Received: 31.3.2024
Revised: 10.10.2024
Accepted: 13.10.2024
Published: 14.10.2024

Potravinarstvo Slovak Journal of Food Sciences
vol. 18, 2024, p. 874-886
https://doi.org/10.5219/1977
ISSN: 1337-0960 online
www.potravinarstvo.com

Effect of flax and hemp flour on the nutritional value of turkey-duck meat pate

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ABSTRACT
This study focused on developing a nutritionally enhanced turkey meat pate, incorporating plant-based ingredients like flaxseed and hemp flour. Two canned pate samples were produced: a control sample with turkey meat, liver, heart, fat, skin, beans, onions, and spices, and an experimental sample where 20% of turkey meat was replaced with duck meat, and beans were substituted with zucchini, flaxseed, and hemp flour. The experimental pate showed significant differences in chemical composition compared to the control. It had lower moisture and fat content but higher protein, ash, and carbohydrate content. The energy value slightly decreased from 153.01 kcal/100g to 146.9 kcal/100g. The sensory evaluation found similarities in appearance, consistency, and colour, with the experimental pate receiving a slightly higher colour rating. The amino acid profile of the experimental pate was significantly altered, with increases in methionine, isoleucine, threonine, glutamic acid, alanine, and cysteine. Vitamin and mineral content also significantly increased, particularly vitamins A, D, E, and B group vitamins, calcium, potassium, magnesium, and iron. Microscopic analysis revealed a more heterogeneous microstructure in the experimental pate due to the plant ingredients. This research demonstrates the potential of developing a healthier turkey meat pate using plant-based ingredients, catering to the growing demand for healthier food options.

Keywords: pate, duck meat, flaxseed, hemp flour, canned meat

INTRODUCTION
The turkey meat industry has witnessed significant growth globally and in Kazakhstan due to the increasing popularity of healthy nutrition and the rising demand for processed products such as turkey sausage and ham. The relevance of turkey meat processing is underscored by the popularity of turkey meat in the human diet, owing to its dietary properties **[1]**. Renowned for its rich protein content, phosphorus, B vitamins, PP vitamins, and mineral salts, turkey meat is a valuable ingredient for innovating new product varieties **[2]**, **[3]**. Its exceptional chemical composition, boasting essential minerals such as zinc, potassium, phosphorus, magnesium, and iron, along with significant B vitamin content, notably vitamin B12, and a protein content of 23 g per 100 g, all contribute to its nutritional value **[4]**, **[5]**. Moreover, its low-fat content and minimal cholesterol render it hypoallergenic and suitable for children and the elderly **[6]**.

The combination of turkey and duck meat for producing meat products offers a promising opportunity to enhance the nutritional and biological value of the final product. Introducing duck meat into the recipe with partial replacement of turkey meat can lead to a more balanced product in vitamin, mineral, and fatty acid composition **[7]**. Duck meat is characterised by a more balanced fatty acid composition and a higher content of unsaturated fatty acids, monounsaturated fatty acids, certain minerals, and vitamins than turkey meat **[8]**, **[9]**. Therefore, combining these two meats can result in a product with enhanced nutritional benefits and unique sensory properties.

The development of functional meat products enriched with dietary fibers, vitamins, and mineral substances is gaining attention due to the growing demand for healthier food options. This trend is driven by the potential to enrich meat products with bioactive substances from raw vegetable materials, enhancing their nutritional value. Flax, for instance, is a dietary product rich in fatty acids, vitamins of various groups, antioxidants, and trace elements. The seed squeeze of flax is a source of essential micro- and macroelements for humans, including potassium, phosphorus, sodium, manganese, zinc, and nickel **[10]**, **[11]**. Moreover, flaxseed cake, which contains 30% dietary fiber, is rich in natural phenolic compounds – lignans **[12]**.

Flaxseed-derived components, such as mucilage, exhibit remarkable potential as meat binders due to their synergistic interactions with meat proteins, thermal stability, and desirable gel properties, even in high-salt environments **[13]**. Previous research has consistently demonstrated the positive impacts of incorporating flaxseed flour into meat products. Studies have shown significant improvements in organoleptic properties and functional-technological aspects of minced meat, including increased water-holding capacity and enhanced product yield **[14]**. Similarly, Sannikov & Gurinovich (2019) observed a rise in pH and water-binding capacity when adding flaxseed flour to minced meat. Their research focused on optimising the incorporation level in poultry semi-smoked sausage, ultimately establishing a 10% addition based on organoleptic evaluation **[15]**. Ayrapetyan et al. (2022) have demonstrated that including 4.4% flax meal positively affects the qualitative composition of protein, improves the fatty acid composition, and enhances the content of dietary fiber and polyphenolic compounds **[16]**.

