Replacement of meat fat with olive oil and its effect on mortadella properties

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The use of healthy ingredients in the formulation of meat-based products has gained a growing interest. The effect of replacing meat fat with olive oil on mortadella properties was investigated. Mortadella was produced by the addition of the normal level of meat (control sample), low levels of meat fat with or without the addition of the replacements (olive oil 0%, 3%, 5%, and 8%), and the lipid reformulation effects on mortadella properties were studied. The results revealed that the control mortadella had the highest cholesterol content compared to the experimental treatments. Mortadella samples with 8% olive oil were less acceptable to the panellists. Juiciness and soft texture parameters of mortadella were not significantly different among the control and samples with 8% and 5% olive oil, nevertheless, they were significantly higher than lean and low-fat mortadella (0% and 3% olive oil, respectively). Lean meat samples (without any fat addition) received lower scores in terms of overall acceptability but had the lowest TBA value. The control sample had the highest saturated fatty acid percentage (52%) which was higher ($p<0.05$) when compared to samples incorporated with olive oil, however, it did not statistically differ when compared to lean meat mortadella. Mortadella sample produced with 3% olive oil exhibited the highest monounsaturated fatty acid percentage. This study demonstrated the importance of fat in mortadella products. The results indicated that the complete replacement of animal fat in mortadella by olive oil is not sensorially possible, however, a partial replacement of low levels of olive oil (3%-5%) can be successfully achieved.
Keywords: Mortadella, Fat replacement, Cholesterol, Sensory characteristics.

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1. INTRODUCTION

Fats and oils play vital functional and sensory roles in food products, since they carry, enhance, and release the flavour of other ingredients. Fats also aid in developing texture, mouth feel, and the overall sensation of lubricity and moistness in the mouth [1]. Besides their importance in the food industry, fats have positive nutritional aspects, since they are essential for the human body's process of cell building and repairing. Moreover, fats carry and aid the absorption of fat-soluble vitamins A, D, E, and K [2-3].

However, there are several health concerns associated with fat consumption that can promote obesity among other serious non-communicable diseases, including diabetes, cardiovascular disease (CVD), coronary heart disease, and hypertension [4]. The world health organisation has recently declared that it is mandatory to reduce the total fat intake (particularly saturated) to maintain a healthy diet since, according to previous studies, high-fat diets are linked to an increased risk of colon cancer [5-7].

In recent times, healthy eating has become an ongoing topic around the globe [5]. Thus, to meet consumers' demand for healthier foods, food technologists have put an emphasis on developing reduced-fat products without any adverse effect on their organoleptic properties, texture, and flavour [8,

9]. To succeed in developing low-fat palatable products, other ingredients have to be chosen to replace fat, since for instance, 20-30 g of fat per 100 g is necessary to make burgers avoiding compromising its quality traits [9]. These ingredients must impart the flavour and mouth feel that would normally be derived from fat [10]. Additionally, fat replacers must not only mimic the natural fat in delivering similar structural configuration and quality characteristics but should be healthier from a nutritional perspective than that of animal fat [11]. For example, [6] investigated the influence of partially and completely replacing pork backfat with soybean oil in mortadella. The authors declared that there were no differences ($p>0.05$) in any of the technological and physicochemical parameters evaluated, whereas mortadella incorporated with vegetable oil showed a higher unsaturated fatty acid content comparable to products made with pork backfat. However, treatments made with vegetable oil showed lower ($p\leq0.05$) sensorial perception than those made with pork fat on all the tested attributes. Similar findings were reported by [12] to substitute animal fat with vegetal fat.

In this study, olive oil was chosen to replace animal fat in mortadella. Olive oil, the primary source of fat in the Mediterranean diet, contains a high percentage (77%) of the monounsaturated oleic acid [13, 14]. This particular fatty acid reduces low-density lipoprotein (LDL) cholesterol and increases high-density lipoprotein (HDL) cholesterol [6]. Moreover, the mixture of oleic acid and polyphenolic compounds (which exist naturally in olive oil) imparts antioxidant and anti-inflammatory properties to olive oil, which tend to promote protection against the development of certain diseases such as CVD, diabetes (type II), and cancer [15].

To the best of our knowledge, there are no sufficient studies on a partial or total substitution of meat fat with olive oil in beef mortadella, with different fat levels and blends, particularly in Jordan. In this context, this study aimed to evaluate the possibility of optimising the fatty acid profile of mortadella by partially or completely replacing meat fat with olive oil, determine the properties of the developed products including sensory characteristics and lipid profile, and evaluate the effect of meat fat replacement with olive oil on cholesterol level of the product.

2. MATERIALS AND METHODS

2.1 MORTADELLA MANUFACTURE

Five mortadella treatments were formulated as shown in Table I. The formula of one of the local meat factories was used. One treatment (sample 1) was produced by the addition of the normal level of beef meat fat commercially used (i.e., the control group). The remaining four treatments were prepared by using lean beef with lower levels of meat fat with or without the addition of fat replacers (olive oil). Replacement levels used were 0%, 3%, 5%, and 8%, and were according to work done by many researchers [16-19].

2.2 RAW BATTER PREPARATION

Batches of mortadella were made using the formulations shown in Table I. Commercial olive oil and beef meat were purchased from a local market in Amman (Jordan). Tthe other ingredients used were obtained from a local meat factory (Siniora Factory, Amman, Jordan) where mortadella processing took place. Three treatments contained the replacer, olive oil (acidity 1.5%) at three levels (3%, 5%, and 8%) in the form of emulsion with soybean concentrate and water. Other ingredients were added in order, sodium tripolyphosphate, sodium nitrite, sodium ascorbate, garlic, and water (ice). The mixture was chopped for 2 minutes, then spices, soybean, and finally starch were added and chopped for 5 additional minutes. All ingredients added, except the beef fat amount and source, were constant for all treatments. The mixture was chopped for a total of 10 minutes; the

Table I - Formulations of reduced-fat mortadella samples prepared with the addition of olive oil

		Treatments				
Ingredients		**1**	**2**	**3**	**4**	**5**
Meat (%)	Normal fat level meat	81.3	-	-	-	-
	Reduced fat level meat (Lean)	-	81.3	73.3	76.3	78.3
Sodium nitrite (ppm)		120	120	120	120	120
Sodium tripolyphosphate (g)		60	60	60	60	60
Starch (%)		4.0	4.0	4.0	4.0	4.0
Soybean (%)		1.0	1.0	1.0	1.0	1.0
Salt (%)		2.0	2.0	2.0	2.0	2.0
Spices (%)		1.5	1.5	1.5	1.5	1.5
Sodium ascorbate (ppm)		500	500	500	500	500
Water (ice) (%)		10	10	10	10	10
Garlic (g)		20	20	20	20	20
Olive oil (%)		-	-	8.0	5.0	3.0
Total (Kg)		20	20	20	20	20

Treatments: 1 = control mortadella (normal fat level), 2 = lean mortadella (reduced fat level), 3 = lean meat + 8% olive oil, 4 = lean meat + 5% olive oil, 5 = lean meat + 3% olive oil.

final meat blend temperature was 15°C. Immediately after chopping, the batter was stuffed in polyethylene-based casings (a roll of 90mm diameter, 500g weight) using a stuffer (Handtman, Germany). The method of mortadella preparation and cooking used is according to an internal factory procedure.

