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DEVELOPMENT OF TECHNOLOGY FOR FUNCTIONAL COMBINED MEAT CUTLETS "TURKESTAN" ENRICHED WITH TOMATO POMACE POWDER

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This study investigates the development of technology for functional combined meat cutlets "Turkestan", enriched with tomato pomace powder, aiming to enhance their nutritional value, oxidative stability, and safety while maintaining sensory appeal. The research addresses the challenge of improving the nutritional profile of meat products by incorporating tomato pomace, a byproduct of tomato processing rich in bioactive compounds such as β-carotene, lycopene, pectin, and vitamin C. These compounds contribute to the product's antioxidant and functional properties.

The study examines the effects of incorporating different concentrations of tomato pomace powder (1 %, 3 %, 5 %, and 7 %) into a mutton-turkey meat blend (50:50) on the physicochemical, microbiological, and organoleptic characteristics of the final product.

The results indicate a significant increase in essential minerals, amino acids, and antioxidant capacity. Sensory evaluation determined that cutlets containing 1 % and 3 % tomato pomace powder exhibited the best flavor, texture, and overall acceptability. The amino acid profile of "Turkestan" cutlets improved notably, with arginine increasing by 56.6 %, lysine by 49.7 %, and threonine by 17.3 %. Additionally, the mineral content was enriched, particularly in potassium, magnesium, and calcium. Microbiological analysis confirmed the product's safety, meeting food safety standards and ensuring the absence of harmful pathogens, including Salmonella and Listeria monocytogenes.

The developed formulation sustainably enhances the nutritional and functional properties of meat cutlets using a plant-based byproduct. These findings demonstrate the potential for practical application in developing functional meat products for health-conscious consumers

Keywords: combined meat product, functional cutlet, tomato pomace powder, antioxidants, carotenoids

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1. Introduction

The increasing focus on sustainability and health in the food industry has driven the exploration of organic waste materials as valuable resources for developing innovative food products. A significant amount of biological waste generated in the agricultural sector and society poses environmental, economic, and social challenges. The rational utilization of such waste, particularly byproducts of agricultural raw material processing, presents promising opportunities for the development of functional foods.

The food industry, particularly tomato processing enterprises, is a major source of organic waste. Tomato pomace, a byproduct consisting of crushed tomato skins and seeds, accounts for 3–5 % of the processed raw material's mass. It is a valuable source of bioactive compounds, including carotenoids (lycopene, β-carotene), dietary fiber, vitamins, and minerals, making it a promising ingredient for developing functional food products.

In the Turkestan region of Kazakhstan, where favorable climatic conditions enable the large-scale cultivation of tomatoes, processing enterprises such as "Altyn-Dan" LLP, "Ecoproductgroup" LLP, and "Agrofirma Zhana Akdala" LLP generate significant amounts of tomato pomace, estimated at approximately 3.2 thousand tons annually. However, despite its nutritional and functional potential, tomato pomace remains underutilized, primarily used as livestock feed or fertilizers. Maximizing its application in food production offers an opportunity to enhance sustainability, reduce food waste, and improve the nutritional value of various food products.

The inclusion of functional ingredients in food formulations is particularly important in the context of increasing health concerns, including declining immunity, premature aging, and the growing prevalence of chronic diseases. Antioxidant-rich substances, such as those found in tomato pomace, can reduce oxidative stress and inflammation, aligning with the demand for functional foods that promote well-being. Consequently, the incorporation of tomato pomace into food systems aligns with contemporary scientific priorities in food science and nutrition.

In the meat industry, the demand for healthier and more sustainable products continues to rise. Functional meat products enriched with plant-based bioactive compounds offer a way to improve their nutritional profile while maintaining desirable sensory properties. While tomato pomace has been utilized in select food applications, its broader integration into meat products remains largely unexplored. Research into its incorporation as a functional ingredient in combined meat products can contribute to the development of functional foods and the diversification of the meat processing sector.

Therefore, research on the development of technology for functional combined meat cutlets enriched with tomato pomace is relevant. It addresses key challenges in sustainability, nutrition, and food innovation, supporting both industry advancements and public health objectives.

2. Literature review and problem statement

Tomato pomace is increasingly recognized as a sustainable and valuable source of bioactive compounds, such as carotenoids and dietary fiber, making it a promising ingredient for functional food applications. Several studies have demonstrated its potential for enhancing food products' nutritional and functional properties. For instance, the paper [1, 2] reported on the bioactive potential of tomato byproducts, emphasizing their significant antioxidant activity and fiber content.

Studies have demonstrated the potential of tomato pomace in food applications. For example, the paper [3] investigated its use in bakery products, reporting improved antioxidant activity and dietary fiber content. The study provides detailed physicochemical analyses of the enriched bakery products, including moisture content, water activity, color, texture, and antioxidant properties. These evaluations support the findings on the nutritional and functional benefits of tomato processing by-products. The addition of tomato pomace resulted in increased fiber content, improved antioxidant activity, and improved shelf life compared to the control samples. Although the study evaluates microbial stability, it does not provide a detailed analysis of microbial diversity. The bioactive compounds responsible for the antioxidant effect are not fully characterized. A more detailed phytochemical analysis (e. g., quantification of flavonoids and phenolic compounds) would clarify which components contribute most to improved product stability. Similarly, the paper [4] presents the results of research on the enrichment of bread with tomato pomace waste, demonstrating increased lycopene content and antioxidant activity. This aligns with the trend of developing functional foods with potential health benefits. The study includes detailed physicochemical analyses, such as moisture content, ash content, protein content, and colorimetric measurements, providing a thorough characterization of the impact of tomato pomace on bread formulation. While the study provides physicochemical data, it lacks a robust sensory evaluation. Consumer acceptability is crucial for the commercial success of functional bread products, and a more detailed sensory analysis (e.g., flavor, texture, overall acceptability) would strengthen the study's practical implications.