Another promising ingredient is hemp flour, obtained from hemp cake after cold pressing of hemp seed oils. The chemical composition of hemp cake includes water (11%), crude protein (31%), protein (29.6%), fat (7.7%), fiber (24.7%), and nitrogen-free extract substances (17.7%). Notably, hemp cake is rich in phytin (calcium-magnesium salt of inositophosphoric acid), which stimulates hematopoiesis, enhances the growth and development of bone tissue, and improves the function of the nervous system in diseases associated with phosphorus deficiency in the body **[17]**, **[18]**. Vaitanis and Khodyreva (2021) developed recipes for turkey meat stuffing with hemp flour, which provided significant nutritional benefits. In a serving of 100g of stuffed turkey meat with 20% hemp flour, consumers could meet their daily requirements for dietary fiber, vitamin B, potassium, calcium, magnesium, phosphorus, iron, selenium, and zinc **[19]**. Further studies by Kerner et al. (2021) have demonstrated the feasibility of incorporating hemp seed press-cake ingredients into the production of pork meat burger patties **[20]**. These findings underscore the versatility of hemp-derived components in diversifying the formulation of meat products, offering opportunities to enhance both nutritional content and sensory attributes.
Building upon these insights, this research investigates the potential utilisation of flax and hemp seed-derived ingredients in developing turkey meat pate.

Scientific hypothesis

Incorporating flaxseed and hemp flour in turkey meat pate can improve nutritional value by increasing protein, vitamin, and mineral content without deteriorating sensory properties.

MATERIAL AND METHODOLOGY

Samples

Turkey meat, duck meat, and by-products were purchased from Semey (Kazakhstan) meat pavilions. Flax flour (protein 32.4 g, fat 8.8 g, carbohydrates 6.9 g) and hemp flour (protein 30 g, fat 7.9 g, carbohydrates 24.7 g) from the company " Kompas Zdorovya" (Russia) were purchased in local supermarkets. According to the recipe, other ingredients and spices were purchased in local supermarkets.

Chemicals and biological material

Hydrochloric acid (mass fraction of hydrochloric acid (HCl), 35-38%, pure for analysis, Snabservice Astana LLP, Astana, Kazakhstan).

Formalin (mass fraction of formaldehyde 37.0%, Chemical Industrial Reagent LLP, Shymkent, Kazakhstan).
Hematoxylin and eosin alcohol solution (ErgoProduction Ltd., Russia).

Instruments

Dionex Ultimate 3000 chromatograph ("Dionex", USA)
SHIMADZU LC-20 Prominence HPLC (Japan) with Supelco SUPELCOSIL LC-PAH 5 µm 4.6 x 150 mm column
microtome MS-2

Laboratory Methods

Method of determining the chemical composition

The moisture content was determined using the method described in **[21]**. After the moisture content was determined, each dried sample was used for fat determination, according to **[22]**. The samples were calcined in a muffle furnace (500°C-600°C) to measure the ash content **[23]**. The protein content was analysed according to **[24]**.

Determination of mineral content

All samples for determining the mineral content were weighed 5 g each, placed on a container and incinerated in a microwave muffle for 12 hours to a final temperature of 600°C. After microwave splitting, the samples were diluted with 10ml hydrochloric acid (HCl) in distilled water (1:1), mixed with a glass rod and passed through a paper filter. Mineral elements were determined on a spectrometer ICP-OES (Spectro, Boschstr, Germany) **[25]**.

Determination of vitamin composition

Vitamin content was determined according to GOST 55482-2013 **[26]** for water-soluble vitamins using single-substituted potassium phosphate buffer solution and GOST 32307-2013 for fat-soluble vitamins **[27]**. The analysis was performed on a Dionex Ultimate 3000 chromatograph ("Dionex", USA) with a Supelco SUPELCOSIL LC-PAH 5 µm 4.6 x 150 mm column. Eluent composition: a mixture of methanol and distilled water (92:8).