2.3 OIL EMULSION PREPARATION

Olive oil was heated to 60°C and mixed with soybean and warmed water (80°C) at the ratio of (1:3:4) soybean concentrate (powder): olive oil: water, respectively in a bowel chopper (Alpina, Switzerland) for 5 minutes. The mixture was then frozen for one week prior to using. In treatments 3 and 4 (8% and 5% olive oil, respectively), the soybean concentrate incorporated was less than 1% to achieve a similar quantity of soybean concentrate to that in the other treatments.

2.4 COOKING AND STORAGE

Mortadella batches were thermally processed in an oven (Franco-Mat) with the following temperature/humidity cycles:

- Heating: 30 minutes at 55°C and 10% relative humidity (RH).
- Cooking at 80°C to reach 72°C internal temperature and 100% (RH).

Internal temperatures were measured by inserting the thermometer in the centre of the mortadella samples before cooling. After cooling the mortadella, samples were stored at 4°C until analysed. This procedure was followed for both the first and second experiments.

2.5 CHEMICAL ANALYSES

2.5.1 PH

Mortadella samples were homogenized in distilled water in a ratio of 1:10 sample/water, the pH was measured using a pH meter (model WPA, Cambridge) after proper calibration [20]. The measurements were performed in duplicate.

2.5.2 Proximate analyses

Samples were analysed for moisture, ash, fat, and protein following AOAC [21] procedures. The oven drying method was used to determine the moisture content at which 5g sample was heated at an oven temperature of 105°C for 3 hours (AOAC Method 950.46). The ash contents were assessed by sample incineration in a Muffle Furnace at 550°C for 12 hours (AOAC method 940.26).

Protein was determined by the micro-Kjeldahl method, a 0.5 g of the sample was first digested in a 10 ml sulfuric acid (98% w/w) with the addition of a digestive mixture of K_2SO_4+$CuSO_4$×$5H_2O$ to break down organic matter and reduce nitrogenous compounds to ammonium salts. Ammonia was liberated by boiling with sodium hydroxide (50% w/v) aqueous solution and steam distilled into boric acid to form ammonium borate. Ammonia was then titrated with 0.1 N HCl and screened methyl red was used as an indicator solution. Protein nitrogen content was obtained by multiplying the result by the factor 6.25.

For fat determination, the Soxhlet method (AOAC Method 963.15) was applied. In brief, ether was continuously volatilised then condensed and allowed to pass through the 5 g moisture-free sample, prepared into the extraction thimble and covered with cotton wool. The extract was collected in a beaker after extraction for 16 hours, the ether was afterward distilled and collected in another container and the remaining crude fat was dried and weighed. All determinations were performed in duplicate.

2.5.3 Thiobarbituric acid number (TBA)

Ten-gram portions of mortadella were combined with each of 25 ml of 20% trichloroacetic acid (TCA) and 20 ml of warmed distilled water, and homogenised in a stomacher (Model AES, Labprat) for 30 seconds. The homogenate was filtered through a Whatman #1 filter paper and then in a test tube, 2 ml of the filtrate was combined with a 2 ml of 0.02 M aqueous 2- thiobarbituric acid (TBA). The tubes were incubated at 22°C in the dark for 20 hours. At the end of that time, the absorbance of the resulting solution was measured at 532 nm according to [22] using a UV-visible spectrophotometer (Spectro 2000RS, Labomed, Inc., USA).

The thiobarbituric number (TBA) mg of malondialdehyde/kg sample (ppm) was calculated by multiplying the measured absorbance of pink-coloured chromagen of the TBA-reactive substances at 532 nm by a factor of 7.8 [23]. The TBA was carried out in triplicate at weeks 1, 2, 3, 4, and 5 of refrigeration storage.

2.5.4 Cholesterol content

Cholesterol content was determined in triplicate using the Colorimetric method directly in mortadella samples according to the test kit instructions (Cat. No.139,050, Boehringer Mannheim, Germany) [24]. First, cholesterol is oxidised by cholesterol oxidase to cholestenone. Then, in the presence of catalase, the hydrogen peroxide produced in this reaction oxidises methanol to formaldehyde. The latter reacts with acetylacetone forming a yellow lutidine dye in the presence of NH_4 ions.

The concentration of the lutidine-dye (3,5-diacetyl-1,4-dihydrolutidine) formed is stoichiometric to the amount of cholesterol and is measured by the increase of light absorbance in the visible range using a spectrophotometer at 405 nm. Subsequently, 10 ml of a freshly prepared methanolic potassium hydroxide solution (1mol/L) was added to a 2.5 g mortadella placed in a 50 ml round-bottomed flask. The flask was heated under a reflux condenser for 25 minutes, and then the supernatant solution was transferred into a 25ml volumetric flask using a pipette and allowed to cool. Afterward, the contents were diluted up to the mark with isopropanol and fil-

tered. The clear solution was used for the assay in which 5 ml of cholesterol reagent mixture was mixed with 0.4 ml of the sample solution. Then, 2.5 ml of this mixture was pipetted into a test tube, followed by the addition of 0.02 ml of cholesterol oxidase. After covering the test tube, it was incubated in a water bath at 39 °C for 60 minutes. The absorbance readings of both the blank and the sample were measured using a UV spectrophotometer (Spectro 2000RS, Labomed, Inc., USA) at 405nm. Cholesterol concentrations (g/L sample solution) were measured by multiplying the absorbance difference by 0.711. Cholesterol content was calculated according to the following equation and expressed as mg × 100 g^{-1} product:

Cholesterol content (mg/100 g) =

= [C cholesterol (g/L sample solution)/ Weight sample (g)] × 100 × 25

2.5.5 Fatty acid profile determination

For the extraction of lipids, a 10 g mortadella sample was homogenised in chloroform: methanol (2:1 v/v) according to [25, 26], then filtered. The filtrate was then placed in a separatory funnel; the lipid phase of the chloroform fractions was collected.

A rotary evaporator was used to get rid of chloroform; 3 ml of petroleum ether was added to 0.5 g of the extracted fat, then 0.15 ml of potassium hydroxide solution (2N) was added. It is worth noting that sodium hydroxide was substituted in this procedure with potassium hydroxide because it was very difficult to prepare sodium methoxide. Potassium hydroxide, however, gave good results for the fatty acid esterification. The mixture was left for 5 min and then injected into a gas chromatograph (Shimadzu GC-2010). The employed working conditions were as follows: column (Restek, Rtx-225, USA, cross bond 50%-cyanopropylmethyl 50%-phenylmethyl polysiloxane, 60 m, 0.25 mm/D, 0.25 µm df) carrier gas, helium; injector temperature, 250°C; detector temperature, 280°C; temperature program, 175°C at first, then 220°C at a rate of 2°C/min for 20 minutes. The fatty methyl esters were identified and quantified using the concept of internal standardisation by comparing their retention periods to those of established standards. Each measurement was performed in triplicate.

