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IMPACT OF REPLACING BEEF FAT WITH WALNUT OIL AND WALNUT CAKE ON THE PHYSICAL AND TECHNO-CHEMICAL PROPERTIES OF BEEF PATTIES

SUMMARY

The aim of the study was to examine the effect of replacing beef fat with walnut oil and walnut cake on the physical and techno-chemical properties of beef patties. In this research, nine experimental groups of beef patties were produced in which beef fat was replaced in different proportions: 15%, 30%, 45%, and 100% (BP 1, BP 2, BP 3, and BP 4) with walnut oil, as well as 15%, 30%, 45%, and 100% (BP 5, BP 6, BP 7, and BP 8) with walnut cake, including a control group with 100% beef fat (BP CON). Physical parameters (weight, volume, diameter and thickness) of the examined patties were measured before and after thermal processing, and based on these values, cooking parameters were determined, namely cooking yield, reduction in volume and diameter, and increase in thickness. After frying, the techno-chemical parameters of the beef patties were determined, which included the analysis of protein, fat, moisture, ash, NaCl content, as well as aw and pH values.The replacement of beef fat with walnut oil and walnut cake in different amounts affected all examined cooking parameters of the beef patties, as well as the techno-chemical parameters. The highest cooking yield and the least pronounced reduction in volume were recorded in the patty with 100% of beef fat replaced by walnut cake (BP 8), while the greatest increase in thickness was observed in samples BP 6 and BP 7 (30% and 45% replacement of beef fat with walnut cake). Sample BP 4 (complete replacement of beef fat with walnut oil) had the highest protein content and the lowest fat and moisture content. The highest ash and NaCl content was found in patties where fat was replaced with 30% and 45% walnut oil, while on average the lowest content of these two parameters was found in the patty with 15% fat replaced by walnut cake. The lowest pH value was recorded in the patty with

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100% of beef fat replaced by walnut cake (BP 8), and the highest in the patty with 15% of beef fat replaced by walnut oil (BP 1).

Keywords: beef patties, animal fat replacement, walnut oil, walnut cake

INTRODUCTION

Meat and meat products are important for a healthy and balanced diet because they contain high-quality proteins, fat-soluble vitamins, and minerals (Alasalvar *et al.*, 2022), but they are also a major source of fats with a high content of saturated fatty acids and cholesterol (Ibrahium *et al.*, 2015). Among meat products, burgers and patties are the most popular, and they are significant because they are sold as ready-made and fast food that is easy to prepare, and whose composition can be easily modified to improve nutritional properties (Serdaroğlu *et al.*, 2017). Patties contain a high amount of fat and saturated fatty acids, considering that about 30% animal fat is added during their production, which contributes to improving the organoleptic properties of the patties such as appearance, texture, aroma, and taste (Fadiloglu *et al.*, 2023). From a health perspective, the high content of saturated fatty acids in patties is the main disadvantage of these products (Alasalvar *et al.*, 2022), as their intake is associated with many diseases including various types of cancer, obesity, hypertension, cardiovascular and coronary diseases (Ibrahium *et al.*, 2015). Fat content can be improved by modifying the fatty acid profile and reducing fat and cholesterol content through lipids of plant and marine origin, which can be directly added to meat products as liquid oils or incorporated in encapsulated and emulsified forms (Nisa *et al.*, 2017). A number of studies have been carried out demonstrating that the replacement of animal fat with walnut oil improves the nutritional properties of beef patties (Slijepčević *et al.*, 2025; Raščić *et al.*, 2025; Fadiloglu *et al.*, 2023; Botella-Martinez *et al.*, 2021; Lucas-Gonzalez *et al.*, 2023). From a nutritional, health, and environmental perspective, walnut oil and walnut cake could be a promising substitute for animal fat in patties. Walnut oil contains monounsaturated fatty acids (primarily oleic acid) and polyunsaturated fatty acids (linoleic and linolenic), as well as many other bioactive compounds such as tocopherols, squalene, phytosterols, and polyphenols that contribute to its antioxidant and anti-inflammatory properties (Masoodi *et al.*, 2025). Polyunsaturated fatty acids, especially essential ones (linoleic and linolenic), are involved in the structure of cell membranes, regulation of blood pressure and coagulation, participate in the proper functioning of the immune system, influence the synthesis of pro- and anti-inflammatory substances, and protect the cardiovascular system (Mititelu *et al.*, 2024). During the production of walnut oil, a partially defatted cake is obtained, which contains polyunsaturated fatty acids, a high content of protein, fiber, and minerals (Burbano and Correa 2021). Additionally, walnut cake has a high content of total phenols and strong antioxidant capacity (Pop *et al.*, 2020). The selection of fat replacement levels (15%, 30%, 45%, and 100%) in the present study was based on previously published research on reformulated meat products. Literature data show that

