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Determination of Properties of Meat Products with Plant Supplements †

Natalia Murlykina [1,2]

[1] Department of Chemistry, Biochemistry, Microbiology and Hygiene of Nutrition, State Biotechnological University, 61051 Kharkiv, Ukraine; nvmurlykina@karazin.ua
[2] Department of Applied Chemistry, V.N. Karazin Kharkiv National University, Svobody Sq., 4, 61022 Kharkiv, Ukraine

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Abstract: One approach to improving population nutrition is the development of widely consumed minced meat products (MMPs) enriched with biologically active compounds such as polyunsaturated fatty acids, dietary fibers, and iron. This study investigated the functional–technological properties and chemical composition of MMPs with plant supplements—fenugreek and dried leaves of blackcurrant (DLBC). The emulsion stability of minced meat was assessed based on the mass fraction of the intact emulsion, which lost a certain amount of moisture and fat after heat treatment. The water-holding capacity (WHC), fat-holding capacity (FHC), energy value as well as a proximate composition, including the total iron content were determined using standard methods. Sensory evaluation was conducted using quantitative descriptive analysis and profile analysis methods based on the descriptors of appearance, consistency, cross-sections appearance, flavour, and taste. The protein content of MMPs with plant supplements ranged from 16.4 to 19.0%. Fenugreek increased iron levels from 1.27 ± 0.03 mg/100 g to 2.14 ± 0.04 mg/100 g. FHC and WHC values in samples with fenugreek or DLBC surpassed control values by 6.3–23.0% and 2.7–5.0%, respectively. Sunflower oil, fenugreek, and DLBC not only enhanced nutritional value, but also improved functional–technological properties, sensory quality, and reduced heat-treatment losses. These MMPs can be classified as health-oriented foods suitable for dietary adjustments.

Keywords: the minced meat; fenugreek; the emulsion stability; water-holding capacity; fat-holding capacity

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1. Introduction

Key strategies to overcome the problem of reducing nutrition quality are aimed at developing food products with increased nutritional value, aimed in particular at foods containing animal proteins [1,2]. Such products include widely consumed items, primarily semi-finished minced meat products and finished meat products based on minced meat emulsions. These products are highly regarded by consumers and continue to play an increasingly significant role in their diet each year [3–5].

Beef is considered one of the most popular types of meat. It is nutritious, the least fatty, and contains easily digestible protein [6–8]. Beef is rich in vitamins that accelerate metabolism (B_1, B_2, B_3, B_5, B_6, B_9, B_{12}, K, A) as well as macro- and microelements (Mg, Ca, K, Na, P, Fe) that are associated with promoting the functioning of the nervous system, overcoming iron deficiency, helping with problems with hematopoiesis, and maintaining

and improving the condition of teeth, nails, hair, and skin. Including beef products in the diet helps strengthen immunity and blood vessels, prevent atherosclerosis, improve sleep, eliminate cholesterol, maintain a normal level of acidity, etc. [5,9,10].

Thus, the exceptional importance of beef meat indicates the relevance of developing the minced meat products (MMPs) based on it. Equally important is the careful selection of additional recipe components, particularly plant-based raw materials rich in beneficial micronutrients that can enhance the body's resistance to diseases and support physiological functions [7–9]. This strategy aligns with the global program for sustainable development and ensures adequate nutrition for the population by creating minced meat products additionally enriched with various biologically active compounds [11]. Such goals can be achieved with the help of various promising plant supplements that have not previously been used in traditional minced meat products [12–14]. In particular, vegetables, cereals, flour, and vegetable protein components have been widely developed [7,8,10,15] as MMP additives.

Vegetable fats, in particular sunflower oil, are often used as a functional supplement [1,2,15]. This oil belongs to the group of fats with a high content of polyunsaturated fatty acids, which are capable of producing anti-inflammatory compounds [16] and also have inhibitory activity against gram-positive and gram-negative bacteria [17]. Sunflower oil contains 55–72% linoleic, 25–35% oleic acid, and a small amount of linolenic acid, along with 0.3–1.2% phosphatides, which play an important role in all metabolic processes in the human body. It also contains fat-soluble vitamins, in particular vitamin E and antihemorrhagic vitamin K [16,17]. In beef patties with plant supplements, pork backfat can be partially or completely replaced with an emulsion of olive oil in water [18,19]. The presence of vegetable fats in MMP formulations increases the digestibility of meat proteins [8,9].

