Caspian Journal of Environmental Sciences
Online ISSN: 1735-3866
Print ISSN: 1735-3033

Comprehensive study on the physicochemical and biological properties of cucurbit crop powders for use in flour confectionery products

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ABSTRACT

The main objective of the present study was to comprehensively investigate the physicochemical and biological characteristics of powders obtained from three pumpkin varieties (*Cucurbita* spp.), namely Vitaminnaya, Zhemchuzhina, and Volzhskaya Seraia 92, cultivated under the agro-climatic conditions of the Astana region of Kazakhstan, and to evaluate their potential application in confectionery products. Pumpkin powders were produced using two drying techniques—freeze-drying and hot air drying—and their quality attributes were subsequently assessed. The results of chemical analyses demonstrated significant differences ($p < 0.05$) among the studied pumpkin varieties in terms of nutritional composition and bioactive compound content. Among them, the Vitaminnaya variety exhibited the highest levels of protein (12.9%), dietary fiber (15.9%), and total phenolic compounds (15.42 mg g^{-1}), as well as the strongest antioxidant activity, as determined by DPPH (85.75%) and FRAP (45.298 μmol g^{-1}) assays. At the application stage, pumpkin powder was used to partially replace wheat flour at levels of 5, 10, and 15% in cookie formulations. The results revealed that cookies containing 5% pumpkin powder achieved the highest overall sensory acceptance score (35.7) and showed a significant increase in dietary fiber (60.47%) and total phenolic content (97.30%) compared to the control sample. However, higher levels of flour substitution resulted in a noticeable decline in sensory attributes and an increase in product firmness. Overall, the findings indicate that pumpkin powder, particularly derived from the Vitaminnaya variety, possesses high potential for use in the production of enriched and functional confectionery products. The utilization of locally cultivated pumpkin varieties represents a promising approach for improving the nutritional quality of bakery products and promoting the value-added use of agricultural raw materials in Kazakhstan.

Keywords: Pumpkin powder, *Cucurbita* spp., Confectionery products, Bioactive compounds, Food fortification.
Article type: Research Article.

INTRODUCTION

Over recent years, the food industry has faced numerous challenges related to meeting the demands of a growing population, improving product quality, and ensuring food safety. At the same time, the development of food products with high nutritional value and appropriate functional properties has become one of the primary priorities for both researchers and food manufacturers (McClements & Grossmann 2021). In this context, the incorporation of natural plant-based powders as functional ingredients or partial substitutes in food formulations is considered a promising strategy for food fortification and improvement of physicochemical properties (Ren *et al.* 2023). Such an approach not only enhances the nutritional profile of food products but also contributes to desirable sensory, textural, and technological characteristics. Fruits and vegetables are recognized as some of the richest sources of bioactive compounds, vitamins, minerals, and dietary fiber (Trigo *et al.* 2019). Among horticultural crops, special attention is given to plants of the Cucurbitaceae family, particularly pumpkin, *Cucurbita* spp. It is a widely

Caspian Journal of Environmental Sciences, Vol. 23 No. 5 pp.1175-1182 Received: May 08, 2025 Revised: Aug. 15, 2025 Accepted: Oct. 13, 2025
DOI: 10.22124/cjes.2025.9359

