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Effect of Pork Back Fat Replacement with Inulin Gel and Oat Bran Flour on the Physicochemical and Sensory Evaluation of a Leberkäse Meat Product

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Abstract: This paper presents a study of the possibilities of using inulin gel and oat bran flour, in combination or individually, as substitutes for pork back fat in the formulation for a leberkäse meat product. Different concentrations of pork back fat, inulin gel, and oat bran flour were used for the preparation of the samples. The samples were analyzed based on physicochemical indicators, color characteristics, emulsion stability, sensory evaluation, and texture properties by performing a cutting test analysis using a texture analyzer. Adding oat bran flour and inulin gel led to a significant ($P<0.05$) increase in the moisture content and a decrease in the fat content. The addition of oat bran flour affected the color parameters considerably, and the a*, b*, C, and h values increased compared to the inulin gel samples and the control sample. The content and type of the functional additives used had a significant effect ($P<0.05$) on the texture of the finished leberkäse samples, with a direct relationship between their hardness and the inulin gel and oat bran flour quantity. Using oat bran flour and inulin gel enhanced the nutritional profile of the leberkäse meat products by enriching them with dietary fibers.

Keywords: meat products; functional ingredients; emulsion stability; fat replacer; color.

1. Introduction

The meat industry nowadays, in particular, shows increasing interest in the reformulation of traditional meat products, taking into account people's growing awareness of healthy and balanced diets. Traditional meat products are high in fat; hence, the efforts directed toward fat reduction aim to help consumers limit the intake of large fat amounts, including saturated fatty acids and cholesterol [1]. Excessive fat consumption is related to the development of cardiovascular and chronic diseases [2,3]. Fats, however, are an important factor in the quality of products, their technological properties, and consumer sensory perception. Fat reduction may have a negative effect on several technological and sensory characteristics of meat products; it may result in changes in emulsion stability, such as fat and water loss during heat treatment, and degrade the quality of the finished products [4]. The meat industry is challenged to develop meat products with reduced fat content without compromising their technological and sensory characteristics. In this aspect, the possibility of using inulin in gel form and oat bran flour as fat substitutes would be a suitable approach to reducing animal fats and simultaneously improving the nutritional value of products by enriching them with dietary fiber and encouraging consumers' healthy habits [5,6].

Different data are available in the literature on the use of inulin and oats in various forms as sources of dietary fiber [7,8]. Oats and all their forms are rich in high-quality proteins, vitamins, and unsaturated fatty acids [9] and contain a specific type of fiber known as β-glucan [10]. The health claim of oat fiber is related to the β-glucan it contains, which can actively reduce the LDL cholesterol and the total cholesterol in the blood [11]. Oat fiber is added to different meat products to counteract the fat reduction problems [12-14]. Thus, it was reported that the meatballs to which oat bran had been added as a fat substitute had a lower concentration of total fat and trans-fatty acids than the control samples [15].

On the other hand, inulin and the dietary fiber it contains [16] can form a gel due to its ability to retain fat and water, leading to higher yields and better structural integrity of the meat products with reduced fat content. Inulin is a functional food additive used in various foods as a fat substitute, energy content reducer, and improver of food product structure, viscosity, emulsion, and water holding parameters [17]. Its main health benefits are related to a reduced risk of atherosclerosis, osteoporosis prevention [18], control over the glucose level in the blood [19], and stimulation of the immune system [20].

This study aimed to evaluate the effect of animal fat substitution with inulin gel and oat bran flour, individually or in combination, on the physicochemical and technological parameters, the emulsion stability, and sensory acceptance of the reformulated leberkäse meat products obtained.

2. Materials and Methods

The following formulation of a leberkäse meat product was used in the experiment: beef (300 $g.kg^{-1}$), turkey (300 $g.kg^{-1}$), poultry liver (80 $g.kg^{-1}$); wheat flour (2 $g.kg^{-1}$); fat (370 $g.kg^{-1}$); sodium chloride (2.5 $g.kg^{-1}$); sodium nitrite (0.05 $g.kg^{-1}$); black pepper (1.5 $g.kg^{-1}$); nutmeg (0.8 $g.kg^{-1}$); cardamom (0.8 $g.kg^{-1}$); cumin (0.8 $g.kg^{-1}$) and water (200 $g.kg^{-1}$). Seven experimental samples were prepared with different concentrations of pork back fat, inulin gel, and oat bran flour, according to Table 1.

Table 1. Model formulations of meat products: leberkäse with pork back fat, oat bran flour, and inulin gel.