In contrast to vegetable fats, plant supplements are rarely studied as MMP additives. However, research has recently intensified on the development of products with plant-based supplements that possess biological or pharmacological activity for dietary adjustments [20,21]. Particularly, the seeds of a spicy-aromatic plant—fenugreek (*Trigonella foenum-graecum* L.)—have broad prospects as an important functional nutrient in food products, including meat products. They serve as a unique source of vitamins (A, B_1, B_2, B_5, C), amino acids, phenolic compounds, steroid saponins, minerals (K, Ca, P, Fe, Si as dominant elements), fiber, and galactomannans, and have proven antioxidant activity [20–22]. The functions of fenugreek as a stabilizer and emulsifier have been described [21]. Given its chemical composition and proven medicinal properties, fenugreek is logically classified as a potential nutraceutical in the functional food industry [12,21,23–25].

Another promising supplement is buckwheat flour. Buckwheat flour and buckwheat bread can serve as sources of vegetable proteins, soluble and insoluble dietary fibers, and phenolic compounds [26]. Their polysaccharides contribute to structure formation in meat products [27,28].

Unlike fenugreek and buckwheat flour, blackcurrant (*Ribes nigrum* L.) fruits and leaves have been scarcely studied as supplements for functional foods. Most research has focused on their pharmacotherapeutic activity and medical applications [13,14]. Blackcurrant leaves contain vitamins (C, P), flavonoids, coumarins, oxycinnamic acids, tannins, macro- and microelements, 1.58% oils, 12% polysaccharides, 13.71% reducing saccharides, 31.19% peptides, and amino acids [13–15]. The powerful nutraceutical potential of blackcurrant leaves has led to their evaluation as promising plant-based supplements for functional minced meat products, as described in our previous study [15].

Another advantage of incorporating plant supplements into MMPs is their potential to improve the water-holding and fat-holding capacities of meat. This is because plant supplements are rich in polyphenolic compounds, complex lipids containing polyunsaturated

fatty acids, complex carbohydrates such as polysaccharides, along with other bioactive components. These properties are crucial for enhancing the functional and technological qualities of high-quality minced meat products [1,2,29].

Although limited research [18,19] has explored the link between the functional and technological properties of minced meat products and the addition of plant-based bioactive supplements, the effects of fenugreek and dried blackcurrant leaves remain unstudied. Given that these supplements provide polyphenols, antioxidants, and dietary fibers, they have the potential to enhance the nutritional value, sensory qualities, and functional and technological properties of meat products while reducing heat-treatment losses. The aim of this research is to investigate the functional and technological properties as well as the chemical composition of meat products with plant supplements of fenugreek and dried blackcurrant leaves.

2. Materials and Methods

2.1. Raw Materials

The following ingredients were used for the production of meat products with plant supplements: lean beef flank (Yakim, Kyiv, Ukraine), vegetable oil of the linoleic–oleic group—refined deodorized sunflower oil called "Oleyna Traditional" (SE Suntrade, Dnipro, Ukraine), fenugreek (*Trigonella foenum-graecum* L.) powder (Yogi Globals, Jaipur, Republic of India), dried leaves of black currant (*Ribes nigrum* L.)—DLBC (Elit trava, Kharkiv, Ukraine), and buckwheat bread ("Concern Khlibprom" PrJSC, Vinnytsia, Ukraine). As additional ingredients drinking water, table salt, and black pepper were used. The appearance of fenugreek powder and dried leaves of black currant is shown in Figure 1.



(**a**) (**b**)

Figure 1. Appearance of plant supplements: fenugreek powder (**a**); dried leaves of black currant (**b**).

The choice of fenugreek and blackcurrant leaves was related to the task of increasing the nutritional value and functional and technological properties of minced meat products based on beef flank. The beef flank was characterized by pH = 5.78 ± 0.16 and was bright red in color with marbling on the cut. The consistency of the meat on the cut was dense and elastic. The smell of the meat was typical of fresh beef flank. Refined deodorized sunflower oil contained 11.30% saturated acids, and 83.6% unsaturated acids, including 23.80% monounsaturated acids (of which 23.72% was oleic acid) and 59.82% polyunsaturated linoleic acid [10]. The introduction of buckwheat bread was used as an additional binder. It also contains substances with high nutritional value and can act as a nutritional enhancer [26–28].

