butchery and the additives and spices were provided by an authorized supplier of food ingredients Suministros River S.L.U. (Alicante, Spain) (Table 1).

2.2. Pâté manufacturing and sampling

For pâté elaboration, three batches (1 Kg of each) were prepared: control pâté (CP), pâté with 10 % of hemp-GE as replacer of pork backfat (PGEH10), and pâté with 20% of hemp-GE as replacer of pork backfat plus 10 % of dewlap (PGEH20) (Table 1). The rest of the ingredients (liver, water, additives, and spices) used following a traditional pâté formulation were the same in the three batches and are specified in Table 1. The pâtés were elaborated in the food pilot plant of the Miguel Hernández University in the Polytechnic School of Orihuela (Orihuela, Alicante, Spain). The pâte processing as well as packaging and preservation methods employed were identical to those utilized in the study conducted by Lucas-González et al. (2019). Once the desired temperature was reached, the samples were chilled in ice/water for subsequent analysis. The entire process was conducted in triplicate.

Table 1
Formulation of pâtés with hemp oil gelled emulsion as partial animal fat replacer.

Ingredients	CP	PGEH10	PGEH20
Dewlap (%)	65	65	55
Liver (%)	25	25	25
Backfat (%)	10	0	0
Hemp-GE (%)	0	10	20
Water (%)	15	15	15
Salt (%)	2	2	2
Caseinate (%)	1	1	1
Polyphosphates (mg/Kg)	300	300	300
Nitrite (mg/Kg)	125	125	125
White pepper (%)	0.05	0.05	0.05
Nutmeg (%)	0.03	0.03	0.03
Thyme (%)	0.03	0.03	0.03

Percentages of non-meat ingredients are related to 100% meat block (dewlap, liver and backfat). CP: control pâté; PGEH10: pâté with 10% hemp oil gelled emulsion as animal fat substitute; PGEH20: pâté with 20% hemp oil gelled emulsion as animal fat substitute.

2.3. Total expelled fluid of raw pâté

The emulsion stability of the pâtés (pre-cooking) was assessed using the total expressible fluid (TEF) method as outlined by Pintado et al. (2015), with minor adjustments. Samples were centrifuged in 15 mL centrifuge tubes at 3000 rpm for 1 min. Subsequently, they underwent heating in a water bath at 70 °C for 30 min, followed by cooling to room temperature. Afterward, the samples were centrifuged again for 3 min at 3000 rpm. The expressible fluid (comprising fat and water) was allowed to drain onto filter paper by placing the tubes upside down. Each sample was analyzed in triplicate, and the results were presented in grams of total fluid expelled per 100 g of the sample. The calculation was based on the following expression (Equation (1)):

$$\%TEF = \frac{Weight\ of\ tube\ with\ sample - Weight\ of\ tube\ with\ pellet}{Weight\ of\ sample} x100 \quad \text{(Eq. 1)}$$

2.4. Chemical composition

Fat, protein, ash, and moisture content were determined according to AOAC methods (AOAC, 2000). Heme iron was determined by a spectrometric method with acidified acetone and water as reagents (Sánchez-Zapata et al., 2013). All assays were taken on three samples of each formulation. Total cholesterol was determined by HPLC using 2-propanol and hexane (2:98) in mode isocratic (1 mL/min) with a photodiode array detector (DAD) at 208 nm, following the procedures described by Domínguez et al. (2016). The analysis of mineral content was made using a MS-2030 (Shimadzu, Tokyo, Japan) inductively coupled plasma mass spectrometry (ICP-MS).

2.5. Fatty acids composition, nutritional parameters, and health indices analysis

The method described by Folch et al. (1957) was applied for the lipid extraction from the pâté samples. The fatty acids were transesterified following the method reported by Domínguez et al. (2015). As an internal standard, the nonadoic acid (C19:0) at 0.3 mg/mL was added to the samples before methylation. Results regarding FAME composition were expressed in g/100 g of fat.

The nutritional parameters refer to the sum of total saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), polyunsaturated fatty acids (PUFA), the sum of omega 3 (n-3) and omega 6 (n-6) fatty acids. Health indices including n-6 and n-3 ratio, PUFA, and SFA ratio were calculated. The index of atherogenicity (AI) and the thrombogenicity index (TI) were calculated following the formula described by Ulbricht and Southgate (1991). The hypocholesterolemic/hypercholesterolemic ratio (h/H) was calculated as described by Fernández et al. (2007).

2.6. Physico-chemical analysis

The pH of pâté samples was determined using a Crison micro pH-meter model GLP 21 equipped with a penetrating electrode (Crison Instrument S.A., Barcelona, Spain). The water activity was assessed using a Novasina TH-500 analyzer (Novasina, Axair LTD., Pfaeffikon, Switzerland). Color analysis of pâté samples was determined on their surfaces utilizing a Minolta spectrophotometer Model CM-700 with 10° observer angle and D65 illumination conditions (Konica Minolta Sensing, Inc., Tokyo, Japan). CIEL*a*b* color space was used to obtain the color coordinates (L*-lightness, a*- red/green coordinate and b*-yellow/blue coordinate) from which hue (H*) and Chrome (C*) were calculated. The total color differences (ΔE) for each reformulated pâté relative to the control sample were determined with the following Equation (2).