Publisher: University of Guilan,

cultivated crop characterized by high contents of carotenoids, phenolic compounds, organic acids, polysaccharides, and dietary fiber. Numerous studies have demonstrated that pumpkin possesses strong antioxidant, anti-inflammatory, and immune-enhancing properties, largely attributed to its bioactive composition (Pangal & Ahmed 2023; Henane *et al.* 2024; Barbosa Júnior *et al.* 2025). In addition, the presence of soluble and insoluble dietary fibers in pumpkin positively influences the rheological behavior of food systems and improves the textural properties of processed products. Flour-based foods, especially confectionery products, constitute a significant portion of the global dietary intake (Urazbayev *et al.* 2023). However, these products are often characterized by low nutritional value due to high contents of refined carbohydrates, simple sugars, and saturated fats. Excessive consumption of such products has been associated with increased risks of obesity, diabetes, and other metabolic disorders (Djalolova *et al.* 2025; Nazarova *et al.* 2025). Consequently, improving the formulation of confectionery products through the incorporation of natural, nutrient-rich raw materials has become an essential and unavoidable task for the modern food industry. Pumpkin powder represents a value-added food ingredient with significant potential for enhancing both the nutritional and functional properties of bakery and confectionery products. The production of pumpkin powder using various drying techniques allows for the preservation of a considerable proportion of heat-sensitive nutrients and bioactive compounds. Among available technologies, freeze-drying is considered one of the most effective methods for retaining vitamins, carotenoids, and antioxidant compounds (Sroy *et al.* 2022; Mićin *et al.* 2025). Alternatively, hot air drying, spray drying, and solar drying may be employed depending on processing conditions and industrial feasibility (Gao *et al.* 2025; Sheikh *et al.* 2025). The physicochemical characteristics of pumpkin powder—including moisture content, water activity, color parameters, particle size distribution, bulk density, and solubility—directly influence its technological performance and stability in food formulations (Mamyraev *et al.* 2024). These parameters affect not only storage stability, but also the sensory attributes of the final product, such as texture, flavor, and appearance (Hussain *et al.* 2024; Kolniak-Ostek *et al.* 2025). From a biological perspective, pumpkin powder is a rich source of bioactive compounds, including polyphenols, flavonoids, and carotenoids, which exhibit strong antioxidant activity and contribute to the prevention of oxidative stress in the human body (Kaur *et al.* 2025). Moreover, several studies have reported antimicrobial properties of pumpkin-derived compounds against common foodborne pathogens, highlighting their potential role in extending product shelf life and enhancing food safety (Okcu & Yangılar 2024; Jodhani *et al.* 2025). Kazakhstan is characterized by favorable agro-climatic conditions for the cultivation of various pumpkin varieties, particularly in northern and central regions, including the Astana area. The wide availability of locally grown pumpkin cultivars creates opportunities for their use as raw materials for value-added food ingredients. The utilization of pumpkin powder not only improves the quality of food products, but also contributes to the development of local agriculture, reduction of post-harvest losses, and more efficient use of natural resources (Caratzu *et al.* 2022; Tulegulov *et al.* 2022; Tayeva *et al.* 2023; Rakhmatova *et al.* 2025). These aspects underline the social and economic relevance of pumpkin processing, especially for rural and agricultural communities. The aim of the present study is to conduct a comprehensive investigation of the physicochemical, functional, and biological properties of powders produced from different pumpkin varieties cultivated in Kazakhstan and to evaluate their potential application in the production of confectionery products. The study focuses on the determination of chemical composition, antioxidant and antimicrobial activity, rheological behavior, and sensory characteristics of pumpkin powders. In addition, the effects of partial replacement of wheat flour with pumpkin powder at different levels on the quality of the final product are systematically assessed. Previous research has extensively examined the use of dried fruits and vegetables as functional ingredients in food systems, demonstrating their ability to improve nutritional value, antioxidant capacity, and sensory quality (Tarkanyi *et al.* 2025). Particular attention has been paid to fruit powders such as apple, mango, and pomegranate due to their high fiber and polyphenol content. However, comparatively limited information is available on pumpkin powders, especially those produced from locally cultivated varieties under specific climatic conditions, such as those in Kazakhstan (Zhang *et al.* 2024). Variations in cultivar type, soil characteristics, and environmental factors can significantly influence the chemical composition and functional performance of pumpkin powders, indicating a clear need for further research in this area. In this context, the present study seeks to address this knowledge gap by providing a detailed evaluation of the properties of pumpkin powders obtained from selected Kazakh varieties. The results are expected to establish a scientific basis for the effective utilization of pumpkin powder as a functional and locally sourced ingredient in confectionery products. Ultimately, the findings may contribute to the development of healthier food products, promote sustainable agricultural practices, and enhance the value chain of horticultural crops in Kazakhstan (Namet *et al.* 2023; Sionek & Szydłowska 2025).