Sample	Ingredient proportion, g.kg-1		
	Pork back fat (X1)	Inulin gel (X2)	Oat bran flour (X3)
1	370	0	0
2	0	370	0
3	0	0	370
4	185	185	0
5	185	0	185
6	0	185	185
7	123	123	123

The turkey meat, beef meat, pork back fat, and poultry liver were purchased from and supplied by meat manufacturing companies in the region. The oat flour was purchased from shops. The inulin (Orafti®HPX) was provided by ARTEMIS Ltd and was used in the experiment in the form of a gel obtained through hydration in a 1: 4 (w/v) ratio as described by

Latoch *et al*. [21]. The oat bran flour was hydrated in the same ratio. The two functional ingredients were added during the processing in the cutter. During cutting, water was added to the amount of 20% of the weight of the raw meat material. The ready mixture was filled in aluminum trays, which were baked in a convection oven under the following conditions: first, at 70 °C for 30 minutes; next, the temperature was increased constantly up to 110°C; afterward, at the second hour, the temperature was increased to 130°C. The total baking time was 120 minutes until a temperature of 72°C was reached at the center. The resultant samples were cooled at 2 – 4°C until the temperature at the center of the samples was not higher than 4°C.

Physicochemical analyses of the leberkäse meat product were performed 24 hours after its preparation. The moisture content (MC) of the tested samples was determined by drying at 104±1 °C to a constant weight using a KERN MLS-A moisture analyzer (Kern & Sohn GmbH, Germany). The protein content was evaluated by the Kjeldahl method following [22]; the total fat was assayed by the Soxhlet method following [23]; the ash content was assayed following [24], the carbohydrate content following [25], and the dietary fiber content following [26]. The energy value was calculated using the arithmetic means of the total chemical composition according to EO Regulation 1169/2011.

The water activity (aw) was measured using HygroPalm – HP23 at 22-25ºC. The pH measurement was carried out using an MS 2004 pH meter (Microsyst, Bulgaria) on a pre-prepared aqueous extract of the sample at a sample/water ratio of 1: 9 (w/v).

The assay of the thiobarbituric acid reactive substances (TBARS) was performed according to the method described by Cabral *et al*. [27].

The color parameters were determined spectrophotometrically using a Minolta Chroma meter (model CR 410, Osaka, Japan) in the CIELab system.

The emulsion stability was determined using the method described by Zorba *et al*. [28].

The texture of the samples was analyzed with a cutting test. A TA-XT Plus texture analyzer (Stable Micro Systems, Surrey, England) was used to measure the force–deformation curves. The test cell consisted of a thick steel blade, which was fitted through a slit in a table (like a guillotine blade). The blade edge was not sharpened and fitted loosely into the slit in the table. The pieces of the leberkäse sample (width=50±5 mm, height=25±2 mm) subjected to the test were placed on the table, under the blade, and were cut through as the blade moved down at a constant speed through the slit in the table (the assay parameters were as follows: pre-test speed: 10.0 $mm.s^{-1}$; test speed: 20.0 $mm.s^{-1}$; post-test speed: 20.0 $mm.s^{-1}$). The down stroke distance was 30.0 mm (the blade had to cut the meat completely). The initial slope (slope of the first linear part of the force-deformation curve, N/mm), the cutting force (maximum force, N), cutting deformation (deformation at cutting force, mm), and cutting energy (integrated area under the full cutting, N.mm) were used for statistical evaluation, and three repetitions were performed on the samples [29]. The cutting energy and cutting force were estimated using a knife blade attached to the TA-XT Plus texture analyzer (Stable Micro Systems, Surrey, GB). The cutting force is obtained as the maximum force required for cutting the sample, whereas the TPA hardness is the maximum force needed for compressing the sample [30]. The sensory evaluation of the samples was performed using a five-digit hedonic scale, where 5 corresponded to the highest value and 1 to the lowest value of the assessment for the given indicator. The tasting panel included 10 tasters, and the leberkäse were evaluated according to the following qualitative sensory descriptors: appearance, color, consistency, flavor, aroma, aftertaste, and an overall assessment of the perception of the products.

All the data obtained were analyzed statistically by one-way analysis of variance (ANOVA) using the Statgraphics 16 software product. Significant ($P<0.05$) differences between the treatments were determined using Duncan's post hoc test. All experiments were performed in triplicate, and the data presented in the tables and figures were expressed as means ± standard deviation (SD).

3. Results and Discussion

3.1. Proximate composition analysis.

The results in Table 2 indicate that the content and type of functional additives used had a significant ($P<0.05$) effect on the chemical composition of the finished leberkäse products. The fat substitution with inulin gel and/or oat bran flour resulted in products of reduced energy value, which was inversely proportional to the percentage of fat substitution. The fat reduction was the highest in sample 3, where we had used oat bran flour, followed by sample 7, where equal amounts of pork back fat, inulin gel, and oat bran flour were used. It had been anticipated that the moisture content in the final products would be affected considerably by the percentage of water added to the formulations. The highest water content was registered in sample 6, which was statistically discernible ($P<0.05$) from the other samples. The water content was higher in the oat bran flour samples, followed by the inulin gel samples, and these results could be attributed to the better water retention and hygroscopic properties of oat bran flour [31]. This, in turn, could be expected to affect the texture parameters of the product as well [32,33]. Data similar to ours have been reported by Alves *et al*. [34], who used green banana flour and pork skin emulsion as animal fat substitutes.