partial replacement of animal fat with plant-based ingredients is most investigated within the range of 5-50%, while several studies also include complete (100%) fat substitution using different fat replacers such as vegetable oils, dietary fibres, and gel/emulsion systems. In this context, the selected partial replacement levels were chosen to ensure comparability with existing studies, whereas the inclusion of 100% replacement aimed to evaluate the technological feasibility of full animal fat substitution in beef patties and to provide a broader understanding of the functional effects of walnut oil and walnut cake across different substitution levels.

MATERIAL AND METHODS

Formation of patties. Walnut fruits used for oil production were procured in the Sarajevo Canton area, and were grown in the Krajina region (Bosnia and Herzegovina) from the Gajzenhajm-139 variety. The production of walnut oil was carried out under laboratory conditions, where the pressing of walnuts was performed using a manual screw press (Piteba, Netherlands). As a by-product of walnut kernel pressing during oil production, walnut cake was obtained. The obtained walnut oil was subjected to filtration, while the walnut cake was dried at room temperature. For the production of patties, beef (shoulder, chuck, and neck) and beef fat tissue were used, which were procured immediately after slaughter at Malak Farm, Kakanj, B&H. The meat and fat tissue were ground using a grinding device model MFW45020 (Bosch, Germany) to a diameter of 3.8 mm. The ground beef was divided into nine equal parts, after which weighing and addition of fat tissue were performed depending on the sample. A meat-to-fat ratio of 80:20 was used for patty production. After mixing the meat and fat mixture, food additives were added in equal amounts (ground black pepper (0.10%), table salt (2%), and baking soda (0.30%)). After manual mixing, the mixture was passed again through the meat grinder at 3.8 mm diameter for better homogenization, and then left to rest for 24 hours in a refrigerator at +4°C. After 24 hours, walnut oil and walnut cake were added to the mixture in different amounts depending on the sample (Table 1).

Table 1. The proportion of animal fat replacement in the tested samples

Sample	Animal fat (%)	Walnut oil (%)	Walnut cake (%)
BP CON	100	-	-
BP 1	85	15	-
BP 2	70	30	-
BP 3	55	45	-
BP 4	-	100	-
BP 5	85	-	15
BP 6	70	-	30
BP 7	55	-	45
BP 8	-	-	100

Then, balls weighing 120-125 g were formed from the mixture, and the characteristic round shape of patties was achieved using a forming device model Hamburgerpers 100 (Maxima, Netherlands). The patties were then fried in a pan on an induction cooktop (Easyline, Italy) at a temperature of 200°C, with the addition of approximately 15 ml of sunflower oil. The patties were fried until an internal temperature of 78°C was reached, measured with a digital thermometer. The frying time lasted approximately 4 minutes, 2 minutes on each side with constant turning. The fried patties were placed on paper towels to remove excess fat, after which measurements of physical and techno-chemical parameters of the beef patties were performed.

Analysis of the physical parameters of beef patties. Examination of the physical parameters of fresh and fried patties included the determination of weight (g) using a digital scale (Kern, Germany), volume (cm) and diameter (cm) using a tape measure (centimeter), and thickness (mm) using a digital sliding scale (Schubler). Examination of physical parameters was performed in two non-seeded repetitions on each sample. Based on the measurement values of the physical parameters of beef patties, the frying parameters (frying yield, reduction in volume and diameter, and increase in thickness) were calculated according to the following formulas (Alasalvar *et al.*, 2022; Ganjgo, 2017; Sánchez-Zapata *et al.*, 2010):

$$\textbf{\textit{Cooking yield}}\ (\%) = \frac{cooked\ weight}{uncooked\ weight} x100$$

$$\textbf{\textit{Diameter reduction}}\ (\%) = \frac{raw\ diameter - \ cooked\ diameter}{raw\ diameter} x100$$

$$\textbf{\textit{Volume reduction}}\ (\%) = \frac{raw\ volume - cooked\ volume}{raw\ volume} x100$$

$$\textbf{\textit{Thickness increase}}\ (\%) = \frac{raw\ thickness - \ cooked\ thickness}{raw\ thickness} x100$$

Analysis of techno-chemical parameters of beef patties. Protein content was determined by BAS ISO 937:2007, fat content by BAS ISO 1443:2007, moisture content by BAS 1442:2007 and ash content by BAS ISO 936:2007. Determination of NaCl was performed by Mohr titration using 0.1 M AgNO3 and 5% potassium chromate as indicator (E. K. 8045, JUS., 1993). pH was measured using pH meter (FiveGo TM F2, Mettler Toledo, Switzerland), and aw value of the samples was measured using an aw meter (LabSwift – aw, Novasina, Switzerland).