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad \text{(Eq. 2)}$$

2.7. Texture analysis

For the texture analysis of the pâtés a TA. XT2i universal texture analyzer (Stable Microsystem, United Kingdom) equipped with a measuring head having a maximum pressure force of 5 kg and a conical plexiglass sensor designed for spreadability testing (HDP/SR, Stable Microsystem, United Kingdom) was used. The analysis involved a 45° angle formed by the cone base and slant height, with the measuring head moving at a speed of 3.0 mm/s. The spreadability test had two phases, recording force over time at a rate of 200 measurement points per second. In the first phase, the upper cone was immersed in the test sample within a fixed inverted cone-shaped container to a depth of 23 mm. The maximum force recorded, termed firmness, and the area under the curve, representing the total force for the initial phase, termed spreadability, were measured. In the subsequent phase, the head moved in the opposite direction, with the maximum force recorded as firmness and the area under the curve representing the work of shear. Measurements were conducted at a temperature of 18 ± 2 °C, and texture parameters were determined based on five sample replicates.

2.8. Lipid oxidation

The assessment of lipid oxidation in pâté samples through the thiobarbituric acid reactive substances (TBARs) assay involved extracting malondialdehyde (MDA) following the method described by Rosmini et al. (1996). The obtained results were quantified and expressed as milligrams of MDA per kilogram of sample.

2.9. Sensory assessment

Seventy panellists aged between 20 and 65 years old selected from staff and students of the Polytechnic School of Orihuela (Miguel Hernández University) carried out the sensory assessment of the pâté samples. Before starting the analyses, each subject was informed about the specific characteristics of the product to be tasted and about what the analysis would consist of, and a written informed consent was signed by the participants. This project was approved by the Responsible Research Office of the Miguel Hernández University (OIR- Reg. 211019105733, Ref. PRL. DTA.MVM.02.21, UMH, Elche, Alicante, Spain). The test took place in the tasting room of Miguel Hernández University (Orihuela, Alicante, Spain). Three slices of pâté (1 cm thickness approx.), once from each batch, were provided to each panelist at room temperature. They were asked to rate their preference for general appearance, color, brightness, overall odor, rancidity, spreadability, juiciness, cohesiveness, hardness, and overall flavor. At the end, the panellists were asked about the overall acceptance of the product they were testing. Preference was expressed on a 7-point hedonic scale ranging from "dislike extremely" (1) to "like extremely" (7).

2.10. Statistics analysis

The entire process, encompassing the development of hemp seed oil emulsion (Hemp-GE) and the preparation of liver pork pâté samples, was replicated three times (3 independent batches). Repetitions were conducted on different production days, and each batch underwent triplicate analyses. Data analysis employed SPSS software (version 24.0, SPSS Inc., Chicago, USA) selecting one-way analysis of variance (ANOVA) and Tukey-b post-hoc tests at a 5% significance level ($p < 0.05$).

3. Results and discussion

3.1. Emulsion stability of raw pâté dough

The stability of the emulsion was assessed on raw dough before the samples were stuffed and cooked, and the results are shown in Fig. 1. The substitution of animal fat by the Hemp-GE resulted in an increasing amount of total liquid expelled (lower emulsion stability), higher at higher substitution levels ($p < 0.05$). Control pâtés showed TEF values similar to those reported by other authors (Gómez-Estaca et al., 2019). It should be noted that these values were higher than those reported as normal for cooked sausages (0.9–1.7%) (Botella-Martínez, Viuda-Martos, et al., 2021; Goemaere et al., 2021), which could be due to the behavior (lower emulsion capacity) of two specific ingredients used in pâté elaboration (liver and dewlap). In addition, the substitution of animal fat by the Hemp-GE resulted in a 150% increase in TEF for PGEH10 and 310% for PGEH20. Depending on the ingredients used as fat substitutes, the stability of meat emulsion could be increased, decreased or not modified (Botella-Martínez, Viuda-Martos, et al., 2021; Momchilova et al., 2023). In general, the higher the amount of protein in the meat matrix, the higher the emulsion stability, mainly due to its effect on the gel/emulsion matrix. In addition, when the ingredients used for the fat replacement have high WHC or/and OHC, the emulsion stability was improved (Fernández-Martín et al., 2009; Sánchez-Zapata et al., 2013). The relation SFA/UFA has been also proposed as a significant factor in the emulsion stability; it has been pointed out that a higher UFA content (with a lower melting point than saturated fats) may reduce emulsion stability (Martin et al., 2008). In the case of pâté, Delgado-Pando et al., 2011 reported significant increases in TEF in both, low-fat pâtés and pâtes in which the animal fat was replaced by O/W made with olive, linseed, and fish oils. In both cases, the TEF values reported (10.5% and 11.9%) are in line with our values. These authors also reported significant reductions in these TEF values with the addition of konjac gel. Gómez-Estaca et al. (2019) also reported that the replacement of animal fat by ethyl cellulose and beeswax oleogels increased the total fluid loss (%) of reformulated pâtes respect to control. In our case, the high emulsion stability found in control pâté could be associated with its highest protein control (Table 2) and saturated fatty acids content (Table 3).