The paper [5] demonstrated the feasibility of using tomato pomace powder in ketchup production, highlighting its positive effects on texture and nutritional composition. The study revealed that the incorporation of tomato pomace improved the viscosity and antioxidant profile of the final product. However, unresolved issues remain regarding the sensory acceptability and stability of products enriched with tomato pomace, particularly in different food applications. These challenges may be attributed to the inherent taste and texture alterations introduced by high fiber content and the potential for interactions with other food components.

Similarly, the paper [6] explored the application of dietary fiber sources, including dried tomato pomace, in the development of fiber-enriched chicken sausages. Their findings confirmed the enhancement of dietary fiber content and water-holding capacity, which contributed to improved textural properties. Nevertheless, limitations were noted in terms of consumer acceptability, as the addition of pomace altered the organoleptic characteristics of the sausages. This suggests that further research is required to optimize the incorporation process to balance nutritional benefits with sensory attributes.

Moreover, tomato pomace is particularly rich in lycopene, which accounts for over 85 % of its total carotenoid content, and has been associated with health benefits such as reduced oxidative stress [7, 8]. However, the application of tomato pomace in meat products remains a relatively underexplored area.

The paper [9] evaluates the nutritional value and cost of prepared multigrain cookies by incorporating tomato pomace powder into multigrain (wheat, finger millet, and oat) cookies. The research evaluates the physical, sensory, nutritional, and functional properties of the fortified cookies, providing a holistic understanding of product quality. The study reports high acceptability scores for cookies containing 6 % tomato pomace powder, indicating potential market acceptance. The study mentions the nutritional benefits of tomato pomace but lacks detailed quantitative analysis of specific nutrients and bioactive compounds. This information is essential for understanding the health benefits of the cookies.

Tomato pomace, a byproduct of tomato processing, is rich in carotenoids such as lycopene and β-carotene, which vary depending on tomato variety, climatic conditions grown, and processing methods. The main carotenoids in tomato pomace are lycopene, β-carotene, lutein, cis-β-carotene, and zeaxanthin.

Lycopene predominates, accounting for more than 85 % of the total carotenoids. In addition, tomato pomace exhibits strong antioxidant activity (0.68 to 2.2 mMTroloh/100 g). Tomato peel is a rich source of carotenoids, including lycopene [10, 11]. Carotenoids are also biologically active compounds of tomato pomace, with amounts ranging from 272 to 554 mg/kg [12]. With lycopene predominating, tomato pomace exhibits strong antioxidant activity. While current uses of tomato pomace in the food industry include recipes for tomato ketchup [5, 13], sausage products [6] with increased fiber content, its potential as a functional ingredient remains underexplored.

Amidst deteriorating ecological and socio-economic conditions, there's a growing need to innovate and develop new food products. In the meat processing industry, creating novel products with natural flavor and texture is crucial for maintaining consumer preference. This study aims to utilize tomato pomace in the development of functional combined meat cutlet technology.

But there are still unresolved questions related to the compatibility of tomato pomace with the structural and textural requirements of meat products, particularly in terms of sensory acceptability, moisture retention, and shelf-life stability. Additionally, the variability in the composition of tomato pomace, influenced by factors such as tomato variety, processing methods, and storage conditions, poses challenges in achieving consistency in product quality. Another difficulty is the high cost associated with adapting processing techniques for integrating tomato pomace into meat formulations, making its widespread application in the meat processing industry less feasible.

The reasons for these challenges can be attributed to objective difficulties related to the complexity of meat product formulation, the principal impossibility of maintaining a balance between functionality and sensory quality, and the high cost of scaling up tomato pomace integration in meat processing. Despite these barriers, the growing demand for sustainable and functional food products necessitates innovative solutions.

An option to overcome the relevant difficulties can be the development of standardized pre-treatment methods for tomato pomace, such as drying and grinding, to create a consistent ingredient for meat products. Additionally, the paper [14–16] demonstrates the effectiveness of integrating antioxidant-rich byproducts into food systems through advanced processing technologies.

For example, the paper [14] analyzed the impact of tomato pomace powder addition on the quality of combined meat bread. Their findings suggest that tomato pomace contributes positively to the nutritional and sensory properties of the final product. However, the study lacks detailed analysis on long-term stability and scalability of the processing techniques, which remains a key issue for industrial applications.

The paper [15] examined the effects of plum and apple pomace powder on buffalo meat emulsions, demonstrating that the incorporation of fruit-derived byproducts can enhance textural properties and antioxidant potential. Nevertheless, their study does not address potential interactions between different pomace sources and their impact on product consistency, indicating a gap in knowledge regarding optimal formulations.

The paper [16] focused on the techno-functional properties of lemon pomace and its application in biscuit production. Their research underscores the importance of pre-treatment methods in improving the functional characteristics of food byproducts. While promising, their findings primarily pertain to baked goods, and the applicability of similar methods to meat-based products remains uncertain.

This is the approach used in earlier studies, such as, where tomato pomace was successfully integrated into baked snacks to improve their functional and sensory qualities. However, applying these techniques to meat products presents unique challenges, including compatibility with animal protein matrices and consumer acceptance [5].

All this allows us to assert that it is expedient to conduct a study on the integration of tomato pomace into the development of functional combined meat cutlets (50:50 mutton and turkey). By leveraging the antioxidant and nutritional properties of tomato pomace, combined with its potential to enhance the shelf life, sensory quality, and nutritional value of meat products, this study seeks to address the existing knowledge gaps. The research will focus on the formulation, physicochemical analysis, and technological development of combined meat cutlets enriched with tomato pomace, providing a novel solution to sustainability and functional food innovation.

3. The aim and objectives of the study

The aim of the study is to develop a technology for producing functional combined meat cutlets "Turkestan" by integrating tomato pomace, a byproduct of tomato processing, to enhance the nutritional profile, improve functional properties, and promote sustainable utilization of agro-industrial waste.