The study of functional and technological properties (stability of minced meat emulsion, water-holding capacity and fat-holding capacity), post-heat-treatment losses, and sensory characteristics was carried out for minced meat products with and without plant supplements. The proximate composition, the energy value, and the iron content were also determined for these samples.

2.2. Production of Control Samples of Minced Meat Products and Samples with Plant Supplements

The production of minced meat products, the closest analogue of which can be considered a beefsteak, involved the use of a traditional technology previously discussed [2–4,10,29]. The composition of eight samples of minced meat K1, K2, S1, S2, S3, S4, S5, S6 is presented in Table 1. The grinding of meat raw materials was carried out to achieve a particle size of 2–3 mm.

Table 1. Formulations for minced meat products.

Ingredient	K1	S1 DLBC 0.75%	S2 DLBC 1.85%	S3 Fenugreek 0.75%	S4 Fenugreek 1.85%	K2	S5 Fenugreek 1.70%	S6 Fenugreek 3.40%
Meat, g	80.0	80.0	80.0	80.0	80.0	62.2	62.2	62.2
Sunflower oil, g	12.0	11.4	10.3	11.4	10.3	3.4	3.4	3.4
Water, g	6.7	6.7	6.7	6.7	6.7	18.5	18.5	18.5
Table salt, g	1.2	1.1	1.1	1.1	1.1	0.8	0.8	0.8
Black pepper, g	0.1	0.05	0.05	0.05	0.05	0	0	0
Buckwheat bread	0	0	0	0	0	15.1	13.4	11.7
Plant Supplements, g	0	0.75	1.85	0.75	1.85	0	1.7	3.4
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Six samples (only samples S1, S2, S3, S4, S5, S6) contained plant supplements in the amounts indicated in Table 1. Semi-finished products containing a plant supplement with DLBC for samples S1 and S2, with corresponding supplement amounts of 0.75% and 1.85%, were obtained by first grinding dried blackcurrant leaves to a particle size of 0.10–0.12 mm. The ground leaves were then hydrated with one-third of the required drinking water, following the formulations in Table 1, at a temperature of 16 °C for 5–7 min.

Semi-finished products of plant supplements with fenugreek for the production of samples S3, S4, S5, and S6, with corresponding supplement amounts of 0.75%, 1.85%, 1.7%, and 3.4%, were obtained using a similar process. For samples S5 and S6, buckwheat bread was used. The bread was soaked in one-third of the required drinking water, following the formulations in Table 1, at a temperature of 16 °C for 5–7 min. Control samples K1 and K2 were produced without plant supplements. Sample K2, like samples S5 and S6, was produced with the addition of buckwheat bread.

The salt solution for the minced meat was prepared by dissolving salt in the remaining amount of drinking water specified in the formulations (Table 1). Black pepper was sieved to obtain the semi-finished product "Sifted black pepper", which was used only in minced meat samples K1, S1, S2, S3, and S4. Minced meat samples K2, S5, and S6 were prepared without black pepper.

The technological process of minced meat production was carried out by thoroughly mixing the prepared semi-finished products based on the components specified in the formulations (Table 1). The prepared semi-finished products were introduced in the following sequence: "minced meat", "salt solution", "sieved black pepper" (only in samples K1, S1, S2, S3, S4), "semi-finished plant supplement" (only in samples S1, S2 with DLBC and S3, S4, S5, S6 with fenugreek), "soaked buckwheat bread" (only in samples K2, S5, S6), and "refined deodorized sunflower oil".

The mixture was blended for 3–5 min at a temperature of 12–15 °C until the components were evenly distributed, forming an emulsion. The minced meat emulsion consisted of finely ground components with a particle size of 2–3 mm. Then, semi-finished product portions of 100 g were formed and shaped into rounded, flattened pieces with a thickness of 10–17 mm. All formed semi-finished products (samples K1, S1, S2, S3, S4, K2, S5, S6)

underwent heat treatment using two different methods to produce meat products with plant supplements and control samples without plant supplements.

In the first method, eight samples of minced meat were heat-treated by baking at 150–160 °C for 15–20 min. In the second method, the remaining eight samples were heat-treated by steaming at 98–100 °C for 10–15 min. Heat treatment in both methods continued until the internal temperature at the center of the product reached 80 ± 1 °C [2–4].

Sensory evaluation of the quality of all samples of minced meat products was carried out by analytical methods—the quantitative descriptive analysis and profile analysis method [9,30]. The overall score for the selected indicators (the maximum score was 5.00) was calculated using the descriptors of appearance, consistency, cross-section appearance, flavour, and taste according to the developed scale [10,15].