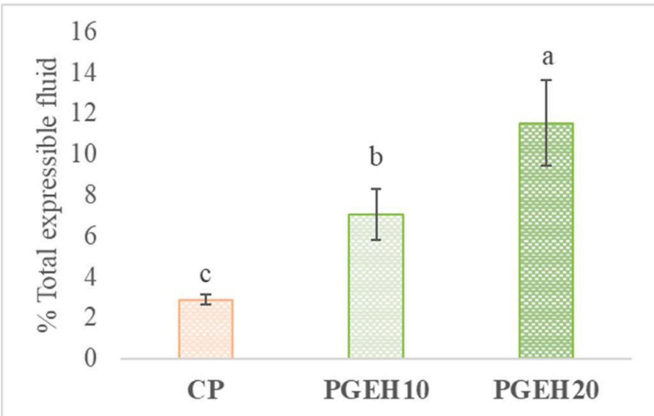

Fig. 1. Total expressible fluid of raw pâté with hemp oil gelled emulsion as partial animal fat replacer
CP: control pâté; PGEH10: pâté with 10% hemp oil gelled emulsion as animal fat substitute; PGEH20: pâté with 20% hemp oil gelled emulsion as animal fat substitute.
Data are presented as mean ± SD. Different letters (a–c) indicate statistically significant differences as determined by Tukey's HSD post-hoc test ($p < 0.05$).

Table 2
Chemical composition of pâté with hemp oil gelled emulsion as partial animal fat replacer.

	CP	PGEH10	PGEH20
Proximate composition (%)			
Moisture	55.14 ± 0.34[a]	52.73 ± 0.62[b]	52.28 ± 0.22[b]
Ash	2.41 ± 0.02[a]	2.22 ± 0.02[b]	2.17 ± 0.04[b]
Fat	23.83 ± 0.09[b]	29.10 ± 0.52[a]	28.32 ± 0.78[a]
Protein	13.35 ± 0.78[a]	10.89 ± 0.03[b]	10.28 ± 0.09[b]
Mineral profile (mg/100g)			
Sodium	797.18 ± 17.16[a]	824.25 ± 12.26[a]	834.09 ± 3.18[a]
Potassium	142.78 ± 4.78[a]	121.81 ± 7.79[a]	132.98 ± 1.75[a]
Calcium	17.88 ± 0.10[a]	17.48 ± 0.55[a]	15.38 ± 0.06[b]
Magnesium	12.75 ± 1.13[a]	11.66 ± 0.66[a]	13.92 ± 0.26[a]
Iron	2.92 ± 0.01[a]	3.05 ± 0.08[a]	3.08 ± 0.06[a]
Zinc	2.06 ± 0.05[a]	1.86 ± 0.02[a]	1.86 ± 0.03[a]
Cupper	0.16 ± 0.00[a]	0.16 ± 0.00[a]	0.17 ± 0.00[a]
Manganese	0.09 ± 0.00[b]	0.10 ± 0.00[b]	0.16 ± 0.01[a]
Heme iron (mg/100g)	2.36 ± 0.14[a]	2.43 ± 0.16[a]	2.49 ± 0.11[a]
Cholesterol (mg/100g)	69.29 ± 3.30[a]	58.01 ± 0.31[b]	60.61 ± 0.85[b]

CP: control pâté; PGEH10: pâté with 10% hemp oil gelled emulsion as animal fat substitute; PGEH20: pâté with 20% hemp oil gelled emulsion as animal fat substitute.
Data are presented as mean ± SD. Different letters (a-b) in the same row indicate statistically significant differences as determined by Tukey's HSD post-hoc test ($p < 0.05$).

Table 3
Lipid profile (g/100 g fatty acids), nutritional parameters and health indices of control and reformulated pâtés.