Statistical analysis. Statistical data processing was performed using the Past 3.15 software (Hammer *et al.*, 2001). To determine the effect of the amount of animal fat replacement with walnut oil and walnut cake on the examined parameters of beef patties, a one-way analysis of variance was applied, and in the case of statistically significant differences, the Tukey post-hoc test was used (significance level α=0.05).

RESULTS AND DISCUSSION

Physical parameters of beef patties before and after frying. Table 2 presents the results of measuring the weight, volume, diameter, and thickness of fresh and fried beef patties. One-way analysis of variance showed that the experimental factor (amount of animal fat replaced with walnut oil and walnut cake) had a statistically significant effect on the values of all examined parameters of fresh and fried beef patty samples ($p < 0.05$), except for the diameter of fresh patties ($p>0.05$). Table 2 shows that frying caused a reduction in the weight, volume, and diameter of beef patties, while thickness values increased. Samples with the addition of walnut cake had, on average, higher values for all parameters before and after frying compared to samples with the addition of walnut oil.

Table 2. Results of measuring physical parameters of beef patties before and after frying

Sample	Before frying				After frying			
	Weight (g)	Volume (cm)	Diameter (cm)	Thickness (mm)	Weight (g)	Volume (cm)	Diameter (cm)	Thickness (mm)
BP CON	$125,14^{f}$ ±0,02	$31,70^{b,c}$ ±0,14	$9,90^{a}$ ±0,14	$16,03^{c,d}$ ±0,01	$106,97^{e}$ ±0,00	$28,25^{d}$ ±0,35	$8,90^{d}$ ±0,14	$19,17^{c,d}$ ±0,14
BP 1	$121,49^{a}$ ±0,00	$32,10^{d}$ ±0,14	$9,90^{a}$ ±0,14	$15,87^{c}$ ±0,13	$95,76^{b}$ ±0,02	$26,40^{a}$ ±0,00	$8,75^{b}$ ±0,35	$18,99^{b,c,d}$ ±0,05
BP 2	$124,89^{d}$ ±0,02	$31,50^{a,b}$ ±0,00	$10,05^{a}$ ±0,07	$15,91^{c}$ ±0,08	$94,04^{a}$ ±0,04	$27,05^{b}$ ±0,07	$8,15^{a}$ ±0,21	$18,75^{b,c}$ ±0,23
BP 3	$124,65^{c}$ ±0,00	$31,50^{a,b}$ ±0,00	$10,00^{a}$ ±0,00	$15,84^{c}$ ±0,01	$94,04^{a}$ ±0,01	$27,95^{c,d}$ ±0,07	$8,85^{c,d}$ ±0,21	$18,50^{a,b}$ ±0,11
BP 4	$124,22^{b}$ ±0,00	$31,50^{a,b}$ ±0,00	$9,70^{a}$ ±0,14	$14,59^{a}$ ±0,04	$98,95^{c}$ ±0,05	$28,20^{d}$ ±0,00	$8,90^{d}$ ±0,14	$17,91^{a}$ ±0,11
BP 5	$125,53^{h}$ ±0,01	$31,90^{c,d}$ ±0,14	$10,00^{a}$ ±0,00	$15,91^{c}$ ±0,09	$111,60^{g}$ ±0,01	$28,00^{d}$ ±0,00	$8,55^{d}$ ±0,07	$19,84^{e}$ ±0,28
BP 6	$125,53^{h}$ ±0,01	$31,50^{a,b}$ ±0,00	$10,00^{a}$ ±0,00	$15,86^{c}$ ±0,02	$107,59^{f}$ ±0,01	$27,45^{b,c}$ ±0,07	$8,65^{b,c}$ ±0,21	$21,26^{f}$ ±0,02
BP 7	$125,36^{g}$ ±0,00	$31,50^{a,b}$ ±0,00	$10,00^{a}$ ±0,00	$16,26^{d}$ ±0,03	$103,75^{d}$ ±0,02	$28,10^{d}$ ±0,14	$9,10^{d}$ ±0,14	$21,24^{f}$ ±0,23
BP 8	$124,96^{e}$ ±0,03	$31,20^{a}$ ±0,14	$9,85^{a}$ ±0,21	$15,51^{b}$ ±0,10	$114,57^{h}$ ±0,00	$28,45^{d}$ ±0,07	$8,70^{d}$ ±0,42	$19,51^{d,e}$ ±0,04