2.3. Proximate Analysis

Proximate analysis of samples was carried out following the official procedures [31], and the evaluations were as follows: moisture content (44-15.02 Moisture-Air-Oven Method), ash content (08-01.01 Ash-Basic Method), and crude fat content (30-16.01 Crude Fat in Dry Milk Products). Protein and fat content were determined by the Kjeldahl method [32] and the Soxhlet extraction method [33], respectively. The protein conversion ratio was 6.25. Fat extraction from the samples was carried out with petroleum ether in a boiling range of 40–60 °C. The total carbohydrate content of 100 g of minced meat products was calculated by subtracting the sum of the masses of protein, total fat, moisture, and ash from the total mass [1]. The total carbohydrate amount was assumed to be 0 in the control sample (K1).

The energy value of the minced meat products was calculated from their carbohydrate, fat, and protein content. For this purpose, the Atwater–Bryant values of physiological energy as 4.0 kcal per gram of carbohydrate or protein and 9.0 kcal per gram of fat were used [34].

2.4. Determination of Iron Content in the Semi-Finished Minced Meat Products

The total iron content of the minced meat products was quantified spectrophotometrically by the Ferrozine method [35,36]. Determination was performed using a spectrophotometer Specord 200 PLUS (Analytik Jena GmbH, Jena, Germany).

2.5. Study of the Stability of Minced Meat Emulsions, the Water-Holding Capacity, and the Fat-Holding Capacity

The study of the functional and technological properties of minced meat products was carried out using known reviews [1,10,37–39]. Determination of the stability of minced meat emulsions was carried out for all studied products (samples K1, K2, S1, S2, S3, S4, S5, S6), which were prepared according to the formulations (Table 1). In particular, minced meat samples, each with a mass of 100 g, were placed in glass jars with polished lids and heat-treated at a temperature of 75–80 °C for 60 min. After this, they were cooled to 12–15 °C. Then, the separated broth and fat were transferred to quartz crucibles. After the separation of the broth and fat, the minced meat was dried with filter paper and the mass was determined. The crucibles with broth were dried in a drying oven to a constant mass at a temperature of 105–110 °C [10].

The stability of minced meat emulsions (SE) was evaluated based on the mass fraction of the intact emulsion, which lost a certain amount of moisture and fat after heat treatment [37]. The SE was calculated using the following formula:

$$\%SE = ((m - m_{b1})/m) \times 100, \quad (1)$$

where m—mass of a sample minced meat, g; m_{b1}—mass of separated broth and fat, g.

The water-holding capacity (WHC) was calculated based on changes in the mass fraction of moisture in minced meat before and after heat treatment using the formula:

$$\%WHC = W - ((m_{b1} \times m_w) \times 100/(m_{b2} \times m)), \quad (2)$$

where W—mass fraction of moisture in minced meat, %; m—mass of a sample minced meat, g; m_{b1}—mass of separated broth and fat, g; m_{b2}—mass of the test broth with fat, g; m_w—mass of water in the test broth, g.

Fat was extracted with a solvent (mixture of chloroform: ethanol in a ratio of 1:2) in a volume of 10–15 mL in a crucible with residues of broth and fat. The fat-holding capacity (FHC) was calculated based on changes in the mass fraction of fat in minced meat before and after heat treatment using the formula:

$$\%FHC = W_f - ((m_{b1} \times m_f) \times 100/(m_{b2} \times m)), \quad (3)$$

where W_f—mass fraction of fat in minced meat, %; m—mass of a sample minced meat, g; m_{b1}—mass of separated broth and fat, g; m_{b2}—mass of the test broth with fat, g; m_f—mass of fat in the test broth, g.

The mass of the samples was determined on an electronic scale Certus Balance CBA-300-0.01 (Certus, Kharkiv, Ukraine) with an accuracy of 0.1 g.

2.6. Statistical Analysis

All experiments were conducted in triplicate, and the results are expressed as the mean ± standard deviation. The reliability of the results of the analysis of the proximate composition was determined with the help of Student's coefficients for a significance level of $p < 0.05$ and the corresponding (n−1) degrees of freedom. A one-way ANOVA followed by Tukey's post-hoc test for multiple comparisons was used to evaluate differences between groups when studying iron content and functional and technological properties. Statistical significance was set at $p < 0.05$. Data analysis was performed using Minitab version 19 (Minitab Inc., State College, PA, USA).