	CP	PGEH10	PGEH20
C14:0	1.38 ± 0.06[a]	1.32 ± 0.00[a]	1.07 ± 0.01[b]
C16:0	23.95 ± 0.23[a]	22.06 ± 0.06[b]	18.48 ± 0.11[c]
C16:1n-7	2.55 ± 0.11[a]	2.44 ± 0.00[a]	1.95 ± 0.02[b]
C17:0	0.67 ± 0.01[a]	0.59 ± 0.00[b]	0.50 ± 0.00[c]
C17:1n-7	0.57 ± 0.01[a]	0.51 ± 0.00[b]	0.42 ± 0.00[c]
C18:0	12.20 ± 0.31[a]	10.49 ± 0.02[b]	8.91 ± 0.03[c]
C18:1n-9	40.02 ± 0.31[a]	37.63 ± 0.03[b]	31.78 ± 0.12[c]
C18:1n-7	3.18 ± 0.03[a]	2.99 ± 0.00[b]	2.47 ± 0.02[c]
C18:2n-6	10.91 ± 0.26[c]	15.82 ± 0.01[b]	18.62 ± 0.02[a]
C20:0	0.15 ± 0.01[c]	0.18 ± 0.00[b]	0.22 ± 0.00[a]
C20:1n-9	0.90 ± 0.03[a]	0.81 ± 0.00[b]	0.70 ± 0.01[c]
C20:2n-6	0.57 ± 0.01[a]	0.52 ± 0.00[a]	0.45 ± 0.00[b]
C20:4n-6	0.82 ± 0.04[a]	0.72 ± 0.01[b]	0.61 ± 0.01[c]
C18:3n-6	0.04 ± 0.00[b]	0.10 ± 0.00[a]	0.15 ± 0.01[a]
C18:3n-3	0.51 ± 0.02[c]	2.23 ± 0.00[b]	3.56 ± 0.01[a]
C20:2n-6	0.57 ± 0.01[a]	0.52 ± 0.00[a]	0.45 ± 0.00[b]
C20:3n-6	0.14 ± 0.00[a]	0.12 ± 0.00[a]	0.10 ± 0.00[a]
∑SFA	38.82 ± 0.18[a]	35.07 ± 0.05[b]	29.54 ± 0.11[c]
∑MUFA	47.60 ± 0.25[a]	44.74 ± 0.02[c]	46.36 ± 0.11[b]
∑PUFA	13.59 ± 0.32[c]	20.19 ± 0.04[b]	24.09 ± 0.02[a]
∑n3	0.78 ± 0.02[c]	2.53 ± 0.01[b]	3.83 ± 0.01[a]
∑n6	12.81 ± 0.30[c]	17.66 ± 0.02[b]	20.27 ± 0.00[a]
∑PUFA/∑SFA	0.35 ± 0.01[c]	0.58 ± 0.00[b]	0.82 ± 0.00[a]
n6/n3	16.33 ± 0.11[a]	6.97 ± 0.02[b]	5.30 ± 0.02[c]
AI	0.48 ± 0.01[a]	0.42 ± 0.00[b]	0.32 ± 0.00[c]
TI	1.15 ± 0.01[a]	0.87 ± 0.00[b]	0.63 ± 0.00[c]
h/H	2.24 ± 0.03[a]	2.60 ± 0.01[b]	2.98 ± 0.02[c]

CP: control pâté; PGEH10: pâté with 10% hemp oil gelled emulsion as animal fat substitute; PGEH20: pâté with 20% hemp oil gelled emulsion as animal fat substitute. AI: atherogenic index; TI: thrombogenic index; h/H: hypocholesterolemic/hypercholesterolemic index.
Data are presented as mean ± SD. Different letters (a-b) in the same row indicate statistically significant differences as determined by Tukey's HSD post-hoc test ($p < 0.05$).

3.2. Chemical composition

The results of the chemical composition of the control and reformulated pâtés are shown in Table 2. The control sample (CP) showed the highest values ($p < 0.05$) for moisture, and protein content and the lowest for fat content. It should be expected that reformulated pâtés showed higher moisture content and lower fat content than the control because the animal fat was replaced by the Hemp-GE containing 40% water. In this case, the low water content of reformulated pâtés could be related to their low emulsion stability and so, high water losses. In addition, these differences in moisture content among samples would be responsible for the differences in fat and protein content. It is important to notice that although reformulated pâtés (PGEH10 and PGEH20) showed the highest fat content, their cholesterol content was the lowest ($p < 0.05$) (Table 2). In this case, the substitution of animal fat by the Hemp-GE had a positive effect in the reduction of cholesterol in pâtés which is in line with the nutritional recommendations for the development of healthier meat products. Undoubtedly, cholesterol reduction is related to the decrease in the animal fat content in the reformulated pâtés (Domínguez et al., 2016; Martins et al., 2020; Vargas-Ramella et al., 2020). Pâtés are considered good sources of minerals mainly Fe, Mg, and K (Brito et al., 2006; Lucas-González et al., 2019). The reformulation of pâtés had no significant effect on their mineral profile ($p > 0.05$). Only slight differences in the content of Mn resulted statistically significant ($p < 0.05$). Heme iron is an essential micronutrient that promotes growth, supports neurocognitive development, and ensures the proper functioning of the immune system (Assandri et al., 2018). Additionally, iron is actively engaged in the synthesis of essential proteins such as hemoglobin, myoglobin, and specific enzymes. It should be noticed that this reformulation didn't affect ($p < 0.05$) the proportion of heme iron in pâté samples. This is important because the possible increase in non-heme iron could have negative consequences in both, the nutritional and technological properties of pâtés. Regarding that, heme iron is more bioavailable than non-heme iron (Hunt & Roughead, 2000) and, furthermore, non-heme iron (released from the heme molecule) could have a greater effect on promoting oxidation processes in pâtés (Estévez & Cava, 2004).

3.3. Main fatty acids composition and nutritional analysis

Forty-one fatty acids were measured (g/100 g), of which the 17 major ones are showed in Table 3, accounting for 94.91 % of the total fatty acids in control sample (CP), 95.22 % in PGEH10 and 95.76 % in PGEH20. Pâté samples showed statistical differences ($p < 0.05$) in fatty acids profile depending on the replacement level (0, 10 % or 20 %). The use of the Hemp-GE decreased the amount of palmitic acid (C16:0), stearic acid (C18:0), oleic acid (C18:1 n-9), vaccenic acid (C18:1 n-7) and increased linoleic acid (C18:2 n-6) and alpha-linolenic acid (C18:3 n-3) ($p < 0.05$). However, palmitoleic acid (C16:1 n-7) and myristic acid (C14:0) content did not show differences ($p > 0.05$) between PGEH10 and control sample but did show respect to PGEH20 ($p < 0.05$). The 4 fatty acids predominant in all samples were oleic, miristic, palmitic, and linoleic acid but in different order depending on the % of fat replacement: in CP the order was oleic > palmitic > stearic > linoleic acid; in PGEH10 the order was oleic > palmitic > linoleic > stearic; in PGEH20 the order was oleic > linoleic = palmitic > stearic. The higher the fat replacement level by Hemp-GE, the higher the predominance of linoleic acid.