2.6 SENSORY EVALUATION

A 9-point hedonic scale test was carried out as described by [27] to investigate the degree of preference of the mortadella treated with different levels of olive oil. Twenty panellists were chosen from the staff of the Department of Nutrition and Food Technology of the University of Jordan for the sensory evaluation. These panellists were from both sexes and different age groups and were requested to test each sample separately without considering the other samples. Each panellist was instructed to express their evaluation of colour, flavour, juiciness, texture, and overall acceptability by filling out a copy questionnaire. Samples were evaluated in triplicate in separate sessions.

2.7 STATISTICAL ANALYSIS

All statistical analyses were performed by the analysis of variance (ANOVA) using JMP (release 10, SAS institute, Cary, NC) to determine any significant differences among the parameters associated with the study. The significant differences of means were determined at $p \leq 0.05$ using least significant differences (LSD) method [26].

3. RESULTS AND DISCUSSION

3.1 CHEMICAL COMPOSITION

Table II shows the proximate composition and pH values of the developed mortadella treatments. Moisture content ranged from 57.4 to 62.5%, fat content from 2.8-14.8% protein content from 19.3-26.4%, and ash content from 2.84-3.86%. The lipid reformulation did not influence the pH values of all mortadella samples ($p>0.05$) stored at 4°C, which ranged from 6.2- 6.3. Moisture, fat, protein, and ash contents were within the range specified in the Jordanian Standard for meat and meat products – sausage products (JS: 816/2008), which is 65% maximum for moisture, 25% maximum for fat, and 12% minimum for protein content.

Regarding the moisture content, treatment 1 (i.e., the control) had a significantly lower value when compared with the other treatments. This was probably due to the higher fat content of this sample, since water i.e., the most important component of meat quantitatively, comprising up to 75% of its weight, is inversely related to fat content [28]. These results agreed well with the findings of [29, 30] who worked on canned luncheon meat formulations as affected by different raw meat sources. [29] reported that the moisture content of the different formulations reflected the amount of water, where formulation 1 (F1), which had the highest amount of added water and no beef fat (0%) added to its formula during preparation, showed a significantly higher moisture content (63.5%) than the remaining samples. Moreover, the sample that showed the lowest moisture content (61.0%) was the one with the lowest amount of added water and the highest amount of added beef fat (11.2%) to its formulation, and reportedly, that could have been the cause of its reduced moisture content. The authors also concluded that the type of meat used in the product making is more important than the chemical composition. Similarly, [30] found the low-fat product had a significantly higher moisture content than the high-fat version subjected to the same conditions. However, in the current study, there were no significant ($p>0.05$) differences in moisture % among all other experimental treatments ($p>0.05$). Treatment 2 had the highest protein percentage, which was significantly higher when compared with treatments 1, 3, and 4. However, treatment 2 had a

comparable protein% to treatment 5, probably because these two treatments had the lowest fat content among all treatments. Since treatment 1 had significantly lower moisture content compared with the other treatments, it expectedly showed the highest fat content. In addition, protein content did not differ (p>0.05) between the control and treatments 3, 4, and 5.

Despite having no significant differences in ash contents among treatments, treatments 2 and 5 showed the highest ash contents (3.86% and 3.7%, respectively). This is probably due to the higher meat percentages (81.3% and 78.3%) incorporated in the formulation of these two treatments. However, even though a high meat percentage was used in preparing treatment 1 as well, the reason it showed a lower ash content may be attributed to its elevated fat level (14.8%) when compared with treatments 2 and 5, which contained 2.83% and 5.10% fat, respectively.

3.2 CHOLESTEROL CONTENT

The values for the cholesterol content of mortadella are shown in Table III. Treatment 1 (the control mortadella) had the highest cholesterol content of 117 mg/100 g, which was significantly higher (>225%; p<0.05) when compared with all other treatments. This was attributed to the high animal fat percentage in the control sample. [31] reported a significant decrease in the cholesterol level in meat burgers when ground poppy seed was used as a fat replacer. Similar results were observed by [32-38]. Overall, authors reported a cholesterol reduction in meat products when animal fat was replaced by a healthier substitution.

Treatments 3, 4, and 5 did not differ (p>0.05) in cholesterol content, and this can be related to the cholesterol-free olive oil that was added to these treatments. Cholesterol content in these treatments came from the low animal fat content of the lean meat that was used in mortadella preparation because it is a well-known fact that fatty meats contain higher cholesterol levels than lean ones [39, 40].

Although treatment 2 had higher cholesterol content (52 mg/100 g) than treatments 3, 4, and 5, no significant differences were observed among these four experimental treatments. This is due to the notably low animal fat percentage (2.83%) of treatment 2. This value was lower when compared with other studies (13), in which extra-lean ground beef (Total fat is 17.1%) was used. [41] reported that it is important to remove external fat to reduce the total fat intake and total cholesterol intake. Consistent data were also provided by [42].

A wide range of cholesterol is found in separable lean meat of beef and pork, which is influenced by many factors such as age, breed, gender, kind of muscle (type of cut), animal diet, and degree of marbling [43-46]. Previous literature also demonstrated that greater cholesterol content is usually found in cooked or processed meat products than that of raw, which is due to moisture loss while cholesterol is retained in the tissues [44, 47].

3.3 FATTY ACID PROFILE

Percentages of major fatty acids of the prepared mortadella are displayed in Table IV. Stearic acid, which is found in many animal fats in relatively large amounts, was significantly lower in treatments 3, 4, and 5 when

Table II - Proximate analysis and pH values of the reduced-fat mortadella samples formulated with meat fat replacement with olive oil.

Treatments	Moisture%**	Fat%	Protein%	Ash%	pH
1	57.37^{b} ±0.02	14.80^{a} ±0.05	19.30^{a} ±0.02	2.84^{a} ±0.01	6.3^{a} ±0.02
2	62.51^{a} ±0.01	2.83^{c} ±0.00	26.39^{b} ±0.04	3.86^{a} ±0.01	6.2^{a} ±0.01
3	61.85^{a} ±0.01	11.30^{a} ±0.02	19.26^{a} ±0.01	2.85^{a} ±0.00	6.3^{a} ±0.01
4	62.30^{a} ±0.05	8.10^{b} ±0.01	21.47^{a} ±0.01	3.10^{a} ±0.00	6.2^{a} ±0.01
5	62.32^{a} ±0.02	5.10^{b} ±0.01	23.40^{ab} ±0.02	3.70^{a} ±0.01	6.2^{a} ±0.01

Each value is the average of two determinations, with coefficient of variability less than 5%.

^{a,b} Superscripts within the same column indicate statistically significant differences ($p<0.05$).

*Treatments: 1 = control mortadella (normal fat level), 2 = lean mortadella (reduced fat level), 3 = lean meat+8% olive oil, 4 = lean meat+5% olive oil, 5 = lean meat+3% olive oil.

Table III - Cholesterol content (mg/100g) of the mortadella samples formulated with the substitution of meat fat by olive oil.

Treatment*	1	2	3	4	5
Cholesterol (mg/100g food)	117^{b} ±0.36	52^{a} ±0.28	48.2^{a} ±0.23	48.1^{a} ±0.18	47.6^{a} ±0.19

*Results are expressed as means of triplicate determinations.

^{a,b} Superscripts indicate statistically significant differences ($p<0.05$).

*Treatments: 1 = control mortadella (normal fat level), 2 = lean mortadella (reduced fat level), 3 = lean meat+8% olive oil, 4 = lean meat+5% olive oil, 5 = lean meat+3% olive oil.