To achieve this aim, the following objectives are accomplished:

– to conduct a physicochemical analysis of the tomato pomace powder;

– to develop a technological scheme of functional combined meat cutlets "Turkestan" by integrating tomato pomace and to study their organoleptic characteristics;

– to analyze the mineral composition of the developed product;

– to examine the amino acid composition of the developed product;

– to assess the nutritional and microbiological parameters of the developed product.

4. Materials and methods

4. 1. Object and hypothesis of the study

The study focused on the development of combined meat cutlets "Turkestan" technology, which were formulated using vacuum-dried tomato pomace powder as a functional ingredient, along with a combination of mutton and turkey meat. The tomato pomace was sourced from IE "Aidinov", a tomato-processing enterprise based in Shymkent, Republic of Kazakhstan. Mutton, rich in protein and essential amino acids [17], and turkey [18], known for its high protein and low collagen content, are chosen as the base meats for the combined meat cutlets. Mutton was obtained according to the standard GOST 34200-2017 (Federal Agency on Technical Regulating and Metrology, 2012), while turkey meat adhered to GOST 31473-2012 (Federal Agency on Technical Regulating and Metrology, 2012).

The study's main hypothesis posits that incorporating tomato pomace powder into the formulation of "Turkestan" meat cutlets will improve their nutritional profile and functional properties, including increased dietary fiber content, enhanced antioxidant activity, and extended shelf-life. It further assumes that these improvements will be achieved without compromising the product's sensory qualities, such as taste, texture, and overall acceptability.

Assumptions made in the work: the study assumes that the processing of tomato pomace retains significant amounts of bioactive compounds, such as carotenoids, dietary fiber, and antioxidants, making it a suitable functional ingredient for meat cutlets. It further assumes that the incorporation of tomato pomace powder into the formulation will not compromise the sensory attributes of the final product, such as taste, texture, and appearance, and that its functional benefits, including improved nutritional value, antioxidant properties, and shelf-life stability, will outweigh any potential challenges related to processing or formulation adjustments. Additionally, consumers are assumed to accept combined meat cutlets with integrated tomato pomace powder as a healthier and more sustainable alternative to conventional products.

Simplifications adopted in the work: to streamline the research process and facilitate analysis, several simplifications were implemented. The study focused exclusively on the development of "Turkestan" combined meat cutlets enriched with tomato pomace powder, without considering the potential use of other food byproducts. Furthermore, the investigation was limited to analyzing key parameters, including physicochemical properties, amino acid and mineral content, as well as the nutritional and microbiological characteristics of the developed products. Broader aspects, such as the exploration of alternative functional ingredients or more extensive microbiological analyses, were not included in this study.

4. 2. Preparation of combined meat cutlet "Turkestan" samples

Mutton and turkey meat were defrosted (if necessary), deboned, trimmed, and ground using a meat grinder. Meat with a fat content of up to 10 % was selected for the preparation. Wheat bread was softened in milk and mixed with the ground meat, melange, and other auxiliary ingredients. Salt, pepper, and water were gradually added to the mixture. Once all the auxiliary ingredients were incorporated, tomato pomace powder was added and the mixture was reground to ensure homogeneity. During mixing, the water facilitated the binding of the disrupted meat tissue structure with the softened bread, resulting in a loosened and homogeneous mixture. The prepared mixture was portioned, shaped into cutlets by hand, packaged, and cooled to 2±2 °C. The cutlets were stored at 4±2 °C for up to 12 hours before being evaluated for sensory, textural, and microbiological qualities.

4. 3. Determination of total carotenoid content

The total carotenoid content was measured using a spectrophotometric method according to the standard GOST 54058-2010 (Federal Agency on Technical Regulating and Metrology, 2010). The optical density of the petroleum ether extract was determined at a wavelength of 450 nm using a UNICO 2800 spectrophotometer. Petroleum ether served as the reference solution. The carotenoid mass fraction was calculated using the formula:

$$X = 4.00 * A * \frac{v}{m}, \tag{1}$$

where V – volume of extract in petroleum ether, cm^3;

m – mass of the product sample, g.

4. 4. Determination of total polyphenol content

The total polyphenol content was analyzed using a colorimetric method with the Folin-Ciocalteu reagent. This reagent contains phosphotungstic and phosphomolybdic acids, which react with phenolic compounds to form a blue complex (tungsten blue) with a maximum absorbance at 765 nm [19].

4. 5. Determination of water-soluble antioxidants (Antioxidant activity)

The content of water-soluble antioxidants in tomato pomace was measured using the method described in [20] on the "Tsvet Yauza-01-AA" device. This method involves measuring the electric current generated by the oxidation of the studied substance on the working electrode at a specific potential. A calibration curve was established using quercetin as a reference standard, and the antioxidant content in the samples was calculated in quercetin-equivalent units.

4. 6. Determination of mineral content

The mineral content of the combined meat cutlets "Turkestan" was determined using a JSM-6490LV scanning electron microscope equipped with an INCA Energy 350 energy-dispersive microanalysis system and an HKL Basic system for structural and textural analysis of polycrystalline samples. The analysis was conducted at the Regional Testing Laboratory for Engineering Profile "Structural and Biochemical Materials" at M. Auezov South Kazakhstan University.

4. 7. Determination of amino acid content

The amino acid content of the samples, including total free and bound forms, was determined using capillary electrophoresis following acid hydrolysis. Since leucine and isoleucine are not separated during hydrolysis, their combined content was measured. The method involved obtaining FTC derivatives of amino acids, separating them, and quantifying them by capillary electrophoresis. Detection was performed in the UV region at a wavelength of 254 nm. For direct tryptophan quantification without FTC derivatization, absorbance was recorded at 219 nm. Measurements were carried out using the "Kapel-105 M" capillary electrophoresis system, equipped with a cassette for amino acid analysis. Data collection and processing were performed on a personal computer with Windows 2000/XP/7 operating systems using the accompanying software [21].