In the study of the proximate composition of minced meat products, the stability of the minced meat emulsions, water-holding capacity, fat-holding capacity, iron content, and post-heat-treatment losses, each data point was measured at least three times for each of the test samples to ensure reproducibility. The above-mentioned procedure was repeated twice.

3. Results and Discussion

3.1. Determination of Proximate Composition of Minced Meat Products

The introduction of plant supplements in the prescribed amounts affected the protein content in the minced meat products: the protein content of the ready-to-eat meat products with plant supplements ranged between 16.6 ± 0.2% and 18.8 ± 0.2% (Table 2). A relative reduction in protein content of no more than 4.2% was observed in samples S1–S4 compared to control sample K1, while samples S5 and S6 showed a relative increase of up to 5.8% compared to control sample K2.

The fat content was found to be lower in samples with plant supplements S1, S3 with DLBC and S3, S4 with fenugreek compared to the control sample K1. Additionally, the fat content in these samples exhibited lesser change after heat treatment compared to the control sample K1. In the Control-2 semi-finished products and samples with fenugreek (S5 and S6), less meat and sunflower oil were used, and buckwheat bread was added as a binder (Table 1). As a result, these samples had a lower protein and fat content, but a higher carbohydrate content compared to samples K1, C1, C2, C3, and C4.

Table 2. Proximate composition of minced meat products.

Product Name	Content, %					Energy Value per 100 g of Product, Kcal
	Moisture	Proteins	Fats	Carbohydrates	Ash	
Control-1:						
semi-finished	64.1 ± 0.3	16.2 ± 0.3	17.6 ± 0.2	0 *	2.1 ± 0.2	223
steamed	58.3 ± 0.2	19.2 ± 0.3	20.3 ± 0.3	0 *	2.2 ± 0.2	261
baked	58.2 ± 0.2	19.2 ± 0.3	20.4 ± 0.3	0 *	2.2 ± 0.2	260
S1 with DLBC (0.75%)						
semi-finished	64.5 ± 0.3	16.2 ± 0.3	16.8 ± 0.2	0.40 ± 0.02	2.1 ± 0.2	218
steamed	59.5 ± 0.3	18.8 ± 0.2	19.1 ± 0.2	0.50 ± 0.02	2.2 ± 0.2	249
S2 with DLBC (1.85%)						
semi-finished	65.1 ± 0.2	16.2 ± 0.2	15.8 ± 0.2	0.80 ± 0.02	2.1 ± 0.2	210
baked	61.1 ± 0.2	18.3 ± 0.2	17.5 ± 0.3	0.90 ± 0.02	2.2 ± 0.2	234
S3 with Fenugreek (0.75%)						
semi-finished	64.2 ± 0.3	16.2 ± 0.3	17.0 ± 0.2	0.50 ± 0.02	2.1 ± 0.2	220
steamed	59.1 ± 0.3	18.8 ± 0.2	19.3 ± 0.2	0.60 ± 0.02	2.2 ± 0.2	251
S4 with Fenugreek (1.85%)						
semi-finished	64.2 ± 0.2	16.2 ± 0.3	16.3 ± 0.2	1.20 ± 0.02	2.1 ± 0.2	216
baked	60.2 ± 0.2	18.3 ± 0.2	18.0 ± 0.3	1.40 ± 0.02	2.2 ± 0.2	244
Control-2:						
semi-finished	69.5 ± 0.3	13.9 ± 0.2	8.2 ± 0.1	7.0 ± 0.1	1.5 ± 0.1	157
steamed	63.8 ± 0.2	16.7 ± 0.2	9.6 ± 0.1	8.4 ± 0.1	1.6 ± 0.1	186
baked	63.9 ± 0.2	16.6 ± 0.2	9.6 ± 0.1	8.3 ± 0.1	1.6 ± 0.1	187
S5 with Fenugreek (1.70%)						
semi-finished	68.8 ± 0.3	14.3 ± 0.2	8.3 ± 0.1	7.2 ± 0.1	1.5 ± 0.1	153
steamed	63.8 ± 0.3	16.7 ± 0.2	9.5 ± 0.1	8.4 ± 0.1	1.6 ± 0.1	186
S6 with Fenugreek (3.40%)						
semi-finished	68.8 ± 0.2	14.7 ± 0.2	8.4 ± 0.1	7.4 ± 0.1	1.5 ± 0.1	149
baked	64.0 ± 0.2	16.7 ± 0.2	9.3 ± 0.1	8.50 ± 0.1	1.5 ± 0.1	184

* The total carbohydrate amount was assumed as 0 in control-1 samples.