Table IV - Means of the major fatty acids, and the saturated, monounsaturated, polyunsaturated fatty acids (expressed as percentage by weight of the total fatty acids detected), and "saturated to unsaturated fatty acids" ratio (SFA/UFA) of the mortadella samples prepared with the replacement of meat fat by olive oil.

Fatty acids	Treatment				
	1	2	3	4	5
Stearic (C18:0)	16.5^{a} ±0.01	15.4^{ab} ±0.01	8.2^{d} ±0.01	11.1^{c} ±0.01	13.3^{bc} ±0.01
Palmitic (C16:0)	27.5^{a} ±0.01	27.2^{ab} ±0.01	23.1^{c} ±0.01	24.6^{bc} ±0.01	25.4^{abc} ±0.01
Oleic (C18 :1)	48.0^{a} ±0.01	50.0^{ca} ±0.02	60.0^{d} ±0.02	53.9^{b} ±0.01	53.3^{bc} ±0.02
Linoleic (C18:2)	-	-	8.0^{a} ±0.01	10.3^{b} ±0.01	7.8^{a} ±0.01
Myristic (C14:0)	8.0^{a} ±0.01	7.4^{a} ±0.01	-	-	-
ΣSFA	52.0^{a}	50.0^{a}	31.3^{b}	35.7^{b}	38.7^{b}
ΣMUFA	48.0^{a}	50.0^{ca}	60.0^{b}	53.9^{b}	53.3^{bc}
ΣPUFA	-	-	8.0^{a}	10.3^{b}	7.8^{a}
SFA/UFA	1.1	1.0	0.41	0.64	0.72

Data are expressed as means of triplicate determinations.

^{a,b,c,d} Superscripts within the same column indicate statistically significant differences ($p<0.05$).

*Treatments: 1 = control mortadella (normal fat level), 2 = lean mortadella (reduced fat level), 3 = lean meat+8% olive oil, 4 = lean meat+5% olive oil, 5 = lean meat+3% olive oil.

Table V - Sensory evaluation scores of the reduced-fat mortadella samples formulated with the substitution of meat fat by olive oil

Treatments	Color	Flavor	Juiciness	Texture	Overall acceptability
1	7.7^{a} ±0.00	7.5^{a} ±0.00	7.6^{a} ±0.01	7.8^{a} ±0.00	7.5^{a} ±0.02
2	7.9^{a} ±0.00	6.6^{b} ±0.01	6.0^{b}±0.02	6.0^{b} ±0.01	6.3^{ab} ±0.01
3	7.5^{a} ±0.01	6.4^{b} ±0.01	7.7^{a} ±0.01	7.5^{a} ±0.00	6.1^{b} ±0.02
4	7.4^{a} ±0.01	7.3^{a} ±0.00	7.5^{a} ±0.00	7.4^{a} ±0.01	7.3^{ab} ±0.01
5	7.5^{a} ±0.00	7.3^{a} ±0.01	6.5^{b} ±0.01	6.6^{b} ±0.01	6.9^{ab} ±0.01

Data are expressed as means of triplicate determinations.

^{a,b} Superscripts within the same column indicate statistically significant differences ($p<0.05$).

*Treatments: 1 = control mortadella (normal fat level), 2 = lean mortadella (reduced fat level), 3 = lean meat+8% olive oil, 4 = lean meat+5% olive oil, 5 = lean meat+3% olive oil.

compared to the control. The lowest stearic acid percentage was reported for treatment 3.

Stearic acid and palmitic acid, which were, in quantitative terms, the major saturated fatty acid (SFA) found in the samples' lipid fraction, were significantly lower in olive oil-containing treatments (i.e., 3, 4, and 5) than the rest of the treatments. This finding was attributed to the reduction of the total SFA (Table IV) in the lipid profile of these modified samples compared to the control, as demonstrated by [38]. Oleic acid (C18:1) was the main fatty acid found in the lipid fraction of the mortadella, with significantly higher values for the modified olive oil-incorporated treatments. This is possibly due to the elevated amount of oleic acid in olive oil, which represents 70-80% of its composition [48]. Other studies have yielded similar findings [38, 49, 50]. These results indicate that the use of olive oil as a fat replacer in mortadella has positively impacted its health properties. Myristic acid (C14:0) was only detected in treatments 1 and 2, while not detected in the rest of the treatments (i.e., olive oil included). [38] studied the effect of the partial and total replacement of pork backfat by oleogel from high-oleic sunflower oil gel on the fatty acid profile of bologna-type sausages, which is a product similar to the mortadella sausage, the subject of this study. The authors found that when the replacement percentage increased from 25 to 100%, the myristic acid content reduced from 2.37% in the control bologna-type down to 1.56% in the same product with 100% replacement. This, in addition to our results, can be mainly attributed to the very low content of myristic acid (0.03 g/100 g total fatty acid) in olive oil compared to 3.54 g and 1.19 g/100 g total fatty acid in the beef fat and pork backfat, respectively [51].

[52] Reported that in contrast to palmitic acid, olive oil elicits a beneficial influence on insulin sensitivity. Moreover, the authors added that oleic acid inhibits palmitic acid-induced inflammation and insulin resistance. Health studies have shed light on increasing oleic acid intake, and if possible, lowering the palmitic acid content of meat fats by using oleic acid-rich oils such as high oleic sunflower and olive oils [52-55]. It was stated by [56] that the most consumed saturated long-chain fatty acids in the American diet are palmitic acid, myristic acid, and stearic acid.

Percentages of the SFA, monounsaturated (MUFA), and polyunsaturated (PUFA) fatty acids, in addition to the saturated to unsaturated fatty acid (UFA) ratio of the prepared mortadella treatments, are shown

in Table IV. Treatment 1 (the control, whichcontained normal fat level without olive oil) had, as expected, the highest level of SFA as palmitic acid (C16:0), stearic acid (C18:0), and myristic acid (C14:0), the lowest MUFA content, and thus the highest SFA/UFA ratio. A similar trend was observed by [50] who reported that the inclusion of olive oil had modified the total fatty acid profile of dry-ripened sausages. Additionally, both treatments 1 and 2, which were prepared without the addition of olive oil, had a significantly higher SFA content and subsequently higher SFA/UFA ratio when compared with treatments 3, 4, and 5.

Treatment 3 (highest olive oil content) had the highest MUFA fatty acid percentage as oleic acid (C18:1), followed by treatments 4 and 5. This can be attributed to the abundantly high oleic acid content in olive oil, which was added to these three treatments. [57] reported that when MUFAs are used as a substitute for certain SFAs, they tend to reduce plasma LDL (undesirable) cholesterol without decreasing plasma HDL (desirable) cholesterol, whereas PUFAs may decrease both. According to [58], lean roasted beef or lean roasted pork contains about 15 g total fat /100 g meat, from which 6 g are SFA in beef and 4 g in pork, with equal amounts of MUFA (6 g), and with 1.5 g PUFA in pork and a trace in beef. The author reported that the degree of saturation of fatty acids in beef is more than that of pork. [59] reported that subjects consumed higher meat fat when they ate beef and pork than when they ate poultry or fish, and more SFA when they ate beef than other meats, and yet the mean values for serum total cholesterol did not differ significantly.