4. 8. Analysis of experimental data

Statistical analysis of experimental data was conducted using Microsoft Excel 7.0 (MS Office, USA) and Statistica 6.0 (StatSoft, USA) software. Results are expressed as means ± standard deviations from three independent experiments (n=3) with a 90 % confidence level (P=0.90).

5. Results of the evaluation of combined meat cutlets "Turkestan" technology

5. 1. Physicochemical analysis of tomato pomace powder

The powder of crushed tomato pomace used in the meatball recipe was processed by vacuum drying at 60 °C. The physicochemical parameters of the tomato pomace, obtained from IE "Aidinov" (Shymkent, Republic of Kazakhstan), were analyzed before and after vacuum drying. These results are summarized in Table 1.

Table 1

Physicochemical parameters of tomato pomace before and after vacuum drying

Parameter	Control sample (before drying)	Experimental sample (after drying)
Mass fraction of moisture, %	75.1	3.4
Antioxidant activity, mg/g	2.33 ±0.004	2.65 ±0.017
β-carotenoid content, mg/100 g	0.85±0.04	1.05±0.02
Polyphenol content, %	0.28±0.006	0.41±0.002
Vitamin C, mg/100	2.90±1.00	3.10±1.05

The data indicate that the moisture content of tomato pomace decreased significantly after vacuum drying, reducing by approximately 22-fold. The polyphenolic compound content increased by 46.4 %, from 0.28 % to 0.41 %, while the β-carotenoid content rose from 0.85 mg/100 g to 1.05 mg/100 g. These changes reflect the beneficial effects of vacuum drying, which enhances the concentration of bioactive compounds by removing water and breaking down the cellular matrix, facilitating the release of phenolic compounds.

The antioxidant activity of the dried tomato pomace was slightly higher than that of the fresh sample, indicating its potential to enrich functional food products with bioactive compounds. The increase in vitamin C content after drying, although minimal, supports the preservation of essential nutrients.

The study highlights the suitability of tomato pomace as an enriching ingredient in combined meat cutlets. Its β-carotenoids and polyphenols contribute to the biological, energy, and physiological value of the product, enhancing its functional properties.

5. 2. Development of the technological scheme and organoleptic evaluation of functional combined meat cutlets "Turkestan"

The primary ingredients in the combined meat cutlets "Turkestan" include mutton, turkey meat, and tomato pomace powder. A 50:50 ratio of mutton to turkey meat was used to achieve the desired taste and aroma reminiscent of oriental dishes. Tomato pomace powder was added as a functional ingredient to enrich the cutlets with antioxidants and polyphenols.

The technological process for preparing the combined meat cutlets involves the following key operations: preparation of tomato powder and flavoring additives, preparation of combined minced meat, forming cutlets, cooling, storage, and product sales. This process is visually represented in the technological flow diagram (Fig. 1). The combined meat cutlets "Turkestan" serve as a functional food product enriched with bioactive compounds. The incorporation of tomato pomace enhances their nutritional profile, while the combination of mutton and turkey meat ensures a unique sensory experience characteristic of traditional oriental cuisine.

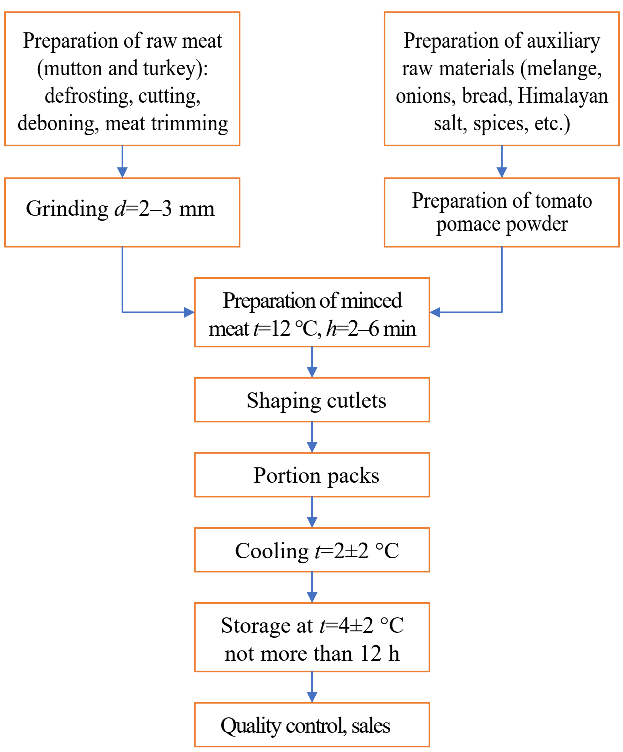

Fig. 1. Technological scheme of combined meat cutlet "Turkestan" production

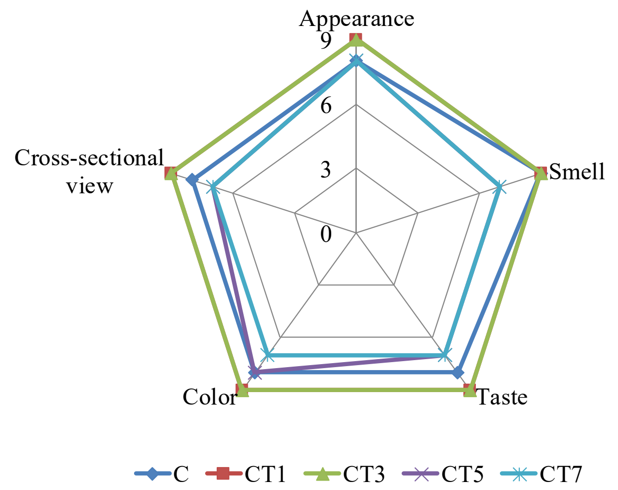

Fig. 2. Organoleptic characteristics of combined meat cutlets "Turkestan"