Regarding the proteins in the finished products, there were also statistically significant ($P<0.05$) differences between the control and the test samples. The lowest and statistically discernible ($P<0.05$) protein quantity was found in sample 4, followed by sample 6. This quantity was the highest in sample 7, where we had added equal amounts of pork back fat and the two functional additives. The carbohydrate content ranged between 6.8% and 12.32%, this content being higher in the inulin gel samples compared to the oat bran flour and the control samples. This, as well as the dietary fiber content, resulted directly from the chemical nature of the ingredients. The dietary fiber content was the highest in the samples where the animal fat had been replaced by inulin gel, followed by the oat bran flour samples.

Table 2. Proximate composition (%), dietary fiber, and energy value of control and reformulated leberkäse samples.

Sample	Indicator						
	Moisture content, %	Protein, %	Fat, %	Carbohydrates, %	Dietary fiber, %	Ash, %	Energy value, KJ/kcal
1	$35.73±5.45^{a}$	$9.18±0.12^{c}$	$28.50±0.22^{f}$	$8.77±0.28^{b}$	$4.57±0.23^{a}$	$3.00±0.9^{ab}$	326/1362
2	$66.49±4.49^{cd}$	$10.62±0.05^{e}$	$11.93±0.12^{e}$	$12.32±0.09^{e}$	$15.71±0.38^{f}$	$2.55±0.5^{a}$	199/832
3	$66.89±2.11^{d}$	$9.50±0.18^{d}$	$8.00±0.18^{a}$	$8.90±0.14^{b}$	$11.74±0.21^{d}$	$2.98±0.05^{ab}$	153/639
4	$59.69±2.71^{b}$	$7.80±0.2^{a}$	$11.66±0.25^{e}$	$10.09±0.21^{d}$	$14.59±0.22^{e}$	$2.82±0.14^{a}$	177/739
5	$63.98±2.08^{bcd}$	$9.14±0.05^{c}$	$10.93±0.21^{d}$	$6.80±0.05^{a}$	$6.12±0.12^{b}$	$3.60±0.21^{b}$	162/677
6	$68.80±2.8^{cd}$	$8.12±0.17^{b}$	$9.70±0.15^{c}$	$9.96±0.1^{d}$	$8.77±0.01^{c}$	$3.27±0.17^{ab}$	159/667
7	$63.64±3.37^{bc}$	$11.32±0.21^{f}$	$9.17±0.23^{b}$	$9.20±0.12^{c}$	$4.82±0.16^{a}$	$3.10±0.19^{ab}$	164/688

[a-f] - values within the same column bearing a common superscript did not differ statistically ($P>0.05$).

Sample description: sample 1 –pork back fat only; sample 2 –inulin gel only; sample 3 – oat bran flour only; sample 4 – equal proportions of pork back fat and inulin gel; sample 5 – equal proportions of pork back fat and oat bran flour; sample 6 – equal proportions of inulin gel and oat bran flour; sample 7 – equal proportions of pork back fat, inulin gel and oat bran flour.

3.2. TBARS value, pH, and aw analysis.

Table 3 shows the results on the TBARS, water activity (a_w), and pH values of the leberkäse samples. The quantity of the lipid oxidation by-products was determined through TBA and expressed as mg MDA kg^{-1} leberkäse. The resultant values ranged from 0.048 mg MDA kg^{-1} for sample 1 to 0.241 mg MDA kg^{-1} for sample 6, where the fats had been completely replaced by equal amounts of inulin gel and oat bran flour. According to some authors [35-38], a higher fat content led to larger amounts of oxidation products. In our samples, however, more significant oxidation products were observed in the samples with reduced fat. Also, adding oat bran flour led to higher values of this parameter compared to the inulin gel samples. The water activity in the different formulations did not differ significantly (P>0.05) and ranged between 0.945 and 0.957. Regarding the pH values of the leberkäse products, higher values were observed in the inulin gel samples compared to the control and oat bran flour samples. A similar increase in pH was also reported by Méndez-Zamora *et al*. [39].

Table 3. Effects on the TBARS, pH, and a_w values of the control and reformulated leberkäse with different degrees of fat substitution with inulin gel and oat bran flour.

Sample	Indicator		
	pH	**a_w**	**TBARS, mg MDA/kg**
1	5.61±0.02^a	0.945±0.002^a	0.048±0.001^a
2	6.17±0.01^d	0.954±0.003^{ab}	0.084±0.001^b
3	5.92±0.03^b	0.954±0.006^{ab}	0.152±0.002^f
4	6.2±0.05^d	0.948±0.002^{ab}	0.094±0.001^c
5	6.07±0.03c	0.954±0.008^{ab}	0.118±0.003^e
6	6.03±0.02^c	0.957±0.009^b	0.241±0.007^g
7	6.06±0.07^c	0.952±0.001^{ab}	0.11±0.002^d

$^{a-d}$ - values within the same column bearing a common superscript did not differ statistically (P>0.05)
Sample description: sample 1 –pork back fat only; sample 2 –inulin gel only; sample 3 – oat bran flour only; sample 4 – equal proportions of pork back fat and inulin gel; sample 5 – equal proportions of pork back fat and oat flour; sample 6 – equal proportions of inulin gel and oat bran flour; sample 7 – equal proportions of pork back fat, inulin gel and oat bran flour.