Polyunsaturated fatty acids were only detected in treatments 3, 4, and 5 as linoleic acid (C18:2), with significantly higher linoleic acid content in treatment 4 than in treatments 3 and 5.

It is worthy to highlight that, according to the food labelling guide established by the US food and drug administration [58], treatments 3, 4, and 5 can be nutritionally labelled as SFA-reduced since they contained 39.8%, 31.3%, and 25.5% less SFA, respectively than the control (must achieve at least 25% less SFA).

3.4 OXIDATIVE RANCIDITY TEST

The estimated TBA values, a measure of oxidative rancidity, are shown in Figure 1. Treatment 2 (lean without any fat addition) showed the lowest TBA value of 0.172, which was significantly lower when compared with the other treatments. This is probably due to the diminished fat level in treatment 2 (2.83%). The TBA values of all mortadella treatments increased with time, indicating that the oxidation process had taken place during storage. A similar trend was reported in previous studies done with cured meat products [34, 38]. Moreover, an increase in TBA values was observed with increasing the amount of olive oil included in the formulation. These results are in accordance with [34] who reported higher TBA values in samples containing olive oil. This may be related to the increased level of UFA in olive oil, which is more susceptible to oxidation reactions as demonstrated by [50]. On the other hand, in a study of fat replacement by high-oleic oleogel in bologna-type sausages, [38] found that TBA values of the experimental samples were lower than the controls. All treatments, in our study, had acceptable TBA values for rancidity (<1.0) after 5 weeks of storage, which was consistent with other studies [38, 49].

Olive oil-incorporated treatments (3, 4, and 5) had the highest TBA values. This fact could be related to the greater susceptibility of UFA to lipid oxidation, in addition to PUFAs that are present in olive oil such as linoleic acid. [61] and [62] reported that the presence

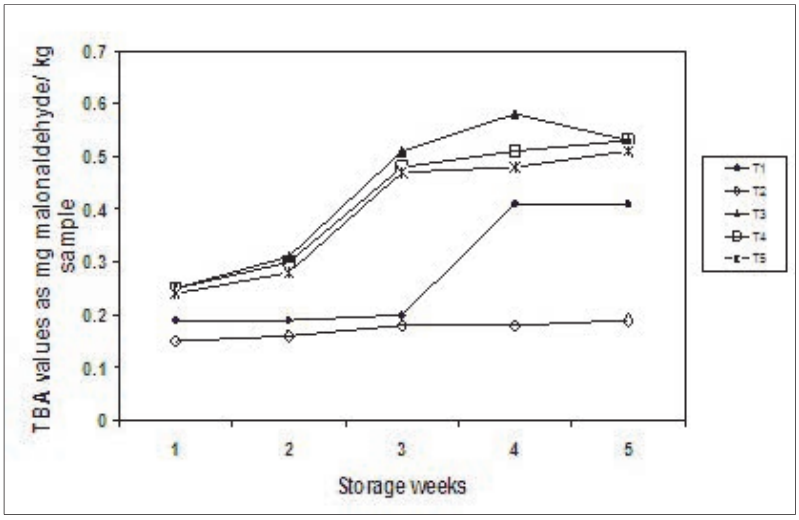

Figure 1: Thiobarbituric acid (TBA) values of the mortadella samples prepared with the substitution of meat fat by olive oil. (Treatments: 1 = control mortadella (normal fat level), 2 = lean mortadella (reduced fat level), 3 = lean meat+8% olive oil, 4 = lean meat+5% olive oil, 5 = lean meat+3% olive oil).

of PUFAs in meats is a major factor in lipid oxidation and shelf-life shortening.
However, the modified treatments; 3, 4, and 5 did not differ (p>0.05) in TBA values when compared to the control. Suggestively, this may be due to the presence of natural antioxidants in olive oil, such as tocopherols which might have reduced lipid oxidation in these treatments. This finding agrees with previous studies [12, 63] which declared that TBA values were not influenced by the fat replacement despite the high UFA content. Additionally, olive oil contains an elevated level of MUFA in the form of oleic acid (77%), which is less susceptible to lipid oxidation.

3.5 SENSORY EVALUATION

Table V displays the sensory evaluation scores of the developed mortadella using a 9-point hedonic scale. Colour, flavour, juiciness, texture, and overall acceptability scores of all samples were relatively within acceptable ranges, with mean scores above 6 ("like"). No significant differences were observed between all treatments for the attribute colour (p>0.05). This result suggested that the inclusion of olive oil did not alter visual sensory features. Several studies have reported that low-fat products were darker, darker red, or rather more intensive in colour than high-fat products [64-69]. The authors have further added that the increase in the red colour intensity presumably resulted from both the increased lean meat content and the lack of fat which possesses a whitening property [68]. This might justify the fact that, in the present study, treatment 2, which had the lowest fat content, received the highest colour-liking scores. Moreover, [70] found that burger patties treated with olive oil presented a darker colour, whilst like our study, [71] and [34] reported no significant differences in terms of salami and Turkish soudjouk colour, respectively, between oil-containing samples and the basic formulations.
The estimated scores for mortadella flavour are shown in Table V. No statistical differences (p>0.05) were observed between control and treatments 4 and 5. However, treatment 2 was less preferred than samples with higher fat content, probably due to its reduced fat level which is known to affect meat flavour and palatability [72]. Treatment 3, which had 8% olive oil, achieved the least consumer acceptance, possibly due to the distinguished olive oil flavour. Thus, these results imply that olive oil can be used as a fat replacer in mortadella at levels below 8% without negatively affecting its acceptance. The juiciness and texture acceptability scores of treatments 1, 3, and 4 were comparable (p>0.05), but they were significantly higher when compared with treatments 2 and 5. This is probably due to differences in the fat content, since fat is known to affect the juiciness of meat products, and a decrease in meat juiciness was reported [68, 73, 74] as a result of fat reduction. Also, low-fat products were further reported to easily become dry, firm, and rubbery [75, 76] and higher tenderness and juiciness values were related to higher fat contents [16, 74, 77]. These results were consistent with those of other researchers [63, 78, 79]. They generally reported that low-fat meat products formulated with healthier substitutions were relatively similar in juiciness and/or texture to high-fat products.
Overall acceptability scores were not significantly different (p>0.05) among treatments 1, 2, 4, and 5. Treatment 5, which contained 3% olive oil, achieved a lower degree of consumer acceptance than treatments 1 and 4. A possible explanation is that the latter two treatments were softer than treatment 5. Moreover, treatment 3 received the lowest acceptance scores among all treatments (significantly lower than the control). This was probably attributed to the influence of olive oil taste in this treatment which contained 8% olive oil in its formulation. [80] declared that fat replacers can affect meat flavour by adding flavours of their own.
Treatment 2, which contained only lean meat without any fat addition, was less acceptable by consumers, possibly due to the extremely low-fat content. This agreed with previous studies [18, 76, 81] which reported that fat acts as a reservoir for flavour compounds and contributes to the texture of the product. The authors added that reducing the fat content could alter product quality. Additionally, [80] and [82] reported that the decrease in fat level leads to a reduction of the flavour intensity, juiciness, tenderness, and thus overall acceptability of meat products. [16] and [83] reported that a low-fat product can be made from a lean (greater than 90% fat-reduction) all-meat formulation, but the sensory characteristics would not be acceptable to consumers.