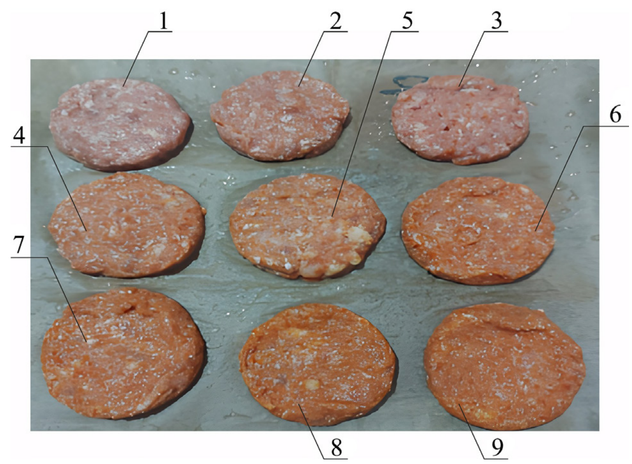

Fig. 3. Organoleptic view of combined meat cutlets "Turkestan" samples: 1– C; 2, 3 – CT 1; 4, 5 – CT 3; 6, 7 – CT 5; 8, 9 – CT 7

According to the specified technology, 5 samples of cutlets were developed:

1) C – cutlet without additives (control);

2) CT 1– cutlet with the addition of 1 % tomato pomace powder;

3) CT 3 – cutlet with the addition of 3 % tomato pomace powder;

4) CT 5 – cutlet with the addition of 5 % tomato pomace powder;

5) CT 7 – cutlet with the addition of 7 % tomato pomace powder.

According to organoleptic parameters, the best and high scores were obtained by samples with the addition of 1 % and 3 % tomato pomace powder in all parameters (Fig. 2) as the other samples did not differ significantly from each other and were too dry with a strongly pronounced sour taste.

By appearance, the product was oval and flattened in shape, the surface and edges were even, without cracks, the surface was smooth, and homogeneous, cross-sectional views of the cutlets were consistently homogeneous, without separate pieces of meat, without lumps of bread and tendons. The colour of the product surface was light brown, on the cut with a red (tomato) shade depending on the ratio in the product. It should be noted that the addition of tomato pomace powder to the experimental sample improved the minced meat colour and increased the aroma intensity (Fig. 3).

Moreover, the samples containing 1 % and 3 % tomato pomace powder turned out to be more saturated and bright, with shades of red color both on the outside and on the cut in comparison with the control sample.

5. 3. Mineral composition of the developed product

The mineral content is presented in Fig. 4 and Table 2.

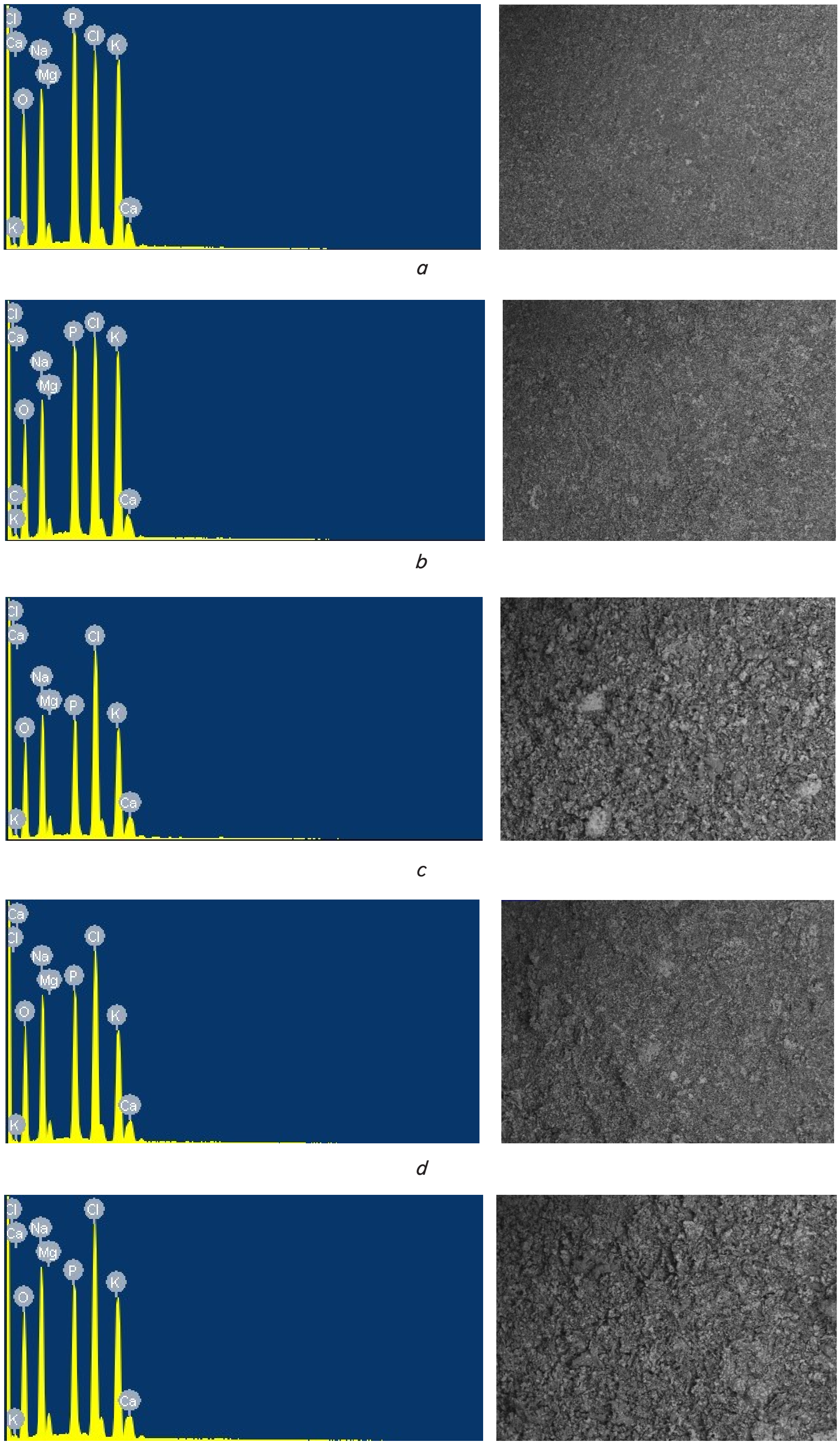

Fig. 4. Spectra of the mineral composition of combined meat cutlets "Turkestan": *a* – C; *b* – CT1; *c* – CT3; *d* – CT5; *e* – CT7