3.2. Determination of Iron Content in the Minced Meat Semi-Finished Products

The minced meat semi-finished products, Control-1 and Control-2, without plant supplements, contained 1.64 ± 0.03 mg/100 g and 1.27 ± 0.03 mg/100 g of iron, respectively (Table 3). The lower content in Control-2 was associated with a lower meat content in the formulation. The iron content in the samples with plant supplements (S1–S6) was higher. In samples S1 and S2 with DLBC, the iron content was 1.73 ± 0.03 mg/100 g and 1.89 ± 0.04 mg/100 g, respectively. Due to the use of fenugreek, the iron content increased more significantly, reaching 2.11 ± 0.03 mg/100 g (Sample S4) and 2.14 ± 0.04 mg/100 g (Sample S6).

Table 3. Iron content in the semi-finished minced meat.

Product Name	Fe Content, mg/100 g Dry Mass
Control-1	1.64 ± 0.03^{f}
S1 with DLBC (0.75%)	1.73 ± 0.03^{e}
S2 with DLBC (1.85%)	1.89 ± 0.04^{c}
S3 with Fenugreek (0.75%)	1.83 ± 0.04^{cd}
S4 with Fenugreek (1.85%)	2.11 ± 0.03^{ab}
Control-2	1.27 ± 0.03^{g}
S5 with Fenugreek (1.70%)	1.71 ± 0.04^{ef}

Table 3. *Cont.*

Product Name	Fe Content, mg/100 g Dry Mass
S6 with Fenugreek (3.40%)	2.14 ± 0.04 [a]

[a–g] Means within each column with different superscripts are significantly different ($p < 0.05$).

3.3. Study of the Stability of Minced Meat Emulsions, the Water-Holding Capacity, and the Fat-Holding Capacity

Fenugreek and blackcurrant leaves contain polysaccharides and pectin substances [12,13,20,25], which can play an important role as structure-forming agents in minced meat products. Additionally, the lipids of these supplements [12,13] contain surfactants, which can improve the dispersion of fat particles in the protein matrix of minced meat [4,6,10]. In this regard, the patterns of influence of these plant supplements on the functional and technological properties of minced meat emulsions were investigated according to Section 2.5. All samples of minced meat with plant supplements (S1–S6) exhibited higher WHC, FHC, and emulsion stability compared to the corresponding control samples (K1, K2). They also showed lower post-heat-treatment losses compared to the corresponding control samples (Table 4) [4,6,34].

Table 4. Functional and technological properties of minced meat products.

Indicator	Control-1 K1	Control-2 K2	Plant Supplements (Content, %)/Sample DLBC (0.75%)/S1	DLBC (1.85%)/S2	Fenugreek (0.75%)/S3	Fenugreek (1.85%)/S4	Fenugreek (1.70%)/S5	Fenugreek (3.40%)/S6
Water-holding capacity, %	64.0 ± 0.3 [g]	73.4 ± 0.4 [c]	65.7 ± 0.3 [f]	66.0 ± 0.3 [ef]	66.5 ± 0.3 [de]	67.2 ± 0.4 [d]	75.8 ± 0.40 [b]	77.1 ± 0.3 [a]
Fat-holding capacity, %	13.9 ± 0.2 [d]	15.9 ± 0.3 [c]	15.9 ± 0.2 [c]	16.8 ± 0.2 [b]	16.9 ± 0.2 [b]	17.1 ± 0.2 [ab]	16.9 ± 0.3 [b]	17.5 ± 0.2 [a]
Emulsion stability, %	83.3 ± 0.3 [f]	89.8 ± 0.4 [e]	90.1 ± 0.4 [e]	91.3 ± 0.4 [c]	90.6 ± 0.3 [cd]	92.2 ± 0.3 [b]	92.5 ± 0.3 [b]	94.2 ± 0.4 [a]
Post-heat-treatment losses, %								
Steamed	20.8 ± 0.4 [a]	15.4 ± 0.3 [f]	18.7 ± 0.3 [b]	18.1 ± 0.2 [c]	17.6 ± 0.3 [cd]	16.8 ± 0.2 [e]	14.5 ± 0.3 [g]	13.8 ± 0.3 [h]
Baked	20.2 ± 0.3 [a]	16.2 ± 0.3 [d]	18.2 ± 0.2 [b]	16.4 ± 0.3 [cd]	16.9 ± 0.3 [c]	15.5 ± 0.2 [e]	15.4 ± 0.3 [e]	15.1 ± 0.3 [ef]

[a–h] Means within each column with different superscripts are significantly different ($p < 0.05$).