Table 4 shows the results of the color evaluation of the samples. The L* values ranged between 50.92 and 58.29, the lowest ones reported for sample 1 and the highest for sample 4, where 50% of the animal fat had been replaced with inulin gel. The inulin and oat bran flour hydration and their color characteristics caused the changes in the lightness of the experimental samples compared to the control sample. A difference in the color lightness of bologna-type sausages was also reported by Fernández-Ginés *et al*. [40]. Higher a* and b* values were observed in the oat bran flour samples, followed by the inulin gel samples. Contrary to the data reported by Keenan *et al*. [41], which indicated that the addition of inulin as a fat animal substitute in sausages had no considerable effect on the a* values, the a* values we measured varied across the individual samples examined (Table 4), with the highest a* value measured in sample 3, and the lowest one in sample 5. Regarding the yellow color component b*, similarly to lightness, the lowest values were measured in the control sample and the highest ones in sample 6. Inulin gel and oat bran flour increased a* and b* values compared to the control sample (P<0.05).

Table 4. Effects on the color parameters of the control and reformulated leberkäse samples with different degrees of fat substitution with inulin gel and oat bran flour.

Sample	Color parameters				
	L*	**a***	**b***	**C**	**h**
1	50.92±0.86^a	11.67±0.52^{bc}	10.22±0.02^a	15.52±0.15^a	41.18±0.57^a
2	55.36±1.58^b	11.39±0.58^{abc}	11.81±0.32^b	16.4±0.63^{ab}	46.06±0.78^b
3	56.78±1.31^{bc}	15.04±0.66^e	15.27±0.41^d	19.24±0.61^c	52.51±0.55^c
4	58.29±0.78^c	10.89±0.49^{ab}	13.16±0.38^c	17.08±0.58^b	50.39±0.5^c

Sample	Color parameters				
	L*	a*	b*	C	h
5	55.45±0.84^{b}	10.49±0.64^{a}	13.00±0.57^{c}	16.76±0.09^{b}	51.1±2.93^{c}
6	57.73±2.6^{bc}	11.92±0.29^{cd}	15.17±0.76^{d}	19.3±0.65^{c}	51.8±1.45^{c}
7	55.71±1.77^{bc}	12.86±0.76^{d}	13.41±0.18^{c}	18.59±0.55^{c}	46.24±1.68^{b}

$^{a-g}$ -values within the same column bearing a common superscript did not differ statistically (P<0.05)
Sample description: sample 1 –pork back fat only; sample 2 –inulin gel only; sample 3 – oat bran flour only; sample 4 – equal proportions of pork back fat and inulin gel; sample 5 – equal proportions of pork back fat and oat bran flour; sample 6 – equal proportions of inulin gel and oat bran flour; sample 7 – equal proportions of pork back fat, inulin gel and oat bran flour.

These results are in conformity with those presented by [42,43], who used oat β-glucan and inulin in the formulation of sausages and poultry burgers. Higher chroma and hue values were obtained in the oat bran flour samples, but the inulin gel samples were closer to the control sample.

3.3. Texture analysis and sensory perception.

Table 5 shows the results concerning the emulsion stability of the leberkäse samples. The highest and statistically discernible emulsion stability compared to the other samples was measured in sample 1 (P<0.05), as the animal fat substitution with inulin gel and/or oat bran flour had reduced it. The lowest emulsion stability was observed in the sample where the fat had been completely replaced with inulin gel, followed by the sample with equal proportions of inulin gel and oat bran flour. Nevertheless, the emulsion stability was the closest to the control sample in the sample, where the addition of inulin gel had reduced the animal fat by half. This conforms with the data reported by Illippangama *et al*. [16], which indicated that the use of inulin could considerably improve some technological properties, particularly the emulsion stability of cooked meat products.

Warner Bratzler's results usually provide information on the softness and tenderness of meat food. Table 5 shows that the highest maximum cutting force and, respectively, energy, were required to cut a piece of sausage from sample 6, where inulin gel and oat bran flour had been used in equal amounts as animal fat substitutes, and from the control sample, the data on these two samples being statistically discernible (P<0.05) from each other and discernible from the other samples (P<0.05). The lowest maximum cutting force and energy were registered with the inulin gel samples. These results correlate with the general opinion expressed by the members of the tasting panel, stating that the oat bran flour samples featured 'too thick consistency', whereas the inulin gel samples had 'too soft consistency'. A similar relation between reduced hardness and the sensory grades of cooked sausages was also reported by Sarteshnizi *et al*. [42], who used β-glucan and starch for fat reduction.

Table 5. Effects on the texture properties and emulsion stability of the control and reformulated leberkäse samples with different degrees of fat substitution with inulin gel and oat bran flour.