Determination of amino acid composition

Amino acids were determined using SHIMADZU LC-20 Prominence HPLC (Japan) with fluorimetric and spectrophotometric detectors. We used a chromatographic column 25 cm x 4.6 mm SUPELCO C18, with a diameter of 5 µm (USA), including a pre-column to protect the main column from foreign impurities. The HPLC analysis was based on the method. Chromatographic analysis was performed in the eluent gradient mode at a 1.2 mL/min flow rate and a column thermostat temperature of 40 °C. The measurement was carried out on a reverse phase column with fluorimetric and spectrophotometric detectors at 246 and 260 nm wavelengths using acid hydrolysis and modification of amino acids with a solution of phenylisothiocyanate in isopropanol to obtain phenylthiohydantoines. A 6.0 mm solution of CH_3COONa with a pH of 5.5 (component A), a 1% solution of isopropanol in acetonitrile (component B), and a 6.0 mM solution of CH_3COONa with a pH of 4.05 (component C) were used as the mobile phase. Samples of amino acids produced by Sigma Aldrich (Germany) were used as standards.

Sensory analysis

Sensory analysis of samples was carried out according to the Interstate standard GOST 33741-2015 **[28]**. Sensory analysis of control and experimental samples of patés was carried out using the profile method. The following indicators were considered: taste, odour, and consistency. In connection with the addition of different components, the following descriptors were selected: taste (sweet, pumpkin, carrot, salty, sharp, spicy, fatty, liver); colour (brown-grey, gray); smell (sharp liver, sharp fatty, specific, pronounced); consistency (delicate, smeary, dry, loose, stiff, watery, fibrous). The intensity of each descriptor was evaluated on a scale from 0 to 5 (if no expression of any characteristic was observed, the intensity was evaluated as zero). After statistical processing, the results were obtained, according to which the profiles were designed.

Histological Study

The minced meat samples for histological study are frozen for fixation and, without defrosting, are placed in fixing liquid -10% neutral formalin. Non-frozen minced meat samples with and without vegetable additives are taken for fixation immediately after obtaining minced meat. They are carefully placed in 10% neutral formalin to avoid destroying the block formed by minced meat. After fixation, the minced meat samples are filled with paraffin. The slices are obtained on sled microtome MS-2 with a 10-30 µm thickness. The sections are stained with hematoxylin and eosin according to the conventional technique. Hematoxylin stains cell nuclei, eosin stains cell protoplasm, and various noncellular structures to a lesser extent. The technique consists of staining the sample with Mayer's hematoxylin for 1 min, flushing with running water and rinsing with distilled water. After that, it is treated with Eosin solution (10 s) for staining in blue colour and rinsed with water. Microscopic investigation of prepared sections is carried out using an MS-100 trinocular microscope. Digital microphotographs are taken using a digital microphotography adapter with a resolution of 9 megapixels at × 4, × 10, and × 40 magnifications **[29]**.

Description of the Experiment
Sample preparation
Production of canned meat pate:

Meat pate contains turkey and duck meat, liver, heart, skin, turkey or duck fat, hemp and flax flour, onion, nutmeg, paprika, ground black pepper, sodium chloride, and broth (Table 1).
We produced two samples of turkey meat pates as canned products. The first sample (control) contains turkey meat, liver, heart, fat, turkey skin, beans, onions and spices. The second sample (experimental) additionally contains duck meat (20% of turkey meat was substituted), and zucchini, flaxseed, and hemp flour were added instead of beans.

Table 1. Recipe of control and experimental samples of meat pate

Ingredient	Control	Experimental
Turkey meat	50	30
Duck meat	-	20
Poultry liver	12	12
Poultry heart	10	10
Poultry fat	4	4
Poultry skin	3	3
Beans	10	-
Zucchini	-	4
Flax flour	-	3
Hemp flour	-	3
Onions	6	6
Cream 10%	5	-
Water for hydration	4	9
Broth	20	20
Caraway	0.2	-
Nutmeg	-	0.2
Turmeric	0,2	-
Paprika	-	0.2
Ground black pepper	0.1	0.1
Salt	1.4	1.4

The production method of the meat-vegetable pâté is carried out as follows. Turkey and duck meat are washed in running water and then separated from bones, skin, and tendons. The meat is preliminarily cut into large pieces. Next, the liver and skin of the poultry, as well as the duck fat, are blanched. The raw materials are loaded into a blancher or pot, and 4-6% of hot water is added based on the weight of the raw materials, and the mixture is blanched for 30-40 minutes. Blanching the raw materials in their juice allows broth production with the required concentration (15-20% solids).
Subsequently, all the meat raw materials are ground, first in a wolf grinder with a screen diameter of 2-3 mm, then in a cutter for 5-8 minutes until a homogeneous paste-like mass is obtained. Initially, coarser raw materials are loaded: duck and turkey meat and hearts, followed by blanched liver, skin, and poultry fat. Then, flaxseed and hemp flour, grated zucchini and onion are added. During the cutting process, table salt, paprika, nutmeg, ground black pepper, and broth are added. The prepared pâté mass is immediately transferred to the packaging.