Table 2

Mineral composition of combined meat cutlets "Turkestan"

Element, weight %	C	CT1	CT3	CT5	CT7
Sodium	15.37	13.22	16.31	17.17	17.43
Magnesium	1.68	1.40	2.25	2.07	2.07
Phosphorus	13.47	11.68	10.25	11.48	10.25
Chlorine	14.41	14.56	18.78	17.07	17.25
Potassium	17.29	17.02	14.12	13.08	14.24
Calcium	1.21	1.21	2.78	2.50	2.22
Oxygen	35.56	33.56	35.52	36.63	36.43

The mineral composition analysis of the combined meat cutlets "Turkestan" (Table 2) revealed significant variations in elemental content depending on the percentage of tomato pomace powder added. Sodium content showed an increasing trend with higher tomato pomace inclusion, rising from 15.37 % in the control (C) to 17.43 % in CT7. Magnesium content also increased, with the highest value observed in CT3 (2.25 %), compared to 1.68 % in the control. Phosphorus levels exhibited a decline in samples containing tomato pomace, with the lowest concentration in CT3 (10.25 %). Chlorine content demonstrated a noticeable increase in supplemented samples, reaching a peak of 18.78 % in CT3. Potassium levels, conversely, showed a decreasing trend, with the lowest value in CT5 (13.08 %), compared to 17.29 % in the control. Calcium content increased significantly in cutlets enriched with tomato pomace, reaching a maximum of 2.78 % in CT3.

Table 3

Amino acid composition of combined meat cutlets "Turkestan"

Indicator, measurement units	Control sample		Experimental sample	
	Conc., mg/l	Weight, %	Conc., mg/l	Weight, %
Arginine	190.0	3.539±1.416	160.0	5.544±2.218
Lysine	91.0	1.695±0.576	68.0	2.536±0.801
Tyrosine	44.0	0.820±0.246	34.0	1.178±0.353
Phenylalanine	42.0	0.782±0.235	27.0	0.936±0.281
Histidine	33.0	0.615±0.307	18.0	0.624±0.312
Leucine+isoleucine	73.0	1.360±0.354	47.0	1.629±0.423
Methionine	33.0	0.615±0.209	22.0	0.762±0.259
Valine	63.0	1.173±0.469	37.0	1.282±0.513
Proline	44.0	0.820±0.213	26.0	0.901±0.234
Threonine	46.0	0.857±0.343	29.0	1.005±0.402
Serine	42.0	0.782±0.203	31.0	1.074±0.279
Alanine	64.0	1.192±0.310	40.0	1.386±0.360
Glycine	42.0	0.782±0.266	25.0	0.866±0.295

5. 4. Amino acid composition of the developed product

The biological value of the combined meat cutlets "Turkestan" was evaluated based on the amino acid content in the control sample (C) and the experimental sample (CT 3). The results indicate that the content of amino acids in the experimental sample CT 3 is generally higher than in the control sample, as shown in Table 3 and Fig. 5.

In terms of specific amino acids, the concentration of arginine was higher in the experimental sample (160 mg/l; 5.544 %) compared to the control sample (190 mg/l; 3.539 %).

The experimental sample CT 3 also demonstrated a higher content of essential amino acids such as lysine, where the percentage weight increased from 1.695 % in the control to 2.536 % in CT 3. Similarly, tyrosine and threonine showed higher percentages in the experimental sample, with tyrosine increasing from 0.820 % to 1.178 %, and threonine from 0.857 % to 1.005 %.

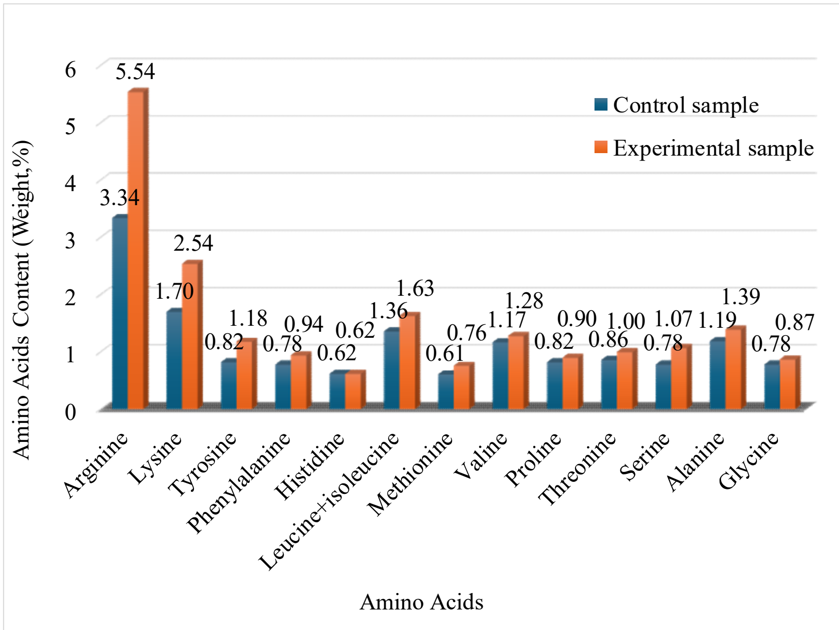

Fig. 5. Comparison of amino acid content between control and experimental samples

Noteworthy increases were also observed in leucine+isoleucine, valine, and serine, where the percentage weights in the experimental sample were 1.629 %, 1.282 %, and 1.074 %, respectively, all higher than the corresponding values in the control sample.