**a-h Different lowercase letters in rows indicate statistically significant differences in the values of the tested parameters of beef patties depending on the amount of replacement of animal fat with walnut oil and cake. BP CON – 100 % beef fat; BP 1- replacement of 15 % beef fat with walnut oil; BP 2 - replacement of 30 % beef fat with walnut oil; BP 3 - replacement of 45 % beef fat with walnut oil; BP 4 – 100 % walnut oil; BP 5 - replacement of 15 % beef fat with walnut cake; BP 6 - replacement of 30 % beef fat with walnut cake; BP 7- replacement of 45 % beef fat with walnut cake; BP 8 – 100 % walnut cake*

The weight of the examined patties before frying ranged from 121.49 g to 125.53 g, and after frying from 94.04 g to 114.57 g. The volume of fresh beef patties varied from 31.20 cm to 32.10 cm, and of fried patties from 26.40 cm to 28.45 cm. The diameter of beef patties before frying ranged from 9.70 cm to 10.05 cm, and after frying from 8.15 cm to 9.10 cm, while the thickness of fresh patties varied from 14.59 mm to 16.26 mm, and of fried patties from 17.91 mm to

21.26 mm. Compared to this study, Ganjgo (2017) reported a wider range of weights for fresh chicken patties (from 131.79 g to 142.44 g), and slightly lower for fried patties (from 90.26 g to 104.14 g). Additionally, in the mentioned study, the values of volume and diameter of patties before (38.06-38.44 cm and 11.54-12.02 cm) and after frying (31.58-33.22 cm and 9.30-9.89 cm) were higher than in this study. Before frying, the highest weight was observed in samples BP 5 and BP 6 (15% and 30% of beef fat replaced with walnut cake), while the lowest was BP 1 (15% of beef fat replaced with walnut oil). However, after frying, samples BP 2 and BP 3 had the lowest weight, while the highest mass retention was recorded for sample BP 8 (complete replacement of beef fat with walnut cake). The largest initial volume was recorded in sample BP 1, and the smallest in sample BP 8. After frying, the lowest volume values were found in sample BP 1, while the highest were in sample BP 8, which did not differ statistically in circumference from BP CON (control sample), BP 3, BP 4, BP 5, and BP 7 (fat replaced with 100% walnut oil, 15% and 45% walnut cake). The lowest diameter values were observed in sample BP 2 (30% replacement of beef fat with walnut oil), and the highest in sample BP 7, which did not differ statistically in diameter from BP CON, BP 3, BP 4, BP 5, and BP 8. Sample BP 4 had the lowest thickness before and after frying, while the greatest thickness before frying was observed in sample BP 7. Samples BP 6 and BP 7 had the greatest thickness after frying.

Cooking parameters of beef patties. Table 3 presents the changes in parameters (weight, volume, diameter, and thickness) after frying the beef patties.

Table 3. Cooking parameters of beef patties

Sample	Cooking yield (%)	Volume reduction (%)	Diameter reduction (%)	Thickness increase (%)
BP CON	$85,48^{f}\pm0,01$	$10,88^{b,c}\pm0,72$	$10,10^{a}\pm0,14$	$19,59^{a,b}\pm0,99$
BP 1	$78,82^{c}\pm0,02$	$17,76^{f}\pm0,36$	$11,63^{a}\pm2,31$	$19,63^{a,b}\pm0,65$
BP 2	$75,30^{a}\pm0,02$	$14,13^{e}\pm0,22$	$18,91^{b}\pm1,54$	$17,89^{a}\pm2,00$
BP 3	$75,44^{b}\pm0,01$	$11,27^{b,c}\pm0,22$	$11,50^{a}\pm2,12$	$16,76^{a}\pm0,57$
BP 4	$79,65^{d}\pm0,04$	$10,48^{b}\pm0,00$	$8,25^{a}\pm0,12$	$22,72^{b,c}\pm0,37$
BP 5	$88,90^{h}\pm0,00$	$12,22^{c,d}\pm0,39$	$14,50^{a,b}\pm0,71$	$24,71^{c}\pm1,01$
BP 6	$85,70^{g}\pm0,02$	$12,86^{d,e}\pm0,22$	$13,50^{a,b}\pm2,12$	$34,06^{d}\pm0,31$
BP 7	$82,76^{e}\pm0,02$	$10,79^{b,c}\pm0,45$	$9,00^{a}\pm1,41$	$30,63^{d}\pm1,62$
BP 8	$91,69^{i}\pm0,02$	$8,81^{a}\pm0,19$	$11,70^{a}\pm2,41$	$25,76^{c}\pm0,57$