Packaging and sealing: The pâté mass is packaged in metal cans (height 70 mm, diameter 76 mm) and sealed hermetically. The net mass of the canned food in cans No. 4 should be 250 g. Automatic doors carry out the filling of the cans. The filled cans are hermetically sealed on sealing machines. The sealing seam should be hermetic, smooth, without burrs, cuts, or wrinkles. Sealed cans, after washing, are loaded into autoclave baskets and sent for sterilisation. The time from can sealing to the start of sterilisation should not exceed 30 minutes.

Sterilisation and cooling: The sterilisation regime for canned food in cans No. 4 is as follows:

$$\frac{20-65-20}{112\ ^{\circ}C}0.08;$$

where:
20 – duration of temperature rise in the autoclave to the set value, min;
65 – duration of canned food holding time (sterilisation), min;
20 – duration of temperature decrease (cooling), min;
112 – sterilisation temperature (ºC);
0.08 – pressure in the autoclave, MPa.

Sorting: After sterilisation, the cans are unloaded and sent for sorting. The sorting is carried out visually, with the separation of cans with manufacturing defects.

Number of samples analyzed: 30 samples of canned meat pate were analysed.
Number of repeated analyses: Each study was carried out 5 times.
Number of experiment replications: The study was repeated three times, with the experimental data processed using mathematical statistics methods.

Design of the experiment: We produced 30 cans of pâté (15 control and 15 experimental) at the initial research stage. We then studied the finished pates' chemical, amino acid, vitamin, and mineral compositions and sensory and microstructural analyses.

Statistical Analysis

All data was subjected to the analysis of variance (ANOVA) using STATISTICA 13 software. When significant differences were found, the Tukey test was used to determine significant differences between individual means ($P < 0.05$). The results are presented as average values ± standard deviation.

RESULTS AND DISCUSSION

Chemical composition of canned meat pate:

The chemical composition of the control and experimental samples is presented in Table 2. The results of the chemical composition of the meat pate showed an increase in protein content by 1.77%, carbohydrates by 4.41%, ash by 1.1%, and a decrease in fat by 3.38% in the experimental samples compared to the control sample.

Table 2 Chemical composition of canned meat pate (mean±SD).

Indicator	Control	Experimental
Moisture, %	72.4±1.4	68.6±0.6
Protein, %	16.73±0.27	18.50±0.39*
Fat, %	9.48±0.14*	6.10±0.08
Ash, %	1.21±0.02	2.30±0.05*
Carbohydrate, %	0.19±0.00	4.50±0.06*
Energy value, kcal/100g	153.01	146.9
Mass fraction of sodium chloride, %	1.5	1.5

Note: *p<0.05

The experimental sample displayed notable alterations in its chemical composition compared to the control sample. The moisture content of the experimental sample decreased from 72.4% in the control to 68.6%, indicating a reduction in water content. This reduction can be attributed to incorporating additional solid ingredients, such as duck meat, zucchini, and flaxseed, which inherently contain lower moisture levels than beans. The protein content increased significantly from 16.73% to 18.50% ($p<0.05$), likely due to the high protein content of duck meat and hemp flour. This increase in protein content enhances the nutritional value of the pate, making it a more substantial source of this essential macronutrient.

Conversely, the fat content in the experimental sample (6.10%) was lower than that of the control (9.48%). This reduction in fat content could be attributed to several factors, including substituting turkey meat with leaner duck meat and incorporating zucchini, which has a lower fat content than some of the original ingredients in the control sample. Additionally, although sources of healthy fats, flaxseed and hemp flour may contribute little to the overall fat content due to their incorporation in smaller quantities.

The ash content increased from 1.21% to 2.30% ($p<0.05$), indicating a higher mineral content in the experimental sample, likely due to the mineral-rich flaxseed and hemp flour.

The carbohydrate content significantly increased from 0.19% to 4.50% ($p<0.05$), which can be attributed to the carbohydrates in zucchini, flaxseed, and hemp flour.

Despite the changes in the macronutrient composition, the pate's energy value decreased slightly from 153.01 kcal/100g to 146.9 kcal/100g. This decrease is likely due to the reduced fat content, as fat has a higher caloric value per gram than proteins and carbohydrates.