MUFA represented the most abundant fraction in all samples, with levels between 44.74 % (PGEH10) to 47.60 % (CP). Oleic acid decreased by about 6% in PGEH10 and 21% in PGEH20, compared to the control. The increase in PUFA content due to the use of Hemp-GE ranged from 49% (PGEH10) to 77% (PGEH20). Quantitatively, linoleic acid was the predominant fatty acid in this fraction (PUFA), representing in all samples more than 50% and reaching increasement level of 45 % for PGEH10 and 70 % for PGEH20, respect to CP. In the case of alpha-linolenic acid (the second one more important in PUFA fraction), the increase was from values of 0.51 g/100 g fat for the CP sample to values of 2.23 g/100 g fat in PGEH10 and to 3.56 g/100 g fat in PGEH20, representing fourfold and sevenfold increase, respectively, compared to the CP. This fact agreed with the fatty acid composition of the hemp oil used to obtain the gelled emulsion (Botella-Martínez, Pérez-Álvarez, et al., 2021; Cittadini et al., 2022; Domínguez et al., 2017) and it is also responsible for the increase in the omega 3 (n3) and omega 6 (n6). Similar values were obtained in the study carried out by Zajac and Światek (2018), in which the addition of hemp seed products to poultry liver pâtés resulted in similar values to those obtained for the PGEH20 sample of the present study in terms of the fatty acid profile, especially in the values of linoleic and alpha-linolenic acid.

A similar trend was also reported, with a decrease in SFA and an increase in MUFA and PUFA depending on the fat source used in several studies in which pâtés were reformulated using fat substitutes with different oils and structuring technologies (microencapsulation, oleogels and hydrogels) (Barbut et al., 2019; Cittadini et al., 2022).

3.4. Health indices of reformulated pâté

Table 3 shows the health indices of pâtés. The PUFA/SFA ratio is considered a good indicator of nutritional quality and in this case, only PGEH10 and PGEH20 showed values higher than 0.4 (PGEH20 >PGEH10), the limit recommended for WHO and FAO in meat products (Oliveira et al., 2023). Control pâté, with a value of 0.35, is under this recommended PUFA/SFA limit ($p < 0.05$).

For the omega-6 to omega-3 (n6/n3) ratio a decrease was observed in reformulated pâtés, indicating a positive result. Because the n-6/n-3 ratio has been linked to a number of pathogenic processes, recent research has emphasized the significance of both lowering it and increasing the amount of polyunsaturated fatty acids (PUFA) in the diet (Mariamenatu & Abdu, 2021). Research demonstrates that PUFA, especially n-3, can relieve symptoms of metabolic syndrome and lower the risk of heart disease by oxidizing fat instead of storing it (Clarke, 2001). It is commonly known that n-3 PUFA intake has health advantages for both treating and avoiding metabolic syndrome and inflammation (Wei et al., 2021).

The directional impact of lipids eaten may be shown by the fatty acid indices (AI, TI, and h/H). Several unhealthy effects have been attributed to different SFA, for example, C14:0, C16:0, and C18:0 have been associated with thrombogenic effects, and C12:0, C14:0, and C16:0 have demonstrated atherogenic effects (increasing total cholesterol and LDL fraction (FAO, 2010). The atherogenic and thrombogenic indices and the hypocholesterolemic-hypercholesterolemic ratio are recommended to be as low as possible for the first two (AI and TI) and as high as possible for the last one (h/H) (FAO, 2008; Abid et al., 2021). Table 3 shows that the use of Hemp-GE as an animal fat replacer, significantly improved the AI, TI, and h/H indices respect to control pâté, being this improvement greater at a higher substitution level ($p < 0.05$).

3.5. Physico-chemical analysis

Slight pH differences between samples were found resulting in statically different ($p < 0.05$) only for PGEH20 samples (the lowest pH value). In addition, all pâtés showed pH values ranging from 6.18 to 6.23 (Table 4) which is according with normal pH values for pâtés (Lucas-González et al., 2019; Sánchez-Zapata et al., 2013). In this case, it could be said that the substitution of animal fat for Hemp-GE didn't cause important pH changes. In line with that, this fat replacement also did not lead to changes in water activity ($p > 0.05$) for the pâtés. The water activity values (Aw) did not show statistically significant differences ($p > 0.05$) for any of the three samples tested.