Sample	Indicator				
	Emulsion stability, %	Initial slope (N/mm)	Cutting force (N)	Cutting distance (mm)	Cutting energy (N mm)
1	75.18±1.62^{f}	1.25±0.24^{d}	20.62±3.02^{e}	24.23±0.51^{cd}	359.89±19.2^{d}
2	43.76±1.69^{a}	0.83±0.03^{b}	7.98±1.34^{bc}	20.42±2.21^{bc}	159.97±22.66^{b}
3	49.97±1.42^{b}	1.21±0.18^{cd}	15.07±2.81^{d}	23.46±0.93^{cd}	236.29±31.39^{c}
4	68.88±1.53^{e}	0.20±0.03^{a}	2.92±0.48^{a}	14.51±2.68^{a}	68.81±3.65^{a}
5	63.48±1.42^{d}	0.29±0.07^{a}	6.42±1.23^{ab}	16.61±2.79^{ab}	82.43±8.96^{a}
6	49.68±1.34^{b}	2.67±0.42^{e}	35.46±3.62^{f}	26.96±4.25^{d}	518.66±73.33^{e}
7	57.9±1.28^{c}	0.92±0.16^{bc}	10.89±1.72^{c}	21.17±3.25^{c}	163.85±22.51^{b}

$^{a-g}$ -values within the same column bearing a common superscript did not differ statistically (P<0.05)
Sample description: sample 1 –pork back fat only; sample 2 –inulin gel only; sample 3 – oat bran flour only; sample 4 – equal proportions of pork back fat and inulin gel; sample 5 – equal proportions of pork back fat and oat bran flour; sample 6 – equal proportions of inulin gel and oat bran flour; sample 7 – equal proportions of pork back fat, inulin gel and oat bran flour.

Table 6 shows that the use of inulin gel as a fat animal substitute affected the appearance and consistency. The grades scored for these samples were significantly lower than those scored for the correspondent oat flour and the control samples. This was most probably due to the too-soft consistency of the products obtained, which the tasters described as untypical of this product range. The lowest grades for these parameters were given to sample 6, where the entire pork back fat had been replaced with equal amounts of inulin gel and oat bran flour. The panelists found a reduced aroma intensity at chewing in samples 2, 6, and 7 compared to the control sample. Afshari *et al*. [44] also reported a reduction in the aroma intensity by adding inulin and β-glucan. Still, their results on the overall acceptance did not differ significantly from the control sample. However, we found significant differences (P<0.05) between the individual samples, the highest overall grade having been scored by sample 1 (the control sample), followed by samples 4 and 7. In contrast, lower grades were given to samples 6, 2, 5 and 3 (fig. 1).

Table 6. Effects on the sensory descriptors of the control and reformulated leberkäse samples with oat bran flour and inulin gel and a different speed/degree of substitution of fats.

Sample	Indicator					
	Appearance	Colour	Consistency	Taste	Aroma	Aftertaste
1	4.33 ± 0.98^{d}	4.33 ± 0.82^{b}	4.33 ± 0.82^{c}	4.08 ± 0.58^{b}	4.42 ± 0.49^{a}	2.92 ± 1.56^{a}
2	2.5 ± 1.25^{ab}	3.42 ± 1.43^{ab}	2.67 ± 1.4^{ab}	2.67 ± 1.17^{a}	3.92 ± 1.5^{a}	2.00 ± 1.26^{a}
3	3.92 ± 1.02^{cd}	3.42 ± 0.92^{ab}	3.83 ± 1.47^{bc}	3.25 ± 1.21^{ab}	3.5 ± 1.18^{a}	2.58 ± 1.39^{a}
4	2.92 ± 1.11^{bc}	3.17 ± 1.21^{ab}	3.25 ± 1.08^{abc}	3.67 ± 0.98^{ab}	4.42 ± 0.8^{a}	2.67 ± 1.44^{a}
5	3.83 ± 0.82^{cd}	3.75 ± 0.76^{ab}	3.58 ± 1.28^{bc}	3.92 ± 0.86^{b}	4.08 ± 0.92^{a}	2.58 ± 1.36^{a}
6	1.58 ± 0.58^{a}	2.67 ± 1.21^{a}	1.83 ± 0.98^{a}	3.58 ± 0.92^{ab}	3.92 ± 0.92^{a}	3.00 ± 1.64^{a}
7	3.42 ± 1.36^{bcd}	4.08 ± 0.2^{b}	3.67 ± 1.4^{bc}	3.08 ± 1.43^{ab}	3.75 ± 1.47^{a}	3.00 ± 1.52^{a}

$^{a-d}$ -values within the same column bearing a common superscript did not differ statistically (P < 0.05)

Sample description: sample 1 –pork back fat only; sample 2 –inulin gel only; sample 3 – oat bran flour only; sample 4 – equal proportions of pork back fat and inulin gel; sample 5 – equal proportions of pork back fat and oat bran flour; sample 6 – equal proportions of inulin gel and oat bran flour; sample 7 – equal proportions of pork back fat, inulin gel and oat bran flour.