The introduction of duck meat, zucchini, flaxseed, and hemp flour in the production of turkey meat pate significantly altered its chemical composition and energy value. These changes resulted in a product with a higher protein and lower fat content, aligning with the increasing consumer demand for healthier food options.

These results are consistent with those reported by **[30]** and **[31]**, who observed a reduced moisture content and increased carbohydrates and minerals by adding flaxseed meal to beef pate. A study **[32]** achieved protein content comparable to our experimental sample, albeit with a different ingredient, eagle fern powder. Despite the distinct source, this indicates the potential of alternative additives in enhancing protein levels in meat products. It was demonstrated in the work **[33]** that poultry pate with flaxseed meal had a higher fat content than our study's results. This discrepancy could stem from variations in formulation or processing techniques, highlighting the importance of precise ingredient proportions and preparation methods. Both studies **[34]**, **[35]** corroborate our findings regarding the effects of hemp flour and hemp cake on moisture reduction and increased ash content in meat products.

Sensory analysis

Comparison of sensory characteristics between the control and experimental samples reveals overall similarities in appearance, consistency, and colour, while differences in odour and taste are noted. The experimental sample received a slightly higher rating for colour (4.6) than the control sample (4.4). This suggests that adding alternative ingredients contributed to a slightly more vibrant or appealing colour in the experimental sample (Figure 1).

Overall, adding duck meat, zucchini, flaxseed, and hemp flour in the canned turkey meat pate production resulted in minor differences in sensory characteristics compared to the control sample. While both samples were well-received in terms of appearance, consistency, and colour, the experimental sample exhibited slightly improved odour and taste, suggesting that adding alternative ingredients enhanced the overall sensory experience of the product. The integrated duck meat has positively influenced the overall appearance and colour of the product, adding richness and depth. Zucchini has contributed to a more appealing consistency, subtly altering the colour. Notably, incorporating flaxseed and hemp flour has elevated the overall aroma and taste, making the experimental sample more robust in sensory attributes. These findings highlight the potential of incorporating alternative ingredients to improve the sensory properties of processed meat products, offering opportunities for innovation and market differentiation in the food industry.

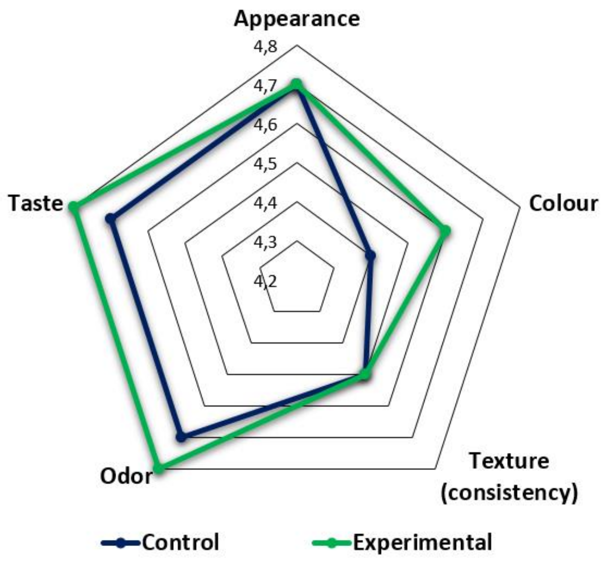


Figure 1 Sensory profile of meat pate (control and experimental samples).

Amino acid composition

The findings of the amino acid composition analysis of the experimental and control samples indicated that the experimental sample contained a higher concentration of amino acids than the control sample. Notably, the experimental sample demonstrated a significant lead in glutamic acid content by 4.7%, attributed to adding hemp flour, as it contains 5.85 g/100g. Furthermore, the experimental sample exhibited higher levels of essential amino acids, such as methionine by 0.09%, isoleucine by 0.18%, threonine by 0.58%, and tryptophan by 0.1%. This elevated concentration of these amino acids can be explained by incorporating flax and hemp flour, both plant-based protein sources.

Adding duck meat, zucchini, flaxseed, and hemp flour to the turkey meat pate significantly altered the product's amino acid composition. The most notable changes were observed in methionine, isoleucine, glutamic acid, alanine, cystine, threonine, and asparagine levels.

Methionine, another essential amino acid crucial for protein synthesis and metabolism, increased from 380 mg/100g in the control sample to 470 mg/100g in the experimental sample (Table 3). This elevation could be linked to adding flaxseed and hemp flour, rich methionine sources **[36]**, **[37]**. The higher methionine content in the experimental sample enhances its nutritional value, contributing to the overall amino acid profile.

Table 3 Amino acid composition of meat pate, g/100g of the product.