Regarding the color of liver pâtés, it is principally derived from the color displayed by the fats, livers, and muscles used for their manufacture (Estévez & Cava, 2004; Vargas-Ramella et al., 2022). Therefore, as the source of fat seems to be relevant in the color of pâtés and trying to ensure that color changes were as few as possible or that such changes did not result in such color modifications that they could not be associated with the original meat product, to assess the color modifications in this reformulation is of great importance. In this case, the replacement

Table 4
Physicochemical parameters and textural properties of pâté with hemp oil gelled emulsion as partial animal fat replacer.

Sample	CP	PGEH10	PGEH20
pH	6.21 ± 0.01[a]	6.23 ± 0.01[a]	6.18 ± 0.01[b]
Aw	0.891 ± 0.00[a]	0.893 ± 0.00[a]	0.891 ± 0.00[a]
*L**	58.56 ± 1.67[a]	57.64 ± 0.29[ab]	57.19 ± 0.84[b]
*a**	6.98 ± 0.26[a]	6.46 ± 0.18[b]	6.35 ± 0.51[b]
*b**	12.95 ± 0.59[a]	13.06 ± 0.22[a]	13.00 ± 0.53[a]
*C**	14.71 ± 0.60[a]	14.57 ± 0.19[a]	14.48 ± 0.55[a]
h	61.65 ± 0.92[b]	63.66 ± 0.83[a]	63.98 ± 1.91[a]
ΔE	–	2.07 ± 0.59[a]	1.16 ± 0.51[b]
Firmness (N)	0.38 ± 0.05[a]	0.21 ± 0.03[b]	0.18 ± 0.02[b]
*Shear work (N*s)*	0.40 ± 0.07[a]	0.22 ± 0.03[b]	0.19 ± 0.02[b]

CP: control pâté; PGEH10: pâté with 10% hemp oil gelled emulsion as animal fat substitute; PGEH20: pâté with 20% hemp oil gelled emulsion as animal fat substitute.
Data are presented as mean ± SD. Different letters (a-b) in the same row indicate statistically significant differences as determined by Tukey's HSD post-hoc test ($p < 0.05$).

of animal fat by Hemp-GE in pâtés didn't result in strong color changes. Yellowness and saturation of pâtés were not affected ($p > 0.05$) by fat replacement. Although PEGH10 and PEGH20 showed L* and a* values lower but higher h* values than control samples ($p < 0.05$), it should be highlighted that in any case, these differences were no higher than 2 units, and so have not practical meaning. Moreover, based on h* values, all pâtés samples showed a hue color defined as orange-yellowish (IRANOR, 1981). Similar results have been observed in other studies such as the one carried out by Skałecki et al. (2021); Zajac & Świątek. (2018); Županjac et al. (2023a) using other sources of fat and other levels of substitution in pâtes, where statistically significant differences did not exceed the 2 units mentioned above. The differences in color between the three samples evaluated were determined with ΔE. This parameter showed that the change in the color between the CP sample and PGEH10 was noticeable with 2.07 units of difference and less difference there were between the CP sample and PGEH20 with 1.16 units of difference. Showing statistical differences ($p > 0.05$) among PGEH10 and PGEH20. It is crucial to emphasize that the human eye is incapable of perceiving color variations (ΔE*) smaller than three units (Goswami et al., 2015; Martínez et al., 2001).

3.6. Texture profile

Regarding texture, pâté should show a fairly homogeneous mass because it is a finely comminuted meat product composed of a mixture of protein, fat globules, water, salt, and spices. This mixture has a paste-like texture in the raw state that gradually should change into a more "rigid" structure by gelation of proteins (denaturation) throughout the cooking process allowing their participation in protein–protein interactions. Microstructurally, the presence of pores and the degree of packing of this protein structure have been related to the spreadability of the pâté (Terrasa et al., 2016). Table 4 displays the impact of the replacement of animal fat by Hemp-GE in pâtes. The reformulated pâtés (PGEH10 and PGEH20) exhibited a noteworthy decrease (without differences between them) in both texture parameters (firmness and shear work) ($p < 0.05$) respect to those of the control sample. From a physical perspective, the decrease in firmness and shear work in meat batters have been related to an improvement in their spreadability (Terrasa et al., 2016) because it refers to the capacity of elasto-viscoplastic materials to deform (Rezler et al., 2021). Consequently, it should be said that the use of Hemp-GE as animal fat replacers in pâtés enhanced their spreadability. Although there are a lot of factors that can influence the textural parameters of a meat product like pâté, such as the raw materials used (type and quantity), the fat source used and how it is incorporated (animal fat, gelled emulsion, oleogel, oil liquid, oil encapsulated, etc.), how the meat proteins interact with fat, and the procedures followed during the pâté processing (Martins et al., 2020; Morales-Irigoyen et al., 2012; Rezler et al., 2021) it seems clear that the substitution of animal fat by vegetable oils reduces the firmness, hardness, penetration test, and shear work of pâtés and so enhancing spreadability. For example, Županjac et al. (2023) reported that the replacement of animal fat (20 and 40%) by oleogel with sunflower oil reduced the firmness and work of shear in 16 and 40% respectively each substitution.