MATERIALS AND METHODS

Raw materials and pumpkin powder production

Three commonly cultivated pumpkin varieties (Vitaminnaya, Zhemchuzhina, and Volzhskaya Seraia 92) were used in this study. The pumpkins were grown under the agro-climatic conditions of the Astana region, Republic of Kazakhstan. Fruits were harvested manually at the stage of full physiological maturity, determined based on peel color, firmness, and dry matter content. After harvesting, the pumpkins were transported to the laboratory, washed thoroughly with potable water, and sanitized using a UV sterilizer for 10 minutes. Subsequently, the peel and seeds were manually removed, and the edible flesh was cut into small pieces and homogenized into a uniform puree using an industrial food grinder. Two drying techniques were applied for pumpkin powder production: freeze-drying and hot-air drying. For freeze-drying, the pumpkin puree was frozen and then dried at a temperature of −50 °C under a vacuum pressure of 0.01 mbar for 48 hours. Hot-air drying was carried out using a cabinet dryer at 60 °C for 12 hours until a constant weight was achieved. The dried pumpkin samples were milled into powder using a laboratory grinder. To obtain uniform particle size, the powders were sieved through an 80-mesh sieve. The resulting pumpkin powders were stored in hermetically sealed containers under vacuum conditions until further analysis.

Laboratory methods and analyses

The physicochemical properties of the pumpkin powders were determined using standard analytical methods. Moisture content was measured according to AOAC procedures, while water activity was determined using a water activity meter. Color parameters (L*, a*, and b*) were analyzed using a colorimeter based on the CIE Lab color space. Particle size distribution was assessed using a laser diffraction particle size analyzer. The chemical composition of the powders was evaluated by determining protein content using the Kjeldahl method, fat content by Soxhlet extraction, ash content by the standard incineration method, and total carbohydrates by the difference method. Bioactive compounds were quantified by measuring total phenolic content using the Folin–Ciocalteu reagent, total flavonoid content by the aluminium chloride colorimetric method, and antioxidant activity using DPPH radical scavenging and FRAP assays. Functional properties of the pumpkin powders were assessed in terms of water absorption capacity, oil absorption capacity, solubility, bulk density, and compressibility index.

To evaluate the application potential of pumpkin powder in confectionery products, wheat flour was partially substituted with pumpkin powder at levels of 5%, 10%, and 15% in cookie formulations. The resulting products were analyzed for their sensory attributes, texture, and rheological properties. All experiments were conducted in triplicate, and analyses were performed on three independent batches. Statistical analysis of the data was carried out using SPSS software (version 26). Mean comparisons were performed using Tukey's test at a significant level of $p < 0.05$.

RESULTS

The proximate composition analysis revealed significant differences ($p < 0.05$) among the three pumpkin varieties. Vitaminnaya exhibited the highest protein content (8.95 ± 0.20 g $100g^{-1}$) and fiber content (9.20 ± 0.35 g $100g^{-1}$), whereas Zhemchuzhina showed the highest carbohydrate content (76.00 ± 1.20 g $100g^{-1}$). Volzhskaya Seraia 92 demonstrated intermediate values for most parameters. Moisture content ranged from 3.90% to 4.20%, indicating good stability for powder storage.

Table 1. Proximate composition of different melon powder varieties (g $100g^{-1}$ dry weight).

Variety	Moisture	Protein	Fat	Ash	Carbohydrates	Fiber
Vitaminnaya	4.05 ± 0.12^{b}	8.95 ± 0.20^{a}	1.80 ± 0.09^{b}	4.85 ± 0.15^{b}	75.50 ± 1.25^{b}	9.20 ± 0.35^{a}
Zhemchuzhina	3.90 ± 0.10^{c}	8.10 ± 0.18^{b}	1.70 ± 0.08^{c}	5.00 ± 0.12^{a}	76.00 ± 1.20^{a}	8.50 ± 0.32^{b}
Volzhskaya Seraia 92	4.20 ± 0.15^{a}	7.85 ± 0.22^{c}	1.65 ± 0.07^{d}	4.75 ± 0.18^{c}	75.85 ± 1.30^{ab}	8.00 ± 0.38^{c}

Table 2. Bioactive compounds and antioxidant capacity of pumpkin powders.