The SE indicators for minced meat with a mass fraction of fenugreek of 1.7% (sample S5) and 3.4% (sample S6) exceeded the SE of the sample without fenugreek (sample K2) by 3.0% and 4.9%, respectively. The SE for minced meat with a mass fraction of DLBC of 0.75% (sample S1) and 1.85% (sample S2) exceeded the results of the sample without DLBC (sample K1) by 7.5% and 8.9%, respectively. The SE indicators showed the greatest increase compared to the control (sample K1), with increases of 8.8% and 10.7% for minced meat samples with a fenugreek content of 0.75% (sample S3) and 1.7% (sample S4), respectively. The FHC and WHC indicators of minced meat with fenugreek exceeded the results of the corresponding control samples without plant supplements (samples K1, K2) by 21.6% and 3.9% (sample S3), 23.0% and 5.0% (sample S4), 6.3% and 3.3% (sample S5), and and 10.1% and 5.0% (sample S6). Sample S2 with DLBC (1.7%) also demonstrated a significant increase in the FHC indicator compared to Control-1, which was 20.9%.

3.4. Study of Post-Heat-Treatment Losses and Sensory Evaluation of Minced Meat Products

Post-heat-treatment losses of minced meat products are presented in Table 4. Samples K2, S5, and S6, with a lower meat content due to the addition of buckwheat bread as an additional binder (Table 1), showed (Table 4) noticeably lower post-heat-treatment losses (no more than 15.4 ± 0.3%). It is also important to note the relative change in losses compared to the control samples after the introduction of plant supplements. Thus, minced meat samples S3 (with 80% meat and 0.75% fenugreek, according to Table 1) and S4 (with 80% meat and 1.7% fenugreek, according to Table 1) without buckwheat bread demonstrated the maximum reduction in post-heat-treatment losses (both steamed and

baked methods) compared to the corresponding control samples K1. The reduction for these samples ranged from 15.4% to 23.3%.

The data from the study of the functional and technological properties of all minced meat samples were fully consistent with the results of their sensory evaluation. All test samples had a non-sticky and undeformed shape, a solid structure, a clean, dry surface that was evenly baked for baked samples and free of fat and moisture droplets for steamed samples. The cross-sections of the minced meat products (MMPs) displayed a homogeneous structure, light pink color, and fine porosity. All samples were characterized by juiciness, tenderness, moderately dense consistency, and a clean, generally balanced, and characteristic taste and flavor typical of meat products. The samples with plant supplements had greater juiciness and a denser structure compared to the control samples. Their taste was moderately salty with a pleasant aroma of spices. The cross-sections of minced meat with DLBC (samples S1, S2) showed evenly distributed inclusions of natural greenery. However, it is worth noting that the samples with a higher content of plant supplements (samples S2, S4, S6) and heat-treated by steaming had a less harmonious, more bitter taste with a noticeably pronounced spice flavor.

Based on the abovementioned and the analysis of minced meat formulations (Table 1), heat treatment by steaming was proposed for samples with a lower content of plant supplements (samples S1, S3, S5), while baking was recommended for samples with a higher content of plant supplements (samples S2, S4, S6). The sensory profiles of these samples and the control samples are shown in Figure 2.