CONCLUSIONS

In this study, the effects of meat fat substitution with olive oil on mortadella properties were evaluated. Results showed that treatments prepared without the addition of olive oil had a significantly higher SFA content than olive oil-incorporated treatments. The lipid reformulation did not only reduce the fat and cholesterol levels, but also enhanced the fatty acid profile. Treatments that contained olive oil could be nutritionally labelled, according to the USFDA guidelines, as "SFA-reduced". Results suggest that it is possible to substitute animal fat with low levels of olive oil (3% - 5%) in mortadella without jeopardising its quality. However, the manufacture of lean mortadella without the addition of any fat replacers has yielded a less desirable product from a sensory standpoint.

BIBLIOGRAPHY

[1] R.V. Rios, M.D.F. Pessanha, P.F.D. Almeida, C.L. Viana, S.C.D.S. Lannes, Application of fats in some food products. Food Science and Technology 34, 3-15 (2014)

[2] T. da Silva Martins, M.V.A. de Lemos, L.F. Mueller, F. Baldi, T.Y. de Amorim, A.M. Ferinho, J.A. Muñoz, I.H. de Souza Fuzikawa, G.V. de Moura, J.L. Gemelli, A.S.C. Pereira, Fat deposition, fatty acid composition, and its relationship with meat quality and human health. Meat science and nutrition 17-37 (2018)
[3] I. Svanberg, The Importance of Animal and Marine Fat in the Faroese Cuisine: The Past, Present, and Future of Local Food Knowledge in an Island Society. Frontiers in Sustainable Food Systems 5, 45 (2021).
[4] Y. Zhu, L. Guo, W. Tang, Q. Yang, Beneficial effects of Jerusalem artichoke powder and olive oil as animal fat replacers and natural healthy compound sources in Harbin dry sausages. Poultry Science 99(12), 7147-7158 (2020)
[5] B. Öztürk-Kerimoğlu, A. Kara, M. Urgu-Öztürk, M. Serdaroğlu, A new inverse olive oil emulsion plus carrot powder to replace animal fat in model meat batters. LWT 135, 110044 (2021a)
[6] M.A. Trindade, J.M. De Oliveira, N.M.G. Nogueira, P.R.C. Oliveira Filho, S.M. De Alencar, C.J. Contreras-Castillo, Mortadella sausage produced with soybean oil instead of pork fat. Italian Journal of Food Science 23(1), 72 (2011)
[7] N. Abu-Ghazaleh, W.J. Chua, V. Gopalan, Intestinal microbiota and its association with colon cancer and red/processed meat consumption. Journal of gastroenterology and hepatology 36(1), 75-88 (2021)
[8] G. Nieto, J.M. Lorenzo, Use of olive oil as fat replacer in meat emulsions. Current Opinion in Food Science (2021)
[9] A.M. Chappalwar, V. Pathak, M. Goswami, A.K. Verma, V. Rajkumar, Efficacy of lemon albedo as fat replacer for development of ultra-low-fat chicken patties. Journal of Food Processing and Preservation 45(7), e15587 (2021)
[10] H. Jalal, S. Mir, S.A. Wani, A.H. Sofi, M.A. Pal, F. Rather, Development of low fat meat products. International Journal of Food Nutrition and Safety 4, 98-107 (2013)
[11] S. Manzoor, F.A. Masoodi, R. Rashid, F. Naqash, M. Ahmad, Oleogels for the development of healthy meat products: A review. Applied Food Research, 100212 (2022)
[12] E. Saldaña, A.L.D.S.C. Lemos, M.M. Selani, F.P. Spada, M.A.D. Almeida, C.J. Contreras-Castillo, Influence of animal fat substitution by vegetal fat on Mortadella-type products formulated with different hydrocolloids. Scientia Agricola 72, 495-503 (2015)
[13] J.H. Giese, Fats, Oils, and Fat Replacers. Journal of Food Technology April; 50 (4), 78-97 (1996)
[14] L. Cazzoletti, M.E. Zanolin, F. Spelta, R. Bono, L. Chamitava, I. Cerveri, V. Garcia-Larsen, A. Grosso, V. Mattioli, P. Pirina, M. Ferrari, Dietary fats, olive oil and respiratory diseases in Italian adults: A population-based study. Clinical & Experimental Allergy 49(6), 799-807 (2019)
[15] B. Romana-Souza, B.O. Saguie, N.P. de Almeida Nogueira, M. Paes, S. dos Santos Valença, G.C. Atella, A. Monte-Alto-Costa, Oleic acid and hydroxytyrosol present in olive oil promote ROS and inflammatory response in normal cultures of murine dermal fibroblasts through the NF-κB and NRF2 pathways. Food Research International 131, 108984 (2020)
[16] J.H. Giese, Developing Low Fat Meat Products. Journal of Food Technology April: 100-107 (1992)
[17] J. Park, K.S. Rhee, J.T. Keeton, Properties of Low Fat Frankfurters Containing Monounsaturated and Omega-3 Polyunsaturated Oils. Journal of Food Science 54 (3) (1989)
[18] K.M. Al-Mrazeeq, B.M. Al-Abdullah, K.M. Al-Ismail, Evaluation of some sensory properties and cooking loss of different burger formulations. Italian Journal of Food Science 22(2), 134 (2010)
[19] L. Echeverria, J. da Mata Rigoto, A.C. Martinez, B.D.A. Porciuncula, J. Scanavacca, B.C.B. Barros, Characterization of lamb burgers with addition of flour from peach palm by-product. Bioscience Journal (2020)
[20] S.T. Ferhi, B. Al-Abdullah Al-Sawalha, The Effect of a Combination of Nitrite With Lactate, and Sorbate on Physical, Chemical, Antioxidant, Sensory Properties of Beef Mortadella During Storage. Unpuplished Doctoral Thesis. The University of Jordan, Amman, Jordan (2022)
[21] AOAC Official Methods of Analysis, Association of Official Analytical Chemists International, Gaithersburg, MD, USA (2012)
[22] A.K. Verma, M.K. Chatli, P. Kumar, N. Mehta, Assessment of quality attributes of porcine blood and liver hydrolysates incorporated pork loaves stored under aerobic and modified atmospheric packaging. Journal of Food Science and Technology, 59(3), 1114-1130 (2022)
[23] S. You, S. Yang, L. Li, B. Zheng, Y. Zhang, H. Zeng, Processing Technology and Quality Change during Storage of Fish Sausages with Textured Soy Protein. Foods, 11(22), 3546 (2022)
[24] Ö. Yüncü, H.S. Kavuşan, M. Serdaroğlu, Chia (Salvia hispanica L.) Mucilage as a Novel Fat Replacer in Beef Patties Cooked with Different Methods: Physico-Chemical, Technological, and Nutritional Perspectives. Journal of Culinary Science & Technology, 1-29 (2022)
[25] Y.I. Taleb, B. Al-Abdullah Al-Sawalha, Enhancement of Chemical, Nutritional Status, and Quality of Low-Fat Mortadella Made From Mechanically Deboned and Whole Chicken Meat With the Addition of Flaxseed and Thyme Oils. Unpuplished