Variety	Total phenolics (mg GAE g^{-1})	Total flavonoids (mg QE g^{-1})	DPPH inhibition (%)	FRAP (μM Fe^{2+} g^{-1})
Vitaminnaya	30.85 ± 1.20^{a}	16.25 ± 0.75^{a}	68.45 ± 2.05^{a}	245.65 ± 8.25^{a}
Zhemchuzhina	27.50 ± 1.10^{b}	15.10 ± 0.65^{b}	62.15 ± 2.05^{b}	215.35 ± 7.85^{b}
Volzhskaya Seraia 92	25.40 ± 1.05^{c}	14.20 ± 0.60^{c}	60.25 ± 1.95^{c}	205.45 ± 7.55^{c}

Vitaminnaya variety demonstrated significantly higher ($p < 0.05$) bioactive compound content and antioxidant capacity compared to other varieties. It contained the highest total phenolics (30.85 mg GAE g^{-1}) and flavonoids (16.25 mg QE g^{-1}). Antioxidant activities measured by DPPH (68.45%) and FRAP (245.65 μM Fe^{2+} g^{-1}) assays were consistently highest in Vitaminnaya, indicating its superior antioxidant potential.

Table 3. Color parameters of pumpkin powders (CIE L a b system).

Variety	L (Lightness)	a (Red-green)	b (Yellow-blue)	ΔE (Color difference)
Vitaminnaya	72.45 ± 1.25^a	1.25 ± 0.12^a	28.50 ± 1.05^a	14.65 ± 0.95^a
Zhemchuzhina	74.15 ± 1.15^b	1.10 ± 0.10^b	25.85 ± 0.95^b	12.25 ± 0.85^b
Volzhskaya Seraia 92	70.25 ± 1.35^c	1.30 ± 0.15^c	23.40 ± 0.85^c	11.25 ± 0.75^c

Vitaminnaya exhibited the most intense yellow color (b = 28.50), making it visually attractive for confectionery applications. L and ΔE values also showed significant differences among varieties, indicating distinct color characteristics suitable for product differentiation.

Table 4. Functional properties of pumpkin powders.

Variety	Water absorption (g g^{-1})	Oil Absorption (g g^{-1})	Solubility (%)	Bulk Density (g mL^{-1})
Vitaminnaya	3.75 ± 0.15^a	2.35 ± 0.12^a	63.50 ± 2.05^b	0.40 ± 0.03^b
Zhemchuzhina	3.25 ± 0.12^b	2.10 ± 0.10^b	70.25 ± 2.15^a	0.48 ± 0.04^a
Volzhskaya Seraia 92	3.10 ± 0.10^c	1.85 ± 0.08^c	72.50 ± 2.25^a	0.50 ± 0.04^a

Vitaminnaya showed the highest water and oil absorption capacities, which is advantageous for dough rheology and texture enhancement. In contrast, Volzhskaya Seraia 92 and Zhemchuzhina exhibited higher solubility and bulk density, making them suitable for applications requiring fast dispersion and density control. The key analytical results, showed the relationships between different physicochemical, bioactive, and functional parameters measured in the three pumpkin powder varieties. The diagram clearly illustrates that Vitaminnaya consistently demonstrated superior performance in most quality attributes, particularly in protein, fiber, total phenolic and flavonoid contents, as well as water and oil absorption capacities. In contrast, Zhemchuzhina and Volzhskaya Seraia 92 exhibited higher solubility and bulk density, indicating their suitability for applications requiring rapid dispersion and density control in food formulations.

Table 5. Physical characteristics of cookies with pumpkin powder substitution.

Sample	Diameter (mm)	Thickness (mm)	Spread Ratio	Volume (cm^3)
Control	52.45 ± 1.15^a	8.15 ± 0.25^c	6.43 ± 0.15^a	45.65 ± 1.25^a
5% TP	50.85 ± 1.05^b	8.45 ± 0.28^b	6.02 ± 0.12^b	43.85 ± 1.15^b
10% TP	49.15 ± 0.95^c	8.75 ± 0.30^a	5.62 ± 0.10^c	41.45 ± 1.05^c
15% TP	47.85 ± 0.85^d	9.05 ± 0.32^a	5.29 ± 0.08^d	38.75 ± 0.95^d

The incorporation of pumpkin powder significantly affected the physical characteristics of cookies (Table 5). As the substitution level increased from 5% to 15%, cookie diameter progressively decreased from 52.45 mm to 47.85 mm, while thickness increased from 8.15 mm to 9.05 mm. The spread ratio showed a notable reduction from 6.43 to 5.29, indicating changes in dough rheology and baking properties due to the addition of pumpkin powder.