3.7. Lipid oxidation

The assessment of liver pâtés' oxidative stability was conducted using the TBARs index, which results are shown in Fig. 2. This index is commonly employed as an indicator of lipid oxidation (Estévez et al., 2005). Lipid oxidation carries negative implications in meat products due to the development of undesirable rancid flavors and a decline in nutritional value (Estévez et al., 2005; Martin et al., 2008)). Regarding lipid stability, traditional pâté is typically regarded as a type of meat product susceptible to oxidation since it is a highly processed product with high fat content and low natural antioxidant levels, affecting their safety, sensory and quality, including color, texture and nutritional value (Cittadini et al., 2022; Skałecki et al., 2021). Several factors, including the complex matrix, the manufacturing process (grinding and heating), and the high fat content, can influence the lipid oxidation of pâtés (Lima et al., 2013). The substitution of animal fat by the Hemp-GE in pâtés resulted in increased TBARs values (both PGEH10 and PGEH20, without differences between them) in comparison with CP ($p < 0.05$). Oils with a high content of PUFAs are more susceptible to oxidation than animal fat, despite being incorporated in a gelled structure and a meat matrix, as previously observed in other products where some gelled emulsions were used as fat replacement (Botella-Martínez, Viuda-Martos, et al., 2021, 2022; Martins et al., 2020; Nacak et al., 2021). However, it's important to emphasize that all pâté samples showed TBARs below the sensory range (2.0 mg MDA/kg sample) at which consumers detect rancidity taste, or odor. This same tendency was observed by other researchers in several meat products like burgers, sausages, frankfurter and dry fermented sausages, among others, when an oleogel or gelled emulsion was used as replacement of animal fat (Glisic et al., 2019; Heck et al., 2019; Öztürk-Kerimoğlu et al., 2021). In the case of pâtés, when the oil (fish oil) was incorporated microencapsulated, no differences were found in the lipid oxidation between reformulated pâtés and control (Vargas-Ramella et al., 2022). In other studies, such as that of Vargas-Ramella et al. (2020), great variability of TBARS values of pâté samples, between 0.26 and 0.64 mg MDA/Kg of product was observed, depending on the oil used for the microencapsulation.

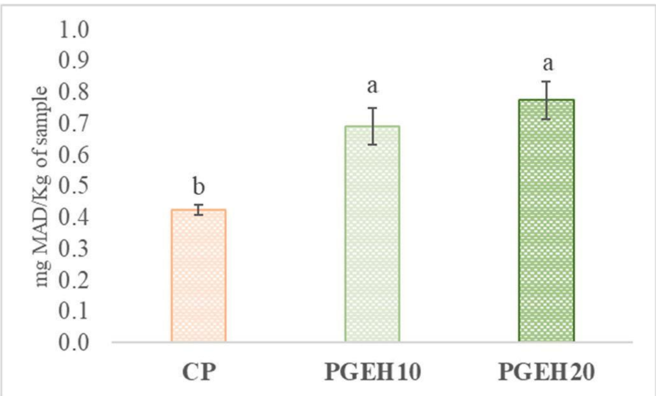

Fig. 2. Lipid oxidation of pâté with hemp oil gelled emulsion as partial fat replacer
CP: control pâté; PGEH10: pâté with 10% hemp oil gelled emulsion as animal fat substitute; PGEH20: pâté with 20% hemp gelled emulsion as animal fat substitute.
Data are presented as mean ± SD. Different letters indicate statistically significant differences as determined by Tukey's HSD post-hoc test ($p < 0.05$).

3.8. Sensory evaluation

Consumer acceptance is a fundamental requirement for the economic viability of innovative food components and, consequently, food products. The appearance, flavor, and aroma of the product stand out as the main factors influencing the consumer's purchasing decisions (Skałecki et al., 2021; Smarzyński et al., 2019). The outcomes of the sensory assessment are depicted in Fig. 3a. Among the sensory attributes evaluated (color, brightness, overall odor, rancidity, spreadability, juiciness, cohesiveness, hardness, overall flavor, and general appearance), only the overall odor, rancidity, spreadability, and juiciness showed significant differences ($p < 0.05$) between PGEH20 and control samples. CP and PGEH10 samples did not show significant differences ($p > 0.05$) for any of the 10 evaluated attributes. The decrease in the scores for spreadability and juiciness in PGEH20 may be due to the higher presence of unbound lipids in 100% pork fat pâtés (CP) compared to the PGEH20 pâtés. It has been reported that vegetable oil tends to form bonds within the gelled emulsion (GE) network, reducing the likelihood of rapid expulsion from the structure (Barbut et al., 2021). This fact is in accordance with the decrease in emulsion stability of the reformulated pâtes (Fig. 1). Panellist detected rancidity in PGEH20, although, as has been previously discussed, this pâte showed TBARS values below the reported detection limit of consumers (section 3.7). In this case, maybe the low scores for overall odor obtained in PGEH20, mainly associated to the particular odor of hemp oil, could be identified as rancidity odors. Furthermore, there were no significant differences in overall acceptance between pâtés ($p > 0.05$) with scores in all cases higher than 5 (7 points hedonic scale) ($p > 0.05$). These results should indicate no changes in the acceptability of pâtés with animal fat replacers (by Hemp-GE emulsion) compared to traditional pâtés. Different results in overall acceptance in reformulated pâtés changing the fat source have been obtained. For example Vargas-Ramella et al. (2022), did not find differences in overall acceptance in pâtes in which the 25 and 50% of the animal fat were replaced with microencapsulated fish oil. But Cittadini et al. (2022) found differences in overall acceptance in pâtés in which 50% of foal fat was replaced by two mixture of microencapsulates oils; walnut oil-seaweed oil and pistachio-seaweed oil.