Name of amino acid	Control	Experimental
Asparagine	1.21 ± 0.02^a	1.43 ± 0.02^b
Glutamic	2.04 ± 0.02^a	6.75 ± 0.12^b
Serine	0.60 ± 0.01^b	0.55 ± 0.01^a
Histidine	0.33 ± 0.00^a	0.35 ± 0.00^a
Glycine	1.03 ± 0.02^b	0.87 ± 0.02^a
Proline	0.74 ± 0.02^b	0.62 ± 0.01^a
Arginine	0.76 ± 0.01^a	0.79 ± 0.01^a
Alanine	0.82 ± 0.01^a	1.17 ± 0.02^b
Tyrosine	0.48 ± 0.01^a	0.58 ± 0.01^b
cystine	0.04 ± 0.00^a	0.30 ± 0.01^b
Valine	0.58 ± 0.01^b	0.51 ± 0.01^a
Methionine	0.38 ± 0.01^a	0.47 ± 0.01^b
Phenylalanine	0.51 ± 0.01^b	0.38 ± 0.00^a
Isoleucine	0.57 ± 0.01^a	0.75 ± 0.01^b
Leucine	1.09 ± 0.02^b	0.84 ± 0.01^a
Lysine	1.25 ± 0.03^b	1.01 ± 0.01^a
Threonine	0.54 ± 0.01^a	1.12 ± 0.01^b
Tryptophan	0.21 ± 0.00^a	0.19 ± 0.00^a
Total	12.97	18.68

Note: $^{a-b}$ Mean ± Standard Deviation in the same row with different superscripts indicates that there are significant differences ($p < 0.01$)

Isoleucine and leucine, essential amino acids involved in protein synthesis and muscle repair, exhibited varying trends in the experimental sample compared to the control. Isoleucine content increased from 570 mg/100g to 750 mg/100g, while leucine content decreased from 1090 mg/100g to 840 mg/100g. Threonine, essential for protein synthesis and immune function **[38]**, increased from 540 mg/100g in the control sample to 1120 mg/100g in the experimental sample.

Glutamic acid content increased significantly ($p<0.001$) from 2010 mg/100g in the control sample to 6750 mg/100g in the experimental sample. This substantial increase can be attributed to the presence of duck meat, which is known to be rich in glutamic acid. Glutamic acid is a non-essential amino acid crucial in various physiological processes, including energy metabolism and neurotransmission. It also contributes to the characteristic savoury taste of meat products **[39]**, **[40]**.

Alanine content also significantly increased ($p<0.001$) from 820 mg/100g in the control sample to 1170 mg/100g in the experimental sample. Alanine is another non-essential amino acid involved in several metabolic pathways, including protein synthesis and gluconeogenesis. It contributes to meat products' overall flavour and texture **[41]**.

Cystine content dramatically increased ($p<0.001$) from 40 mg/100g in the control sample to 300 mg/100g in the experimental sample. This significant change is likely due to the addition of flaxseed and hemp flour, which are rich sources of cysteine. Cystine is a sulfur-containing amino acid vital to protein structure and function. It also involves antioxidant defence mechanisms and immune function **[42]**.
In contrast, the levels of other amino acids, including phenylalanine, leucine, lysine, tryptophan, serine, histidine, glycine, proline, and arginine, were reduced in the experimental samples. This reduction may have been influenced by changes in protein sources and the addition of alternative ingredients, which could have altered the amino acid content of the final product. These findings suggest that adding these ingredients can enhance the nutritional value of the pâté by increasing the content of certain amino acids.

The amino acid scoring analysis revealed that all essential amino acids in the control sample were limiting. In contrast, the experimental sample contained higher levels of isoleucine by 5%, lysine by 1%, methionine + cystine by 22%, threonine by 55%, and tryptophan by 10% compared to the ideal protein recommended by the FAO/WHO. These findings suggest that the experimental sample has a more favourable amino acid profile than the control sample.

Vitamin composition

The analysis of the experimental sample's vitamin composition for vitamins A, D, E, B1, B3, B5, and B6 revealed that the experimental sample contained higher levels of these vitamins than the control sample. This can be attributed to adding plant-based raw materials such as hemp and flax flour. The vitamin composition results for both the control and experimental samples are presented in Table 4. These findings suggest that incorporating hemp and flax flour may enhance the product's nutritional value by increasing its vitamin content.

Table 4 Vitamin composition.