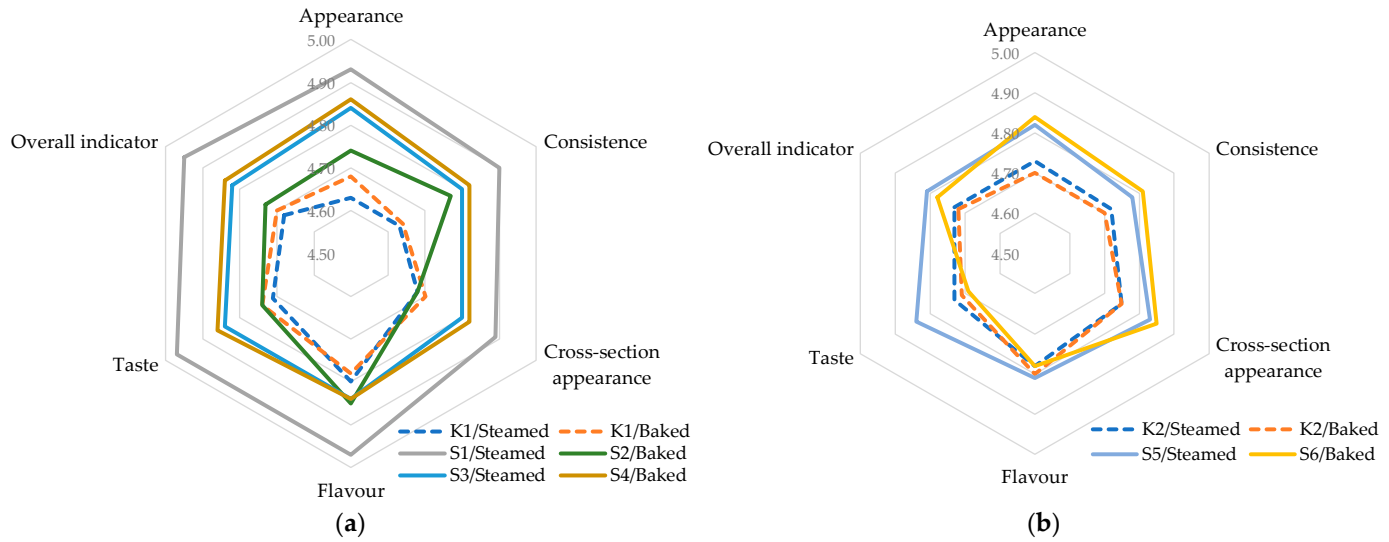


Figure 2. Sensory evaluation of minced meat product samples: K1/steamed, K1/baked—control samples; S1/steamed, S2/baked—minced meat product samples with DLBC; S3/steamed, S4/baked—minced meat product samples with fenugreek (**a**); K2/steamed, K2/baked—control samples; S4/steamed, S5/baked—minced meat product samples with fenugreek (**b**).

The sensory profiles of all products with fenugreek (samples S3, S4, S5, S6) and DLBC (samples S1, S2) were better compared to the controls (samples K1, K2) and showed higher overall indicators. Minced meat products with 0.75% dried blackcurrant leaves (sample S1), which were heat-treated by steaming, received the best sensory score with the highest overall indicator of 4.95.

Consequently, the introduction of plant supplements, including fenugreek and dried blackcurrant leaves, led to an improvement in the functional and technological properties and sensory characteristics, as well as a reduction in post-heat-treatment losses, of the new minced meat products.

4. Conclusions

The proposed formulations for minced meat products with the addition of blackcurrant leaves and fenugreek enabled the development of samples with a controlled chemical composition that are not inferior to similar products without additives and, in many aspects, even outperform them. The new samples had a lower energy value and improved nutritional value. The ready-to-eat products contained a high protein content (16.4–19.0%) and beneficial sunflower oil, along with an increased iron content. Thus, the addition of fenugreek raised the iron content from 1.27 ± 0.03 mg/100 g to 1.71 ± 0.04 mg/100 g and 2.14 ± 0.04 mg/100 g.

Key indicators such as minced meat emulsion stability, fat-holding capacity (FHC), and water-holding capacity (WHC), as well as post-heat-treatment losses and sensory characteristics (consistency, juiciness, tenderness, etc.) can be adjusted depending on the type and amount of plant supplement used. The FHC and WHC values of minced meat samples with fenugreek and with DLBC exceeded those of the corresponding control samples without plant supplements, with relative fluctuations of 6.3–23.0% and 2.7–5.0%. This opens up opportunities to incorporate meat raw materials with increased fat and moisture content, as well as reduced functional and technological properties, into the technological cycle and to obtain minced meat products with stable quality indicators.

Experimental studies on the functional and technological properties, post-heat-treatment losses, chemical composition, energy value, and sensory characteristics of minced meat products with fenugreek and blackcurrant leaves confirm the production of high-quality products. These newly developed products can be classified as health-oriented foods and are recommended for dietary adjustments in the general population.

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Abbreviations

The following abbreviations are used in this manuscript:

DLBC	Dried leaves of black currant
SE	Stability of minced meat emulsions
WHC	Water-holding capacity
FHC	Fat-holding capacity
MMPs	Minced meat products
ANOVA	Analysis of variance

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