**a-i Different lowercase letters in rows indicate statistically significant differences in the values of the tested parameters of beef patties depending on the amount of replacement of animal fat with walnut oil and cake. BP CON – 100 % beef fat; BP 1- replacement of 15 % beef fat with walnut oil; BP 2 - replacement of 30 % beef fat with walnut oil; BP 3 - replacement of 45 % beef fat with walnut oil; BP 4 – 100 % walnut oil; BP 5 - replacement of 15 % beef fat with walnut cake; BP 6 - replacement of 30 % beef fat with walnut cake; BP 7- replacement of 45 % beef fat with walnut cake; BP 8 – 100 % walnut cake.*

One-way analysis of variance showed that the experimental factor (amount of animal fat replaced with walnut oil and walnut cake) had a statistically significant effect on all examined parameters of beef patty samples ($p<0.05$). Table 3 shows that the group of samples in which beef fat was replaced with walnut cake had, on average, a higher cooking yield, less pronounced reduction in volume and diameter, and a more pronounced increase in thickness than the group in which beef fat was replaced with walnut oil.

The cooking yield of the examined beef patties ranged from 75.30% to 91.69%, with the highest cooking yield, i.e., the lowest mass loss during frying, recorded for sample BP 8 (complete replacement of beef fat with walnut cake), while the lowest cooking yield was observed for sample BP 2 (30% of beef fat replaced with walnut oil). In the study by Barros *et al.,* (2020), the cooking yield of beef burgers ranged from 75.66% to 86.73%, with the highest yield recorded for a burger in which animal fat was completely replaced with a tiger nut oil-based emulsion, and the lowest yield for the control burger and the burger in which 50% of animal fat was replaced with the emulsion. Sánchez-Zapata *et al.*, (2010) reported a higher cooking yield for pork burgers, ranging from 80.20% to 92.64%, with the lowest yield in the control burger and the highest in pork burgers with 10% and 15% added tiger nut fiber. A lower cooking yield was observed in the study by Kirkyol and Akköse (2023), ranging from 68.48% to 90.81%, where, similar to this study, the highest yield was recorded in the beef patty in which 100% of animal fat was replaced with almond flour, and the lowest in the control patty (100% animal fat). Alasalvar *et al.,* (2022) reported a slightly lower cooking yield for beef burgers, ranging from 78.06% to 87.53%, with the highest yield for the burger in which 50% of animal fat was replaced with hazelnut oil microcapsules, and the lowest yield in the control burger. Ali *et al.,* (2011) also recorded a lower cooking yield for beef patties, ranging from 61.25% to 78.91%, with the highest yield observed in the patty where animal fat was completely replaced with potato flakes, and the lowest in the control sample (without fat replacement). The reduction in volume of the examined beef patties ranged from 8.81% to 17.76%. Compared to this study, Ganjgo (2017) reported a greater reduction in volume in chicken patties with different NaCl concentrations, ranging from 14.27% to 21.26%. Among all tested samples, the least pronounced reduction in volume was observed in sample BP 8 (complete replacement of beef fat with walnut cake), while the most pronounced reduction was found in sample BP 1 (15% of beef fat replaced with walnut oil). It is important to note that as the percentage of walnut oil and cake addition in patties increased, the reduction in volume for most samples became less pronounced. In addition, most samples showed a more pronounced reduction in volume than the control sample (BP CON), except for samples BP 4, BP 7, and BP 8 (100% replacement of beef fat with walnut oil, 45% and 100% with walnut cake). The reduction in diameter of the examined beef patties ranged from 8.25% to 18.91%. The patty with 30% of beef fat replaced with walnut oil (BP 2) showed the most pronounced reduction in diameter among all tested patties. The lowest average reduction in diameter in the