Vitamin	Control	Experimental
A , µg/100 g	n/d	69.68±1.12
D, µg/100 g	1.04±0.01	2.25±0.04*
E, mg/100 g	0.24±0.00	0.32±0.01*
B_1 , mg/100 g	0.05±0.00	0.40±0.01*
B_3 , mg/100 g	6.72±0.14	9.36±0.20*
B_5 , mg/100 g	1.42±0.02	4.82±0.07*
B_6 , mg/100 g	0.37±0.01	0.66±0.02*

Note: n/d – not detected; *p<0.05

The introduction of duck meat, zucchini, flaxseed, and hemp flour to the production of canned turkey meat pâté resulted in a significant increase in the content of several vitamins in the experimental sample compared to the control sample. Specifically, the experimental sample showed a significant increase ($p<0.05$) in the content of vitamins A, D, E, B1, B3, B5, and B6. The most notable increase was observed in the content of vitamin A, which was 69.68 mcg/100g in the experimental sample, compared to not detected in the control sample.

Mineral composition

The observed increase in mineral content can be attributed to the addition of hemp and flax flour, which are rich in minerals. The mineral composition results for the control and experimental samples are presented in Table 5.

Table 5 Mineral composition.

Mineral	Control	Experimental
Calcium, mg/100g	1.42±0.03	8.47±0.15*
Potassium, mg/100g	369±4	434±6*
Magnesium, mg/100g	25.4±0.34	45.3±0.78*
Iron, mg/100g	3.47 ±0.05	4.39±0.07*

Note: *p<0.05

Comparing the mineral composition of the control and experimental samples reveals substantial improvements in the mineral content of the experimental sample, indicative of the positive effects of incorporating alternative ingredients.

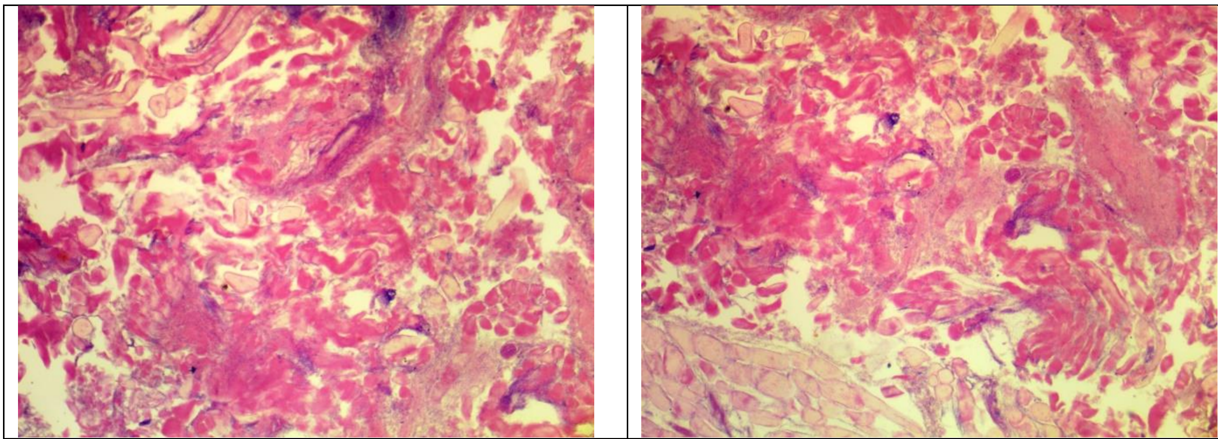
The increase in mineral content in the experimental sample is statistically significant ($p<0.05$), indicating that adding duck meat, zucchini, flaxseed, and hemp flour positively influences the mineral composition of the canned meat pate.

Calcium significantly increased from 1.42 mg/100g in the control sample to 8.47 mg/100g in the experimental sample ($p<0.05$). This notable elevation can be attributed to the inclusion of ingredients such as zucchini, flaxseed, and hemp flour, which are rich sources of calcium. Calcium is essential for bone health and muscle function **[43]**. The experimental sample showed higher levels of potassium (434 mg/100g), magnesium (45.3 mg/100g), and iron (4.39 mg/100g). The notable enhancement in the mineral content of the experimental pate is due to the inclusion of duck meat, which is typically richer in iron and potassium than turkey meat; zucchini which adds potassium and magnesium; and flaxseed and hemp flour, both of which are excellent sources of calcium, magnesium, and iron **[44]**. Additionally, Zając et al. (2019) **[34]** highlighted the enhanced mineral content with hemp flour addition, consistent with our observations.