Doctoral Thesis. The University of Jordan, Amman, Jordan (2022)
[26] Z.K. Daili, B.A.A. Al-Sawalha, R. Mashal, Variability of fat content and fatty acid composition of selected Jordanian fast foods and their impact on nutritional indices. Riv. Ital. Sostanze Grasse (2022)
[27] C. Li, W. Xie, X. Zhang, J. Liu, M. Zhang, J.H. Shao, Pickering emulsion stabilized by modified pea protein-chitosan composite particles as a new fat substitute improves the quality of pork sausages. Meat Science, 197, 109086 (2023)
[28] A. Varnam, J.M. Sutherland, J.P. Sutherland, Meat and meat products: technology, chemistry and microbiology (Vol. 3). Springer Science & Business Media, p.24 (1995)
[29] B. Mohd Abdullah, Properties of five canned luncheon meat formulations as affected by quality of raw materials. International journal of food science & technology 42(1), 30-35 (2007)
[30] B. Al-Abdullah, A. Al-Majali, Effects of fat content and heat treatment on the chemical and sensory characteristics of canned luncheon meat. Jordan Journal of Agricultural Sciences 7(4), 701-709 (2011)
[31] V. Gök, L. Akkaya, E. Obuz, S. Bulut, Effect of ground poppy seed as a fat replacer on meat burgers. Meat science 89(4), 400-404 (2011)
[32] P.T. Berg, M.J. Marchello, D.O. Erikson, W.D. Slanger, Selected Nutrient Content of Beef, Fat Status, and Cooking Method . Journal of Food Science 50: 1029-1033 (1985)
[33] K.K. Kregel, K.J. PRUSA, K.V. HUGHES, Cholesterol content and sensory analysis of ground beef as influenced by fat level, heating, and storage. Journal of Food Science 51(5), 1162-1165 (1986)
[34] S. Kayaardı, V. Gök, Effect of replacing beef fat with olive oil on quality characteristics of Turkish soudjouk (sucuk). Meat science 66(1), 249-257 (2004)
[35] H. Ercoşkun, T.U.Ğ.B.A. Demirci-Ercoşkun, Walnut as fat replacer and functional component in sucuk. Journal of food quality 33(5), 646-659 (2010)
[36] E.A.D.B.J.G.A.I. Muguerza, D. Ansorena, J.G. Bloukas, I. Astiasarán, Effect of fat level and partial replacement of pork backfat with olive oil on the lipid oxidation and volatile compounds of Greek dry fermented sausages. Journal of Food Science 68(4), 1531-1536 (2003)
[37] G.M. Monteiro, X.R. Souza, D.P.B. Costa, P.B. Faria, J. Vicente, Partial substitution of pork fat with canola oil in Toscana sausage. Innovative Food Science & Emerging Technologies 44, 2-8 (2017)
[38] S.L. da Silva, J.T. Amaral, M. Ribeiro, E.E. Sebastião, C. Vargas, F. de Lima Franzen, G. Schneider, J.M. Lorenzo, L.L.M. Fries, A.J. Cichoski, P.C.B. Campagnol, Fat replacement by oleogel rich in oleic acid and its impact on the technological, nutritional, oxidative, and sensory properties of Bologna-type sausages. Meat science 149, 141-148 (2019)
[39] R. Chizzolini, E. Zanardi, V. Dorigoni, S. Ghidini, Calorific value and cholesterol content of normal and low-fat meat and meat products. Trends in Food Science & Technology 10(4-5), 119-128 (1999)
[40] A.N. Madu, F.O. Yakubu, Estimation of Total Cholesterol in Selected Tropical Cow Meat Parts in Ogun State Nigeria (2018)
[41] S.S. Swize, K.B. Harris, H.R. Cross, Cholesterol Content of Lean and Fat from Beef, Pork, and Lamb Cuts. Journal of Food Composition and Analysis 5, 160-167 (1992)
[42] C.C. Perham, C.L. Gifford, D.R. Woerner, T.E. Engle, K.S. Sellins, R.J. Acheson, L.W. Douglass, J.D. Tatum, R.J. Delmore, A. Cifelli, S.H. McNeill, Special-Fed Veal: Separable components, proximate composition, and nutrient analysis of selected raw and cooked, wholesale and retail cuts. Meat science 148, 19-31 (2019)
[43] R.M. Feeley, P.E. Criner, B.K. Watt, Cholesterol content of foods. Journal of the American Dietetic Association 61(2), 134-149 (1972)
[44] T.T. Dinh, L.D. Thompson, M.L. Galyean, J.C. Brooks, K.Y. Patterson, L.M. Boylan, Cholesterol content and methods for cholesterol determination in meat and poultry. Comprehensive Reviews in Food Science and Food Safety 10(5), 269-289 (2011)
[45] M. Reig, M.C. Aristoy, F. Toldrá, Variability in the contents of pork meat nutrients and how it may affect food composition databases. Food chemistry 140(3), 478-482 (2013)
[46] C. Wattanachant, Goat meat: Some factors affecting fat deposition and fatty acid composition. Songklanakarin J. Sci. Technol, 40, 1152-1157 (2018)
[47] S.R. Baggio, N. Bragagnolo, The effect of heat treatment on the cholesterol oxides, cholesterol, total lipid and fatty acid contents of processed meat products. Food Chemistry 95(4), 611-619 (2006)
[48] K.M.C. Nogoy, H.J. Kim, Y. Lee, Y. Zhang, J. Yu, D.H. Lee, X.Z. Li, S.B. Smith, H.A. Seong, S.H. Choi, High dietary oleic acid in olive oil-supplemented diet enhanced omega-3 fatty acid in blood plasma of rats. Food Science & Nutrition 8(7), 3617-3625 (2020)
[49] L.S. John, M.J. Buyck, J.T. Keeton, R. Leu, S.B. Smith, Sensory and physical attributes of frankfurters with reduced fat and elevated monounsaturated fats. Journal of Food Science 51(5), 1144-1146 (1986)
[50] M.C. Utrilla, A.G. Ruiz, A. Soriano, Effect of partial replacement of pork meat with an olive oil