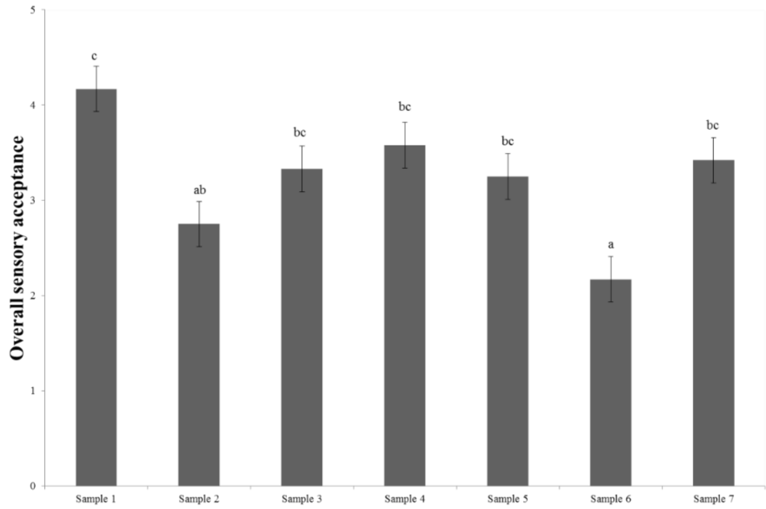

Figure 1. Overall sensory acceptance of the control and reformulated leberkäse samples with inulin gel and oat bran flour with different degrees of fat substitution.

4. Conclusions

The physicochemical, technological, and sensory parameters were largely affected by the functional additives used, inulin or oat bran flour, and the quantity that replaced the pork fat in leberkäse formulations. The addition of hydrated oat bran flour and inulin gel increased the water content and reduced the fat content and the energy score of the product. The use of oat bran flour in the leberkäse composition resulted in meat products more intense in color than standard pork fat products and leberkäse products where inulin had been used for fat reduction. Furthermore, the relation established between hardness and the oat bran flour and inulin gel quantity can be used to enhance the sensory qualities of this type of product and to develop meat products enriched with dietary fiber that are more attractive to consumers due to their health benefits.

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Conflicts of Interest

The authors declare no conflict of interest.

References

1. Souza, C.V.B.; Bellucci, E.R. B.; Lorenzo, J.M.; Barretto, A.C.D.S. Low-fat Brazilian cooked sausage-Paio–with added oat fiber and inulin as a fat substitute: effect on the technological properties and sensory acceptance. *Food Science and Technology* **2019**, *39*, 295-303, https://doi.org/10.1590/fst.03618.
2. Bunmee, T.; Setthaya, P.; Chaiwang, N.; Sansawat, T. Effect of Purple Eggplant Flour on Physicochemical, Lipid Oxidation, and Sensory Properties of Low-Fat Beef Patties. *International Journal of Food Science* **2022,** *2022*, 1-9, https://doi.org/10.1155/2022/9753201.
3. Colomer Sellas, M.; de Souza, D.L.; Vila-Martí, A.; Torres-Moreno, M. Effect of pork back-fat reduction and substitution with texturized pea protein on acceptability and sensory characteristics of dry fermented sausages. *CyTA-Journal of Food* **2021**, *19*, 429-439, https://doi.org/10.1080/19476337.2021.1912188.
4. da Silva Felix, T.M.; de Carvalho, F.A.L.; Ramos, E.J.N.; Ferreira, B.J.M.; de Souza Rodrigues, R.T.; Queiroz, M.A.Á. Replacement meat by commercial flours on physicochemical and sensory properties of low-fat lamb burgers. *Research, Society and Development* **2021**, *10*, http://dx.doi.org/10.33448/rsd-v10i14.21792.
5. Pérez-Burillo, S.; Pastoriza, S.; Gironés, A.; Avellaneda, A.; Francino, M.P.; Rufián-Henares, J.A. Potential probiotic salami with dietary fiber modulates metabolism and gut microbiota in a human intervention study. *Journal of Functional Foods* **2020**, *66*, https://doi.org/10.1016/j.jff.2020.103790.
6. Ferjančič, B.; Kugler, S.; Korošec, M.; Polak, T.; Bertoncelj, J. Development of low-fat chicken bologna sausages enriched with inulin, oat fibre or psyllium. *International Journal of Food Science and Technology* **2021**, *56*, 1818-1828, https://doi.org/10.1111/ijfs.14808.
7. Park, S.Y.; Kim, H.Y. Fried pork loin batter quality with the addition of various dietary fibers. *Journal of animal science and technology* **2021**, *63*, 137–148, https://doi.org/10.5187/jast.2021.e15.
8. Huang, S.; Tsai, Y.; Chen, C. Effects of wheat fiber, oat fiber, and inulin on sensory and physico-chemical properties of Chinese-style sausages. *Asian-Australasian Journal of Animal Sciences* **2011**, *24*, 875-880, https://doi.org/10.5713/ajas.2011.10317.
9. Pintado, T.; Herrero, A.M.; Jiménez-Colmenero, F.; Capillas, C. Emulsion gels as potential fat replacers delivering β-glucan and healthy lipid content for food applications. *Journal of food science and technology*, **2016**, *53*, 4336-4347, https://doi.org/10.1007/s13197-016-2432-4.
10. Ciudad-Mulero, M.; Fernández-Ruiz, V.; Matallana-González, M.C.; Morales, P. Dietary fiber sources and human benefits: The case study of cereal and pseudocereals. *Advances in food and nutrition researc* **2019**, *90*, 83-134, https://doi.org/10.1016/bs.afnr.2019.02.002.
11. EFSA Panel on Dietetic Products, Nutrition and Allergies (NDA). Scientific opinion on the substantiation of a health claim related to oat beta glucan and lowering blood cholesterol and reduced risk of (coronary) heart disease pursuant to Article 14 of Regulation (EC) No 1924/2006. *EFSA Journal* **2010**, *8*, https://doi.org/10.2903/j.efsa.2010.1885.
12. de Sousa, A.M.B.; de Araujo Alves, R.; Madeira, D.S.S.; Santos, R.M.; Pereira, A.L.F.; de Oliveira Lemos, T.; Abreu, V.K.G. Storage of beef burgers containing fructooligosaccharides as fat replacer and potassium