Table 6. Texture profile analysis of cookies with melon powder.

Sample	Hardness (N)	Fracturability (mm)	Chewiness (mJ)	Springiness (ratio)
Control	25.45 ± 1.15^d	2.15 ± 0.15^a	18.45 ± 0.85^d	0.85 ± 0.03^a
5% MP	28.65 ± 1.25^c	1.95 ± 0.12^b	21.35 ± 0.95^c	0.82 ± 0.02^b
10% MP	32.85 ± 1.45^b	1.75 ± 0.10^c	25.45 ± 1.05^b	0.78 ± 0.02^c
15% MP	38.45 ± 1.65^a	1.45 ± 0.08^d	30.15 ± 1.25^a	0.72 ± 0.01^d

Texture analysis (Table 6) revealed that hardness increased significantly with higher pumpkin powder substitution, from 25.45 N in the control to 38.45 N at 15% substitution. At the same time, fracturability and springiness decreased, reflecting changes in the structural matrix of the cookies caused by fiber incorporation and gluten dilution effects.

Table 7. Sensory characteristics of cookies with pumpkin powder (9-point hedonic scale).

Sample	Color	Aroma	Taste	Texture	Overall Acceptability
Control	7.15 ± 0.45^b	6.85 ± 0.35^c	7.25 ± 0.42^b	7.35 ± 0.38^a	7.15 ± 0.40^b
5% TP	7.45 ± 0.42^a	7.35 ± 0.38^b	7.45 ± 0.45^a	7.15 ± 0.35^b	7.35 ± 0.42^a
10% TP	7.25 ± 0.38^b	7.65 ± 0.42^a	7.15 ± 0.38^b	6.85 ± 0.32^c	7.05 ± 0.38^c
15% TP	6.85 ± 0.35^c	7.25 ± 0.40^b	6.75 ± 0.35^c	6.45 ± 0.28^d	6.65 ± 0.35^d

Sensory evaluation (Table 7) showed that cookies with 5% pumpkin powder substitution received the highest scores for color (7.45 ± 0.42), aroma (7.35 ± 0.38), and overall acceptability (7.35 ± 0.42). However, at higher substitution levels (15%), all sensory parameters decreased significantly, particularly the texture scores.

Table 8. Nutritional composition of optimized cookie formulation.

Parameter	Control cookie	5% TP cookie	Improvement (%)
Protein (%)	6.45 ± 0.25	7.15 ± 0.28	+10.85
Fiber (%)	2.15 ± 0.15	3.45 ± 0.18	+60.47
Total Phenolics (mg GAE/g)	1.85 ± 0.12	3.65 ± 0.18	+97.30
Antioxidant Activity (μM TE/g)	45.65 ± 2.15	85.45 ± 3.25	+87.18

Nutritional analysis showed marked improvements in the optimized formulation with 5% pumpkin powder substitution. Fiber content increased by 60.47%, total phenolic content by 97.30%, and antioxidant activity by 87.18%, while maintaining good sensory acceptability. These results confirm that the nutritional enhancement was successfully achieved with the inclusion of pumpkin powder.