organogel on the physicochemical and sensory quality of dry-ripened venison sausages. Meat science 97(4), 575-582 (2014)
[51] I.H. Badar, H. Liu, Q. Chen, X. Xia, B. Kong, Future trends of processed meat products concerning perceived healthiness: A review. Comprehensive Reviews in Food Science and Food Safety 20(5), 4739-4778 (2021)
[52] X. Palomer, J. Pizarro-Delgado, E. Barroso, M. Vázquez-Carrera, Palmitic and oleic acid: the yin and yang of fatty acids in type 2 diabetes mellitus. Trends in Endocrinology & Metabolism 29(3), 178-190 (2018)
[53] F.H. Mattson, S.M. Grundy, Comparison of effects of dietary saturated, monounsaturated, and polyunsaturated fatty acids on plasma lipids and lipoproteins in man. Journal of lipid research 26(2), 194-202 (1985)
[54] P.J. Huth, V.L. Fulgoni III, B.T. Larson, A systematic review of high-oleic vegetable oil substitutions for other fats and oils on cardiovascular disease risk factors: implications for novel high-oleic soybean oils. Advances in Nutrition, 6(6), 674-693 (2015)
[55] J. Fernandes, M. Fialho, R. Santos, C. Peixoto-Placido, T. Madeira, N. Sousa-Santos, A. Virgolino, O. Santos, A.V. Carneiro, Is olive oil good for you? A systematic review and meta-analysis on anti-inflammatory benefits from regular dietary intake. Nutrition, 69 110559 (2020)
[56] M.A. Briggs, K.S. Petersen, P.M. Kris-Etherton, Saturated fatty acids and cardiovascular disease: replacements for saturated fat to reduce cardiovascular risk. In Healthcare (Vol. 5, No. 2, p. 29). Multidisciplinary Digital Publishing Institute (2017)
[57] K.S. Rhee, Fatty Acids in Meats and Meat Products “Fatty Acids in Foods and Their Health Implications”. Food Res. Int. New York: 65-93 (1992)
[58] C.F. Adams, Nutritive value of American foods in common units (No. 456). Agricultural Research Service, US Department of Agriculture (1975)
[59] M.A. Flynn, H.D. Naumann, G.B. Nolph, G. Krause, M. Ellersieck, Dietary “meats” and serum lipids. The American journal of clinical nutrition 35(5), 935-942 (1982)
[60] FDA, Guidance for Industry: Food Labeling Guide, the Food and Drug Administration (FDA), Center for Food Safety and Applied Nutrition (2013)
[61] K.S. Rhee, L.M. Anderson, A.R. Sams, Lipid oxidation potential of beef, chicken, and pork. Journal of Food Science 61(1), 8-12 (1996)
[62] C. Narciso-Gaytán, D. Shin, A.R. Sams, C.A. Bailey, R.K. Miller, S.B. Smith, O.R. Leyva-Ovalle, M.X. Sánchez-Plata, Soybean, palm kernel, and animal-vegetable oils and vitamin E supplementation effect on lipid oxidation stability of sous vide chicken meat. Poultry science 89(4), 721-728 (2010)
[63] M. Alejandre, C. Poyato, D. Ansorena, I. Astiasarán, Linseed oil gelled emulsion: A successful fat replacer in dry fermented sausages. Meat science 121, 107-113 (2016)
[64] E.H. Rongey, L.J. Bratzler, The Effect of Various Binders and Meats on the Palatability and Processing Characteristics of Bologna. Journal of Food Technology 20, 134-137 (1966)
[65] J.A. Van, J.O. Reagan, J.A. Carpenter, D.R. Campion, The Effects of Meat Type and Formulation on the Physical Properties and Sensory Characteristics of Nonspecific Meat Loaves. Journal of Food Quality 4, 113-119 (1980)
[66] L.W. Hand, C.A. Hollingsworth, C.R. Calkins, R.W. Mandigo, Effects of preblending, reduced fat and salt levels on frankfurter characteristics. Journal of Food Science 52(5), 1149-1151 (1987)
[67] J.R. Claus, M.C. Hunt, C.L. Kastner, D.H. Kropf, Low-Fat, High-Added Water Bologna: Effects of Massaging, Preblending, and Time of Addition of Water and Fat on Physical and Sensory Characteristics. Journal of Food Science 55, 338-345 (1990)
[68] M. Tomaschunas, R. Zörb, J. Fischer, E. Köhn, J. Hinrichs, M. Busch-Stockfisch, Changes in sensory properties and consumer acceptance of reduced fat pork Lyon-style and liver sausages containing inulin and citrus fiber as fat replacers. Meat Science 95(3), 629-640 (2013)
[69] G. Xiong, P. Wang, H. Zheng, X. Xu, Y. Zhu, G. Zhou, Effects of Plant Oil Combinations Substituting Pork Back-Fat Combined with Pre-Emulsification on Physicochemical, Textural, Microstructural and Sensory Properties of Spreadable Chicken Liver PÂTÉ. Journal of Food Quality 39(4), 331-341 (2016)
[70] A. Teixeira, I. Ferreira, E. Pereira, L. Vasconcelos, A. Leite, S. Rodrigues, Physicochemical composition and sensory quality of goat meat burgers. Effect of fat source. Foods 10(8), 1824 (2021)
[71] C. Severini, T. De Pilli, A. Baiano, Partial substitution of pork backfat with extra-virgin olive oil in ‘salami’products: effects on chemical, physical and sensorial quality. Meat Science 64(3), 323-331 (2003)
[72] M.I. Khan, C. Jo, M.R. Tariq, Meat flavor precursors and factors influencing flavor precursors - A systematic review. Meat science 110, 278-284 (2015)
[73] S. Ventanas, E. Puolanne, H. Tuorila, Temporal changes of flavour and texture in cooked bologna type sausages as affected by fat and salt content. Meat science 85(3), 410-419 (2010)
[74] L.C. Hoffman, K. Schoon, M. Rudman, T.S.

Brand, A. Dalle Zotte, M. Cullere, Profile of cabanossi made with exotic meats and olive oil. Meat science 147, 20-27 (2019)
[75] M. Ruusunen, J. Vainionpää, E. Puolanne, M. Lyly, L. Lähteenmäki, M. Niemistö, R. Ahvenainen, Effect of sodium citrate, carboxymethyl cellulose and carrageenan levels on quality characteristics of low-salt and low-fat bologna type sausages. Meat science 64(4), 371-381 (2003)
[76] E.N. Mallika, K. Prabhakar, P.M. Reddy, Low Fat Meat Products-An overview. Veterinary world 2(9) (2009)
[77] B.W. Berry, K.F. Leddy, Effects of Fat Level and Cooking Method on Sensory and Textural Properties of Ground Beef Patties. Journal of Food Science 49(3), 870-875 (1984)
[78] J. Park, K.S. Rhee, Y.A. Ziprin, Low Fat Frankfurters with Elevated Levels of Water and Oleic Acid. Journal of Food Science 55, 871-874 (1990)
[79] B. Öztürk-Kerimoğlu, H.S. Kavuşan, D.B. Gürel, Ö. Çağındı, M. Serdaroğlu, Cold-set or hot-set emulsion gels consisted of a healthy oil blend to replace beef fat in heat-treated fermented sausages. Meat Science 176, 108461 (2021b)
[80] M.S. Brewer, Reducing the fat content in ground beef without sacrificing quality: A review. Meat Science 91(4), 385-395 (2012)
[81] J.N, Sofos, C.E. Allen, Effects of Lean Meat Source and Levels of Fat and Soy Protein on the Properties of Wiener-Type Products. Journal of Food Science 42, 875 -878 (1977)
[82] M.P. Pinero, K. Parra, N. Huerta-Leidenz, L.A. De Moreno, M. Ferrer, S. Araujo, Y. Barboza, Effect of oat's soluble fibre (β-glucan) as a fat replacer on physical, chemical, microbiological and sensory properties of low-fat beef patties. Meat science 80(3), 675-680 (2008)
[83] M. Gibis, V. Schuh, J. Weiss, Effects of carboxymethyl cellulose (CMC) and microcrystalline cellulose (MCC) as fat replacers on the microstructure and sensory characteristics of fried beef patties. Food Hydrocolloids 45, 236-246 (2015)