chloride as replacing sodium chloride. *Journal of Food Science and Technology* **2020**, *57*, 3232-3243, https://doi.org/10.1007/s13197-020-04354-0.
13. Yang, H.; Choi, S.; Jeon, J.; Park, G.; Joo, S. Textural and sensory properties of low fat pork sausages with added hydrated oatmeal and tofu as texture modifying agents. *Meat science* **2007**, *75*, 283-289, https://doi.org/10.1016/j.meatsci.2006.07.013.
14. Pinero, M.; Parra, K.; Huerta-Leidenz, N.; Arenas de Moreno, L.; Ferrer, M.; Araujo, S.; Barboza, Y. Effect of 'oat's soluble fibre (b-glucan) as a fat replacer on physical, chemical, microbiological and sensory properties of low-fat beef patties. *Meat science* **2008**, *80*, 675-680, https://doi.org/10.1016/j.meatsci.2008.03.006.
15. Yılmaz, İ.; Dağlıoğlu, O. The effect of replacing fat with oat bran on fatty acid composition and physicochemical properties of meatballs. *Meat science* **2003**, *65*, 819-823, https://doi.org/10.1016/S0309-1740(02)00286-3.
16. Illippangama, A.U.; Jayasena, D.D.; Jo, C.; Mudannayake, D.C. Inulin as a functional ingredient and their applications in meat products. *Carbohydrate Polymers* **2022**, *275*, https://doi.org/10.1016/j.carbpol.2021.118706.
17. Zinina, O.; Merenkova, S.; Tazeddinova, D.; Rebezov, M.; Stuart, M.; Okuskhanova, E.; Yessimbekov, Z.; Baryshnikova, N. Enrichment of meat products with dietary fibers: a review. *Agronomy Research*, **2019**, *17*, 1808-1822, https://doi.org/10.15159/AR.19.163.
18. Anderson-Dekkers, I.; Nouwens-Roest, M.; Peters, B.; Vaughan, E. Inulin. In: *Handbook of Hydrocolloids.* Woodhead Publishing. **2021**; pp. 537-562.
19. Jackson, K.; Taylor, G.; Clohessy, A.; Williams, C. The effect of thedaily intake of insulin on fasting lipids, insulin and glucose concentrations inmiddle-aged men and women. *British Journal of Nutrition* **1999**, *82*, 23–30.
20. Dhingra, D.; Michael, M.; Rajput, H.; Patil, R.T. Dietary fibre in foods: a review. *Journal of food science and technology* **2012** *49*, 255–266, https://doi.org/10.1007/s13197-011-0365-5.
21. Latoch A.; Glibowski P.; Libera J. The effect of replacing pork fat of inulin on the physicochemical and sensory quality of guinea fowl pate. *Acta Scientiarum Polonorum Technologia Alimentari* **2016**, *15*, 311-320, https://doi.org/10.17306/j.afs.2016.3.30.
22. BDS EN ISO 5983-1:2006 - Animal feeding stuffs - Determination of nitrogen content and calculation of crude protein content - Part 1: Kjeldahl method (ISO 5983-1:2005).
23. BDS 8549:1992 - Meat and meat products. Determination of fats.
24. BDS 9373:1980 - Meat and meat products. Determination of ash content.
25. BDS 5713:1984 - Meat products. Method for determination of starch content.
26. AOAC 985.29 - Total Dietary Fibre in Foods - Enzymatic-Gravimetric Method.
27. Cabral, N.O.; Oliveira, R.F.; Henry, F.C.; de Oliveira, D.B.; do Santos Junior, A.C.; Maia Junior, J.A.; Martines MLL. Effect of the fruit aqueous extract of balloon pepper (Capsicum baccatum var. Pendulum) on lipid oxidation, microbiological quality and consumer acceptance of fresh pork sausage and smoked. *Food Science and Technology* **2021**, *42*, 1-8, https://doi.org/10.1590/fst.09221
28. Zorba, Ö.; Kurt, Ş. Optimization of emulsion characteristics of beef, chicken and turkey meat mixtures in model system using mixture design. *Meat science* **2006**, *73*, 611-618, https://doi.org/10.1016/j.meatsci.2006.02.017.
29. De Huidobro, F.; Miguel, E.; Blázquez, B.; Onega, E. A comparison between two methods (Warner–Bratzler and texture profile analysis) for testing either raw meat or cooked meat. *Meat science* **2005**, *69*, 527-536, https://doi.org/10.1016/j.meatsci.2004.09.008.
30. Bourne, M. *Food Texture and Viscosity: Concept and Measurement.* 2nd ed. London: Academic Press. Elsevier, **2002**.
31. Mounika, T.; Sahityarani, M. Development and quality evaluation of oat flour incorporated spent hen meat balls. *The Pharma Innovation Journal* **2021**, *10*, 289-291.
32. Steenblock, R.; Sebranek, J.; Olson, D.; Love, J. The effects of oat fiber on the properties of light Bologna and Fat-free Frankfurters. *Journal of Food Science* **2001**, *66*, 1409-1415, https://doi.org/10.1111/j.1365-2621.2001.tb15223.x.
33. Liu, R.; Wang, N.; Li, Q.; Zhang M. Comparative studies on physicochemical properties of raw and hydrolyzed oat β-glucan and their application in low-fat meatballs. *Food Hydrocolloids* **2015**, *51*, 424-431, https://doi.org/10.1016/j.foodhyd.2015.04.027.
34. Alves, L.; Lorenzo, J.; Gonçalves, C.; Santos, B.; Heck, R.; Cichoski, A.; Campagnol, P. Production of healthier bologna type sausages using pork skin and green banana flour as a fat replacers. *Meat science* **2016**, *121*, 73-78, https://doi.org/10.1016/j.meatsci.2016.06.001.
35. Pan, N.; Dong, C.; Du, X.; Kong, B.; Sun, J.; Xia, X. Effect of freeze-thaw cycles on the quality of quick-frozen pork patty with different fat content by consumer assessment and instrument-based detection. *Meat Science* **2021**, *172*, https://doi.org/10.1016/j.meatsci.2020.108313.
36. Sasaki, K.; Mitsumoto, M.; Kawabata, K. Relationship between lipid peroxidation and fat content in Japanese Black beef Longissimus muscle during storage. *Meat science* **2001**, *59*, 407-410, https://doi.org/10.1016/S0309-1740(01)00093-6.