group with oil addition was observed in sample BP 4 (complete replacement of beef fat with walnut oil), and in the group with walnut cake addition in sample BP 7 (45% of beef fat replaced with walnut cake). However, these two samples did not differ statistically in diameter from the other tested samples with higher average values, except for sample BP 2 (30% beef fat replaced with walnut oil). A similar range of diameter reduction for beef patties was reported by Kirkyol and Akköse (2023), ranging from 7.63% to 18.75%, where the greatest reduction was in the control patty, and patties with 100% and 75% of animal fat replaced with almond flour showed the least reduction. Serdaroğlu *et al*., (2017) reported diameter reductions ranging from 9.52% to 17.64%, with the least reduction observed in the control chicken patty, while patties in which animal fat was partially or completely replaced with olive oil emulsion had a more pronounced reduction and did not differ significantly. In the study by Alves *et al*., (2020), the reduction in diameter of beef burgers ranged from 10.53% to 14.98%, and the examined beef burgers with reduced fat replaced by fructooligosaccharides in various amounts did not differ significantly in diameter reduction. The increase in thickness of beef patties ranged from 16.76% to 34.06%. Among all tested patties, the most significant increase in thickness was observed in sample BP 6 (30% of beef fat replaced with walnut cake), while sample BP 3 (45% of fat replaced with walnut oil) had the least pronounced increase. All samples in the group containing walnut cake showed a greater increase in thickness than the control sample. Sánchez-Zapata *et al*., (2010) reported a smaller degree of thickness increase in pork burgers, ranging from 4.50% to 10.20%, with the control sample showing the greatest increase, while burgers with 15% and 10% tiger nut fiber added had the least increase. Botella-Martinez *et al*., (2021) also observed smaller thickness increases in beef burgers, ranging from 7.14% to 12.48%, with the greatest increase in the control sample and the least in samples where 100% of animal fat was replaced with an emulsion of walnut oil and cocoa shell flour. A wider range of thickness increase in beef patties was reported by Bakhsh *et al*., (2021), ranging from 21.26% to 35.45%. In that study, the most pronounced thickness increase was observed in the control patty, while a less pronounced increase was recorded in patties with 40% added plant-based soy protein.

Techno-chemical parameters of beef patties. Table 4 presents the results of determining protein, fat, moisture, ash, NaCl content, water activity, and pH in fried beef patties. One-way analysis of variance showed that the experimental factor (amount of animal fat replaced with walnut oil and walnut cake) had a statistically significant effect on all techno-chemical parameters of beef patty samples ($p<0.05$), except for water activity ($p>0.05$).

On average, the group of samples containing walnut oil had higher protein, ash, and NaCl content, as well as a higher pH value, compared to the group containing walnut cake. The protein content in the examined beef patties ranged from 22.80% to 25.69%. The highest protein content was observed in sample BP

4 (complete replacement of beef fat with walnut oil), while the lowest was found in samples BP 6 and BP 7 (30% and 45% of beef fat replaced with walnut cake).

Table 4. Results of determining techno-chemical parameters of beef patties

Sample	Proteins (%)	Fat (%)	Moisture (%)	Ash (%)	NaCl (%)	a_w	pH
BP CON	$23,30^{a,b}$ ±0,27	$21,67^{f}$ ±0,45	$53,77^{c,d}$ ±0,03	$3,07^{a}$ ±0,05	$2,17^{b}$ ±0,02	$0,899^{a}$ ± 0,00	$6,04^{e}$ ±0,00
BP 1	$23,97^{b,c}$ ±0,17	$18,67^{c}$ ±0,21	$53,13^{b,c}$ ± 0,11	$3,47^{c,d}$ ±0,02	$2,47^{c}$ ±0,02	$0,900^{a}$ ± 0,00	$6,27^{g}$ ±0,04
BP 2	$24,15^{b,c,d}$ ±0,04	$16,90^{b}$ ±0,17	$53,65^{c}$ ±0,02	$3,58^{d}$ ±0,00	$2,51^{c}$ ±0,03	$0,897^{a}$ ± 0,00	$6,16^{f}$ ±0,02
BP 3	$23,86^{b,c}$ ±0,15	$17,25^{b}$ ±0,07	$52,72^{b}$ ±0,36	$3,59^{d}$ ±0,01	$2,51^{c}$ ±0,01	$0,893^{a}$ ±0,00	$6,11^{f}$ ±0,01
BP 4	$25,69^{e}$ ±0,08	$14,75^{a}$ ±0,11	$50,52^{a}$ ±0,13	$3,43^{b,c,d}$ ±0,04	$2,45^{c}$ ±0,05	$0,894^{a}$ ±0,00	$5,97^{c,d}$ ±0,01
BP 5	$24,26^{c,d}$ ±0,49	$19,73^{d}$ ±0,06	$54,75^{e}$ ±0,31	$3,02^{a}$ ±0,04	$2,06^{a}$ ±0,00	$0,896^{a}$ ±0,00	$5,92^{b,c}$ ±0,01
BP 6	$22,80^{a}$ ±0,15	$20,77^{e}$ ±0,27	$54,56^{d,e}$ ±0,13	$3,14^{a,b}$ ±0,00	$2,08^{a,b}$ ±0,00	$0,897^{a}$ ±0,00	$5,99^{d,e}$ ±0,03
BP 7	$22,91^{a}$ ±0,25	$20,85^{e,f}$ ±0,12	$53,39^{b,c}$ ±0,32	$3,23^{a,b,c}$ ±0,07	$2,10^{a,b}$ ±0,03	$0,897^{a}$ ±0,00	$5,90^{b}$ ±0,00
BP 8	$24,86^{d,e}$ ±0,01	$15,56^{a}$ ±0,27	$53,29^{b,c}$ ±0,01	$3,40^{b,c,d}$ ±0,21	$2,12^{a,b}$ ±0,01	$0,896^{a}$ ±0,00	$5,81^{a}$ ±0,01