4. Conclusion

The reformulation of pâté by the partial replacement (10 and 20%) of animal fat by a gelled emulsion made with hemp oil and buckwheat flour is a technologically feasible option and an effective way to enhance their nutritional quality, mainly focus on a healthier lipid profile (increasing PUFA and an omega-3-fatty acid contents and decreasing cholesterol content), without significantly affecting the sensorial acceptability. Although the increase in PUFA resulted in a faster lipid oxidation, in any case the resulting compounds were higher than the sensorial detection limit by consumers. The reformulation of traditional meat products with the aim of making them healthier but without modifying their typical sensory characteristics can contribute to maintaining the gastronomic heritage of the different regions adapted to new scientific knowledge and consumer demands.

CRediT authorship contribution statement

Carmen Botella-Martínez: Writing – original draft, Methodology, Investigation. **José Ángel Pérez-Álvarez:** Validation, Resources, Funding acquisition, Conceptualization. **Juana Fernández-López:** Writing – review & editing, Supervision, Investigation, Formal analysis, Conceptualization. **Manuel Viuda-Martos:** Writing – review & editing, Supervision, Investigation, Conceptualization.

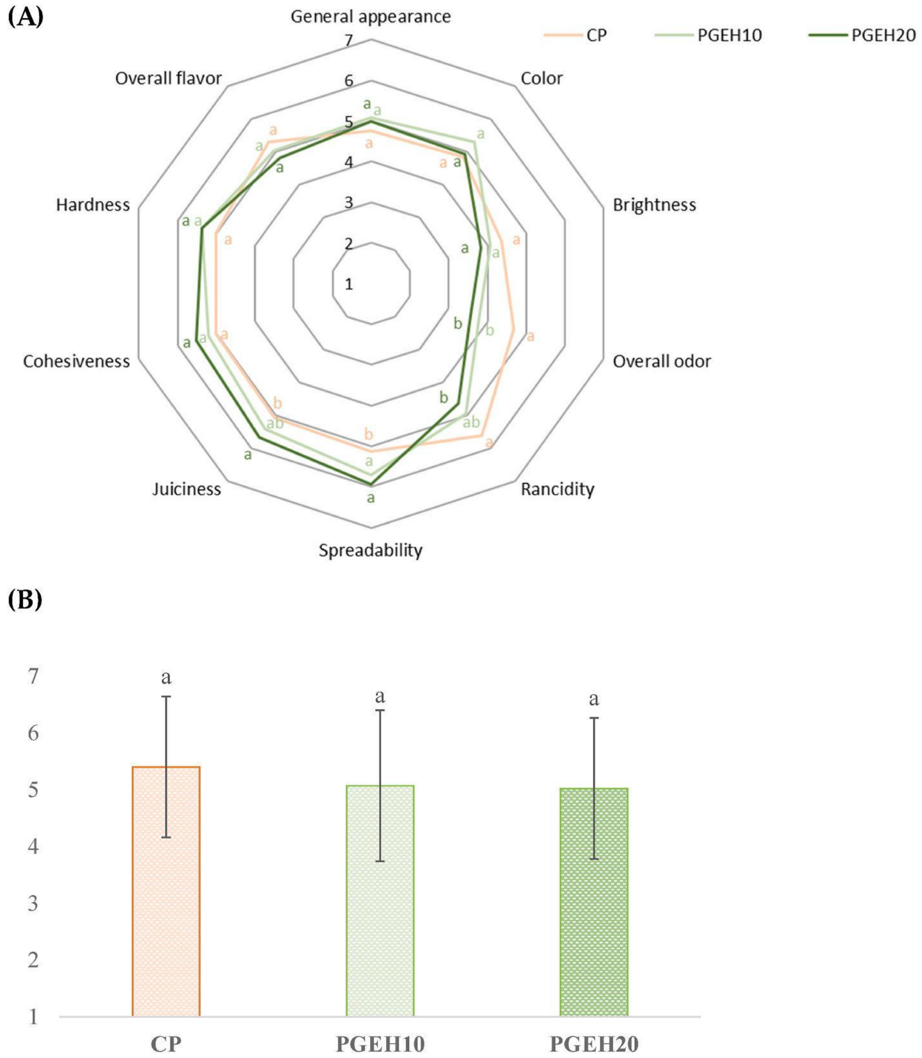

Fig. 3. Sensory evaluation (A) and overall acceptance (B) of pâtés with hemp oil gelled emulsion as partial animal fat replacer.
CP: control pâté; PGEH10: pâté with 10% hemp gelled emulsion as animal fat substitute; PGEH20: pâté with 20% hemp gelled emulsion as animal fat substitute. Data are presented as mean ± SD. Different letters indicate statistically significant differences as determined by Tukey's HSD post-hoc test ($p < 0.05$).

Declaration of competing interest

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

Data availability

Data will be made available on request.

Acknowledgments

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

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