37. Estévez, M.; Morcuende, D.; Ventanas, S.; Cava, R. Analysis of volatiles in meat from Iberian pigs and lean pigs after refrigeration and cooking by using SPME-GC-MS. *Journal of Agricultural and Food Chemistry* **2003**, *51*, 3429-3435, https://doi.org/10.1021/jf026218h.
38. Lorenzo, J.; Pateiro, M. Influence of fat content on physico-chemical and oxidative stability of foal liver pâté. *Meat science* **2013**, *95*, 330–335, https://doi.org/10.1016/j.meatsci.2013.04.045.
39. Méndez-Zamora, G.; García-Macías, J.; Santellano-Estrada, E.; Chávez-Martínez, A.; Durán-Meléndez, L.; Silva-Vázquez, R.; Quintero-Ramos, A. Fat reduction in the formulation of frankfurter sausages using inulin and pectin. *Food Science and Technology* **2015**, *35*, 25-31.
40. Fernández-Ginés, J.; Fernández-López, J.; Sayas-Barberá, E.; Sendra, E.; Pérez-Alvarez, J. Effect of storage conditions on quality characteristics of bologna sausages made with citrus fiber. *Journal of Food Science* **2003**, *68*, 710-714, https://doi.org/10.1111/j.1365-2621.2003.tb05737.x.
41. Keenan, D.; Resconi, V.; Kerry, J.; Hamill, R. Modelling the influence of inulin as a fat substitute in comminuted meat products on their physico-chemical characteristics and eating quality using a mixture design approach. *Meat science* **2014**, *96*, 1384-1394, https://doi.org/10.1016/j.meatsci.2013.11.025.
42. Sarteshnizi, R.; Hosseini, H.; Bondarianzadeh, D.; Colmenero, F. Optimization of prebiotic sausage formulation: Effect of using β-glucan and resistant starch by D-optimal mixture design approach. *LWT-Food Science and Technology* **2015**, *62*, 704-710, https://doi.org/10.1016/j.lwt.2014.05.014.
43. Burdzy, S.; Augustyńska-Prejsnar, A.; Sokołowicz, Z. Effect of the Addition of Inulin on the Quality of Poultry Burgers®. *Postępy Techniki Przetwórstwa Spożywczego* **2021**, *1*, 29-34.
44. Afshari, R.; Hosseini, H.; Khaneghah, A.; Khaksar, R. Physico-chemical properties of functional low-fat beef burgers: Fatty acid profile modification. *LWT* **2017**, *78*, 325-331, https://doi.org/10.1016/j.lwt.2016.12.054.