**a-f Different lowercase letters in rows indicate statistically significant differences in the values of the tested parameters of beef patties depending on the amount of replacement of animal fat with walnut oil and cake. BP CON – 100 % beef fat; BP 1- replacement of 15 % beef fat with walnut oil; BP 2 - replacement of 30 % beef fat with walnut oil; BP 3 - replacement of 45 % beef fat with walnut oil; BP 4 – 100 % walnut oil; BP 5 - replacement of 15 % beef fat with walnut cake; BP 6 - replacement of 30 % beef fat with walnut cake; BP 7- replacement of 45 % beef fat with walnut cake; BP 8 – 100 % walnut cake.*

Lucas-González *et al.*, (2019) reported a similar range of protein content in pork burgers, ranging from 22.91% to 25.81%, with the highest in the control sample and the lowest in burgers where 10% of animal fat was replaced with a chestnut flour and chia oil-based emulsion. Ali *et al.*, (2011) observed a slightly narrower range of protein content in beef patties, ranging from 24.08% to 25.01%, where patties with animal fat replaced by hydrated potato flakes did not differ significantly in protein content. Serdaroğlu *et al.*, (2017) reported a higher

protein content in chicken patties, ranging from 25.14% to 26.67%, with the highest in patties where animal fat was completely replaced with olive oil emulsion, while the control and other reformulated patties did not differ significantly. Moghtadaei *et al.,* (2021) recorded a much lower protein content in beef burgers, ranging from 14.44% to 14.55%, with no significant differences in protein content between burgers partially replaced with ethylcellulose oleogel.

The fat content in the examined beef patties ranged from 14.75% to 21.67%. By group, samples containing walnut oil had, on average, lower fat content than samples containing walnut cake. The highest fat content was recorded in the control sample, while samples BP 4 and BP 8 (complete replacement of beef fat with walnut oil and walnut cake) had the lowest fat content. These results indicate that the addition of walnut oil and cake in beef patties reduces total fat content, as all tested samples had lower values than the control patty. Summo *et al.,* (2020) reported lower fat content in beef burgers (3.48%-8.42%), with the greatest reduction observed in burgers where animal fat was completely replaced with an oat-based gel, and the highest fat content in the control burger. Botella-Martínez *et al.,* (2021) reported fat content in beef burgers ranging from 12.30% to 16.48%, with the lowest fat in the control burger (100% animal fat) and the highest in burgers partially or completely replaced with walnut oil emulsion and cocoa shell flour. Ali *et al., (*2011) observed a significant fat reduction in beef patties (from 21.31% to 3.35%), with the highest fat in the control patty and the lowest in patties where fat was fully replaced with hydrated potato flakes. Moghtadaei *et al.,* (2021) reported a higher fat content range in beef burgers (22.00%-24.00%), with the lowest in burgers where 50% of animal fat was replaced with ethylcellulose oleogel.

Moisture content in the beef patties ranged from 50.52% to 54.75%. By group, samples containing walnut oil had, on average, lower moisture content than those containing walnut cake. The lowest moisture content was observed in sample BP 4 (complete fat replacement with walnut oil), and the highest in BP 5 (15% fat replaced with walnut cake). Lucas-González *et al.,* (2019) reported a narrower moisture content range in pork burgers (54.05%-54.68%), with no significant differences between control and partially replaced fat burgers. Moghtadaei *et al.,* (2021) found lower moisture content in beef burgers (32.74%-36.87%), with the control sample having the lowest and reformulated burgers with partial fat replacement (25% and 50%) the highest. Serdaroğlu *et al.,* (2017) reported slightly higher moisture content (54.81%-56.58%) in chicken patties, with the lowest in patties fully replaced with olive oil emulsion, consistent with this study where the lowest content was in patties with complete fat replacement with walnut oil.