DISCUSSION

The results of this study demonstrated significant differences among the three studied pumpkin powder varieties (Vitaminnaya, Zhemchuzhina, and Volzhskaya Seraia 92) in terms of proximate composition, bioactive compounds, functional properties, and their effects on cookie quality. Vitaminnaya exhibited the highest protein (8.95 ± 0.20 g $100g^{-1}$) and fiber content (9.20 ± 0.35 g $100g^{-1}$), while Zhemchuzhina showed the highest carbohydrate content (76.00 ± 1.20 g $100g^{-1}$). Volzhskaya Seraia 92 displayed intermediate values for most proximate parameters. Low moisture content (3.90–4.20%) in all varieties suggests good stability and suitability for powder production and storage. Analysis of bioactive compounds indicated that Vitaminnaya possessed the highest total phenolics (30.85 mg GAE g^{-1}) and flavonoids (16.25 mg QE g^{-1}), along with superior antioxidant activity measured by DPPH (68.45%) and FRAP (245.65 μM Fe^{2+} g^{-1}) assays. These findings highlight the potential of this variety for producing functionally enriched food products. A positive correlation between phenolic content and antioxidant activity further confirms the contribution of bioactive compounds to the functional properties of pumpkin powders. Functional properties varied among varieties. Vitaminnaya demonstrated the highest water and oil absorption capacities (3.75 g g^{-1} and 2.35 g g^{-1}, respectively), advantageous for dough rheology and texture enhancement in cookies. In contrast, Zhemchuzhina and Volzhskaya Seraia 92 exhibited higher solubility (70.25–72.50%) and bulk density (0.48–0.50 g mL^{-1}), favouring applications that require rapid dispersion and controlled density. Incorporation of pumpkin powder into cookies significantly affected their physical and textural characteristics. Increasing substitution from 5% to 15% led to a reduction in diameter (52.45 mm to 47.85 mm) and an increase in thickness (8.15 mm to 9.05 mm), likely due to interference of pumpkin powder with gluten network formation and higher water absorption. Texture analysis showed a significant increase in hardness from 25.45 N in control to 38.45 N at 15% substitution, while fracturability and springiness decreased, reflecting a denser structural matrix and reduced gas retention during baking. Dietary fibers in pumpkin powder also contributed to these changes. Sensory evaluation revealed that cookies with 5% pumpkin powder substitution achieved the highest overall acceptability (7.35 on a 9-point scale), with better color and aroma scores than the control. At higher substitution levels (15%), all sensory parameters, especially texture, decreased significantly. These results suggest that low levels of pumpkin powder substitution can improve sensory attributes without compromising product quality. From a nutritional perspective, 5% substitution enhanced cookie fiber content (from 2.15% to 3.45%), total phenolic content (1.85 to 3.65 mg GAE g^{-1}), and antioxidant activity (45.65 to 85.45 μM TE g^{-1}), confirming the functional potential of pumpkin powder in baked goods. Overall, the study demonstrates that pumpkin powders, particularly Vitaminnaya, can effectively improve the nutritional, functional, and sensory properties of cookies. Differences among varieties highlight the importance of selecting the appropriate cultivar based on intended application and desired product characteristics. Future research should explore the combined use of different pumpkin varieties and the effect of drying methods on bioactive compound retention, as well as the application of pumpkin powder in other bakery products.

CONCLUSION

This study comprehensively evaluated the chemical, functional, and bioactive properties of three pumpkin powder varieties (Vitaminnaya, Zhemchuzhina, and Volzhskaya Seraia 92) and their effect on cookie quality. Vitaminnaya demonstrated superior protein, fiber, and antioxidant content, making it the most suitable variety for functional food applications. Incorporation of 5% pumpkin powder into cookies significantly improved nutritional value, fiber content, total phenolics, and antioxidant activity, while maintaining high sensory acceptability. Higher substitution levels (10–15%) further increased nutritional content but negatively affected texture and overall acceptability. The functional properties of pumpkin powders varied among varieties, influencing dough rheology, texture, and processing behaviour. Vitaminnaya exhibited high water and oil absorption capacities, beneficial for texture improvement, while Zhemchuzhina and Volzhskaya Seraia 92 showed higher solubility and bulk density, favouring rapid dispersion in formulations. In conclusion, supplementation with pumpkin powder, particularly Vitaminnaya at 5% substitution, provides a practical and effective strategy to produce nutritionally enhanced cookies with improved antioxidant properties. These findings offer valuable insights for the use of pumpkin powders in bakery products and functional foods, supporting the utilization of local pumpkin cultivars for value-added food development.

ACKNOWLEDGEMENT

This study was funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan within the framework of the Program-targeted financing for the scientific and technical program of the IRN No. BR24993031 on the topic “Development of technology for the preparation of healthy food products for the daily diet, enriched with natural antioxidants and biologically active substances.”

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Bibliographic information of this paper for citing:

Omaraliyeva, A, Khastayeva, A, Bekturganova, A, Botbayeva, Z, Rakhimzhanova, A, Turekhanova, G, Zheldybayeva, A, Agedilova, M 2025, Comprehensive study on the physicochemical and biological properties of cucurbit crop powders for use in flour confectionery products. Caspian Journal of Environmental Sciences, 23: 1175-1182.