Despite some fluctuations in the absolute concentrations of amino acids such as histidine, phenylalanine, and glycine, where the control sample had higher values in terms of concentration, the overall percentage weight of these amino acids in the experimental sample suggests a more balanced and biologically valuable composition.

5. 5. Nutritional and microbiological parameters of the developed product

The nutritional parameters and microbiological analysis of the combined meat cutlets "Turkestan" samples (C, CT 1, and CT 3) were evaluated, and the results are presented in Table 4.

All samples of the developed product met microbiological safety standards regulated in the country (the Technical Regulations of the Customs Standard "On the Safety of Meat and Meat Products" TR CS 034/2013). The total number of mesophilic aerobic and facultative anaerobic bacteria in all samples was well below the maximum permissible limit of 5×10^6 CFU/g. Additionally, no coliforms, pathogenic microorganisms (including *Salmonella*), or *Listeria monocytogenes* were detected in any of the samples, ensuring their microbiological safety.

Table 4

Nutritional parameters and microbiological analysis of combined meat cutlets "Turkestan"

Indicator	C	CT 1	CT 3
Mass fraction of fat, %	25.46	19.87	18.82
Mass fraction of protein, %	14.86	17.03	17.96
Total number of mesophilic aerobic and facultative anaerobic bacteria, CFU/g, no more than $5x10^6$	5×10^5		
Coliforms, not allowed in 0.0001 g	not found		
Pathogens, including *Salmonella*, not allowed in 25 g	not found		
Listeria monocytogenes, not allowed in 25 g	not found		

The mass fraction of fat demonstrated notable differences among the samples. The control sample (C) contained 25.46 % fat, while the CT 1 and CT 3 samples had lower fat contents of 19.87 % and 18.82 %, respectively.

Regarding protein content, the experimental samples showed significant improvements compared to the control. The CT 1 and CT 3 samples demonstrated the highest protein content at 17.03 % and 17.96 %, respectively, surpassing the control sample (14.86 %).

6. Discussion of the study results of the addition of tomato pomace powder into combined meat cutlets "Turkestan"

The results obtained from the physicochemical analysis of tomato pomace before and after vacuum drying (Table 1) highlight the effectiveness of vacuum drying at 60 °C in reducing moisture content and concentrating bioactive compounds. The significant reduction in the moisture content, from 75.1 % in the fresh pomace to 3.4 % in the dried sample, is attributed to the efficient removal of water at the applied vacuum drying conditions. This process likely facilitated the breakdown of the cellular matrix, enhancing the release and bioavailability of phenolic compounds and carotenoids. Consequently, the content of polyphenols increased by 46.4 %, and β-carotenoids rose by 23.5 %.

The observed increase in antioxidant activity (from 2.33 mg/g to 2.65 mg/g) indicates the retention and possible augmentation of bioactive compounds during drying, consistent with the enrichment of phenolic compounds and carotenoids. Additionally, the minimal increase in vitamin C content (from 2.90 mg/100 g to 3.10 mg/100 g) (Table 1) demonstrates that vacuum drying preserves this labile nutrient under controlled conditions, reducing oxidative degradation compared to conventional drying methods.

The use of vacuum drying at a moderate temperature (60 °C) is a notable advantage, as it balances the retention of bioactive compounds with the need for moisture removal. Compared to hot air drying, which often leads to significant nutrient degradation, vacuum drying preserves sensitive compounds such as carotenoids and vitamin C. Studies by other researchers, such as [22], have shown similar benefits of vacuum drying for retaining phenolic compounds and antioxidant activity in fruit and vegetable by-products. Furthermore, the paper [23] reported β-carotenoid retention levels of 20–25 % for conventionally dried tomato by-products, which are comparable to or slightly lower than the 23.5 % increase observed in this study, highlighting the efficacy of the proposed method.

The development of the combined meat cutlets "Turkestan" technology successfully integrates functional and sensory attributes, ensuring a nutritionally enhanced product with high consumer acceptability. The combination of mutton, turkey meat, and tomato pomace powder creates a balanced composition that reflects traditional oriental flavors while introducing innovative elements through functional ingredients. The addition of tomato pomace powder significantly improved the sensory characteristics of the cutlets (Fig. 2). Samples with 1 % (CT 1) and 3 % (CT 3) pomace powder received the highest organoleptic scores due to their enhanced flavor, aroma, and color. The bright red shades observed in these samples were attributed to the natural pigmentation of tomato pomace (Fig. 3), which also intensified the aroma and improved the appearance of the minced meat. Higher levels of pomace powder (5 % and 7 %) resulted in excessive dryness and pronounced sourness, underscoring the importance of optimizing additive concentrations for sensory quality. These findings suggest that incorporating 1–3 % tomato pomace powder strikes the ideal balance between functionality and consumer preference.

The proposed technology will allow obtaining a combined meat cutlet "Turkestan" enriched with tomato pomace powder, enriched with minerals and amino acids.

The mineral composition analysis of the combined meat cutlets "Turkestan" (Table 2, Fig. 4) demonstrates that incorporating tomato pomace powder significantly influences the mineral profile. Notably, sodium, magnesium, calcium, and chlorine levels increased with higher concentrations of tomato pomace powder, while phosphorus and potassium levels exhibited a decreasing trend. These variations can be attributed to the natural mineral composition of tomato pomace, which is rich in calcium and magnesium but relatively lower in phosphorus and potassium compared to meat [2]. Additionally, the presence of dietary fiber and polyphenols in tomato pomace may contribute to altered mineral retention and bioavailability [1, 2, 24].