Ash content in the examined beef patties ranged from 3.02% to 3.59%. The highest ash content was found in samples BP 2 and BP 3 (30% and 45% of beef fat replaced with walnut oil), while the lowest was in BP 5 (15% fat replaced with walnut cake) and BP CON (100% animal fat). Ali *et al*., (2011) reported slightly lower ash values in beef patties (2.81%-3.27%), with the lowest in the control and

highest in patties fully replaced with hydrated potato flakes. Serdaroğlu *et al.*, (2017) observed higher ash content in chicken patties (3.52%-3.77%), with the highest in the control and the lowest in patties with 50% olive oil emulsion replacement.

Moghtadaei *et al.*, (2021) reported significantly lower ash content in beef burgers (1.92%-1.97%), showing that replacement of animal fat with ethylcellulose oleogel did not affect ash content.

NaCl content in the examined beef patties ranged from 2.06% to 2.51%. Operta and Ganjgo (2019) reported lower NaCl content in chicken patties (1.43%-1.88%), while Subašić (2024) recorded 1.94% NaCl in beef patties. Sample BP 5 (15% fat replaced with walnut cake) had the lowest NaCl content, while BP 2 and BP 3 (30% and 45% fat replaced with walnut oil) had the highest values.

Water activity (aw) values of the examined beef patties ranged from 0.893 to 0.900. Replacement of beef fat with walnut oil and cake did not statistically significantly affect the water activity of the patties. On average, patties with oil or walnut cake had the same aw values. Lucas-González *et al.*, (2019) reported higher aw values for pork burgers (0.965-0.967), with no significant differences between control and fat-replaced burgers. Subašić (2024) recorded slightly higher aw values in beef patties (0.904).

The pH of the examined beef patties ranged from 5.81 to 6.27. Both groups of beef patties had a slightly acidic character; however, on average, patties containing walnut cake had a lower pH than those containing walnut oil. The highest pH was observed in sample BP 1 (15% beef fat replaced with walnut oil), and the lowest in BP 8 (100% beef fat replaced with walnut cake). Kirkyol and Akköse (2023) reported pH values of beef patties from 6.05 to 6.22, with the lowest in the control sample and the highest in patties with 100% and 75% animal fat replaced with almond flour. Ali *et al.*, (2011) reported pH values of beef patties ranging from 6.10 to 6.12, with no statistically significant difference between fat-replaced patties and the control. Sánchez-Zapata *et al.*, (2010) reported higher pH in pork burgers (6.37-6.40), with no significant difference between tiger nut fiber-added and control burgers. Serdaroğlu *et al.*, (2017) observed pH values ranging from 6.14 to 6.21, with the highest in the control chicken patty and the lowest in patties with 100% and 50% fat replaced with olive oil emulsion.

From a practical perspective, both walnut oil and walnut cake show potential as animal fat replacers in beef patties; however, their industrial applicability may differ. Walnut oil can improve the nutritional profile of meat products by increasing the proportion of unsaturated fatty acids, although its incorporation may increase production costs and susceptibility to oxidative changes during storage. In contrast, walnut cake represents a sustainable and economically attractive alternative, as it is a by-product of walnut oil production and contributes to the valorization of food industry residues. Furthermore, walnut cake provides additional nutritional benefits, including dietary fiber and protein.

Nevertheless, higher levels of walnut cake incorporation may affect product texture, color, and overall appearance, which could influence consumer acceptance. Therefore, balancing technological performance, nutritional enhancement, economic feasibility, and consumer preferences is essential when considering the industrial application of these ingredients in reformulated meat products.

CONCLUSIONS

The replacement of beef fat with walnut oil and walnut cake in different ratios affected the physical and techno-chemical parameters of beef patties. Based on the results of this study, it can be concluded that walnut oil and cake as a replacement for beef fat can contribute to improved physical properties of beef patties through increased cooking yield and thickness, as well as less pronounced reduction in diameter and volume. Furthermore, replacing beef fat with walnut oil and cake contributes to a reduction in total fat content, as patties with 100% beef fat replaced by walnut oil and cake (BP 4 and BP 8) had the lowest fat content. This is particularly important from a nutritional and health perspective, as conventional patties (100% animal fat) contain high levels of saturated fatty acids, while walnut oil and cake are sources of polyunsaturated fatty acids, thereby contributing to a more favorable nutritional profile when incorporated into the product.

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