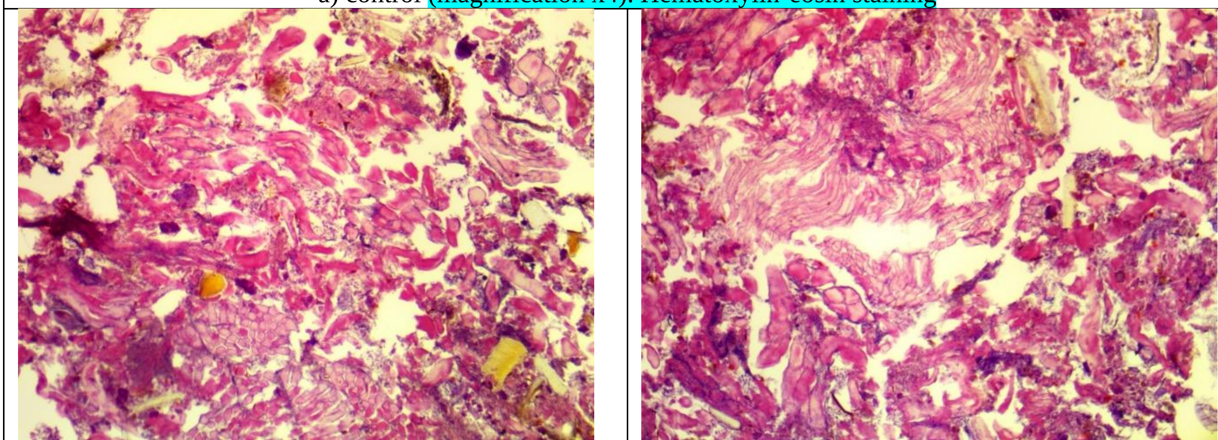
Histologic analysis

The microscopic microstructure analysis provides valuable insights into the effects of flaxseed and hemp flour on the structure of canned meat pate. Comparing the control and experimental samples reveals distinct differences in the distribution and arrangement of tissue components, highlighting the impact of the added ingredients on the microstructure of the final product.

The control sample showed transversely and longitudinally dissected muscle fibres and fragments of connective tissue. Connective tissue fragments, characterised by fibres and fat cells, are also observed within the minced meat. The boundaries between muscle fibres are well-defined; some appear disintegrated into smaller fragments (Figure 2, a). At medium microscope magnification, preserved nuclei of muscle fibres and cells of connective tissue elements are distinguishable. Additionally, transverse striations of muscle fibres are noted, indicating the typical structure of meat tissue.



a) control (magnification x4). Hematoxylin-eosin staining



b) experimental (magnification x4). Hematoxylin-eosin staining

Figure 2 Microstructure of meat pate samples.

In contrast, the micrograph of the experimental sample reveals a more heterogeneous microstructure. Loosely arranged muscle fibres are interspersed with connective tissue fragments and large and small tissue particles of flax and hemp flour (Figure 2, b). The nuclei of the plant supplements appear rounded and much larger than those of muscle fibres and connective tissue cells. Zachesova et al. (2018) noted that the addition of topinambur powder in the range of 8 to 10% leads to a loosening of the ground meat structure, with microvoids located between structural elements increasing on average by 1.5 times compared to the control sample **[45]**.

Furthermore, intracellular inclusions in the form of rounded pink formations and grains of pink color, stained with hematoxylin-eosin, are observed within the plant tissue particles. These inclusions indicate the presence of specific cellular structures or components within the added plant ingredients. Plant tissue nuclei are predominantly located in the centre of cells, highlighting the distinct organisation of plant-based tissues compared to animal-based tissues.

CONCLUSION

This reformulation offers a promising strategy to enhance the nutritional value of processed meat products without compromising consumer preference. The analysis of physicochemical indicators revealed that the meat pâté made from turkey and duck meat possesses high biological and nutritional value. The developed meat-based pâté enables the enrichment of the diet with minerals such as calcium, potassium, magnesium, and iron. Consumption of this meat-based pâté increases the body's resistance to negative environmental factors. This pâté is recommended for inclusion in the diet for mass catering. The results of this study suggest that incorporating flax and hemp seed-derived ingredients in turkey meat pate can provide a promising opportunity to develop functional meat products that meet the growing demand for healthier food options. Future studies can focus on optimising the formulation and sensory characteristics of the product to enhance consumer acceptance and preference.

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Funds:

This work was not supported by external funds.

Acknowledgments:

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Conflict of Interest:

No potential conflict of interest was reported by the author(s).

Ethical Statement:

This article does not contain any studies that would require an ethical statement.

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