The increased calcium content in the experimental samples (CT 3, CT 5, and CT 7) aligns with prior studies indicating that tomato pomace is a good source of calcium [2, 10]. Magnesium levels also increased in the CT 3 sample but stabilized in CT 5 and CT 7, likely due to the saturation effect of mineral solubility in the matrix. The rise in sodium and chlorine content in samples CT 3, CT 5, and CT 7 suggests an enhancement in mineral retention, possibly due to interactions between meat proteins and the dietary fiber in tomato pomace [2, 6]. In contrast, potassium and phosphorus levels decreased, which may be attributed to the dilution effect caused by the substitution of meat with tomato pomace powder.

Compared to traditional meat cutlets, the experimental samples demonstrated an improved calcium-to-phosphorus ratio, which is beneficial for bone health [25]. The findings of this study align with [26], who reported enhanced mineral retention in meat products enriched with fruit and vegetable by-products.

The amino acid analysis demonstrated the superior biological value of the experimental sample CT 3 compared to the control sample (Table 3, Fig. 5). The increased concentrations of essential amino acids, including lysine, leucine, and threonine, in CT 3 highlight its enhanced nutritional profile. Arginine levels, which play a critical role in metabolic regulation and immune support, also increased significantly in the experimental sample. This enhancement is particularly notable given the lower absolute concentrations of certain amino acids in the experimental sample, suggesting that the incorporation of tomato pomace powder contributes to a more balanced and functional amino acid profile.

The findings are consistent with previous studies that highlight the nutritional benefits of incorporating plant-based ingredients into meat products. For instance, papers [3, 4, 6, 9, 13, 14] reported that tomato pomace, when added to food matrices, enhances amino acid content and functional properties due to its high nutrient density. Similarly, research by [24] demonstrated that dietary fiber and bioactive compounds in tomato by-products improve protein quality and nutritional balance in processed foods.

Compared to these studies, the CT 3 sample demonstrated improvements in amino acid percentages, notably for arginine and lysine, underscoring the effectiveness of the proposed method.

The essential amino acids like leucine+isoleucine, valine, and serine play crucial roles in protein synthesis, muscle repair, and metabolic regulation, thus enhancing the biological value of the CT 3 sample.

The study revealed that the incorporation of tomato pomace powder reduced fat content while enhancing protein levels. Compared to the control sample (C), the experimental samples (CT 1 and CT 3) showed reductions in fat content (by 22 % and 26 %, respectively) and increases in protein content (14.6 % for CT 1 and 20.8 % for CT 3) (Table 4). These improvements are likely linked to the low-fat and protein-rich properties of tomato pomace powder, further validating its potential as a functional ingredient for healthier meat products.

The microbiological analysis confirmed that all developed samples met regulatory safety standards (Table 4). The absence of coliforms, *Salmonella*, and *Listeria monocytogenes*, as well as low levels of mesophilic aerobic and facultative anaerobic bacteria, underscores the safety of the production process and the final product. The inclusion of tomato pomace powder did not compromise microbiological safety, further supporting its viability as a functional additive.

Thus, CT 1 and CT 3 not only meet stringent microbiological standards but also display improved nutritional attributes, such as reduced fat content and enhanced protein levels, showcasing the potential benefits of incorporating tomato pomace powder into the product formulation.

The limitation of this study is its focus on a specific formulation using tomato pomace powder sourced from IE "Aidinov". Variations in the chemical composition of tomato pomace from different origins may impact the reproducibility and generalizability of the results. Additionally, the study did not assess the effects of storage conditions or shelf life on the amino acid profile, which could influence the product's long-term stability and nutritional value.

Further research will be directed to the study of the product stability under different storage conditions and conducting instrumental texture analysis.

7. Conclusions

1. The analysis revealed that tomato pomace is rich in dietary fiber, antioxidants, and essential minerals, making it a promising functional ingredient for enhancing the nutritional profile of meat products.

2. The technological scheme for producing functional combined meat cutlets "Turkestan" was successfully developed, integrating tomato pomace powder as a functional ingredient. The process, as outlined in the technological flow diagram, includes key stages such as ingredient preparation, mincing, forming, cooling, and storage. The study confirmed that the optimal formulations were cutlets containing 1 % and 3 % tomato pomace powder, as these samples demonstrated superior organoleptic properties compared to other variations. The developed product is enriched with biologically active compounds, including carotenoids and polyphenols, enhancing its nutritional value. The combination of mutton and turkey meat in a 50:50 ratio ensured a balanced sensory profile characteristic of traditional oriental cuisine.

3. The mineral content of the developed "Turkestan" cutlets was significantly enhanced, with higher levels of essential minerals, including potassium, magnesium, and calcium, as compared to conventional meat cutlets.

4. The amino acid profile of the "Turkestan" cutlets was positively impacted by the incorporation of tomato pomace powder. The experimental sample of combined meat cutlets "Turkestan" exhibited an improved amino acid profile compared to the control sample, with notable percentage increases in several essential amino acids. Arginine content in the experimental sample was 5.544 %, representing a 56.6 % increase compared to the control (3.539 %). Lysine showed a 49.7 % increase, while threonine increased by 17.3 %. Additionally, tyrosine content increased by 43.7 %, leucine + isoleucine by 19.8 %, valine by 9.3 %, and serine by 37.4 %. Despite some reductions in absolute amino acid concentrations, such as histidine and phenylalanine, the overall percentage composition in the experimental sample suggests a more balanced and biologically valuable profile.

5. The study successfully demonstrated that incorporating tomato pomace powder into the formulation of functional combined meat cutlets "Turkestan" enhances their nutritional profile while maintaining microbiological safety. The experimental samples (CT 1 and CT 3) showed significantly reduced fat content (by 22 % and 26 %, respectively) and increased protein levels (by 14.6 % and 20.8 %, respectively) compared to the control sample. The developed cutlets exhibited favorable microbiological parameters, likely due to the antioxidant and antimicrobial properties of tomato pomace, which were confirmed in the study.

Conflict of interest

The authors declare that they have no conflicts of interest in relation to the current research, including financial, personal, copyright or any other that could affect the research and the results presented in this paper.

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Data availability

All data is available in the main text of the manuscript.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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