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Ecological determinants of bee pollen quality in Ukraine

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The article presents the results of monitoring the organoleptic and physicochemical indicators of bee-collected pollen depending on the natural and climatic conditions of Ukraine. The research material consisted of 126 samples of bee-collected pollen collected from regions representing Polissia, the Forest-Steppe, the Steppe, and the Ukrainian Carpathians. Quality assessment was carried out in accordance with the requirements of DSTU 3127–95, taking into account the provisions of the international standard ISO 24382:2023 and applying methods of variation statistics (all differences were considered statistically significant at $p<0.05$). It was established that 100 % of the examined samples complied with the regulatory requirements for organoleptic characteristics (external appearance, color, taste, specific odor, and consistency of granules with a mass of 5–20 mg).The moisture content of bee-collected pollen from all natural and climatic zones did not exceed the maximum permissible level of 10 %; however, the highest mean values were recorded in the Polissia (9.01 %) and Steppe (8.97 %) zones. In the Forest-Steppe and Carpathian zones, a lower mean moisture content was recorded – 8.52 % and 8.55 %, respectively. Analysis of active acidity revealed clear interzonal differences: the lowest pH values were characteristic of the Forest-Steppe zone (4.82), while in the Steppe zone, the indicator was 4.96. In the Polissia (5.08 %) and Carpathian (5.17) zones, the parameter approached the maximum permissible level (pH≤5.3), creating a potential risk of reduced microbiological stability in individual product batches. Overall across Ukraine, the mean active acidity value was 5.01, and 7–9 % of the examined samples failed to comply with the regulatory requirements for the pH parameter (having pH>5.3). The crude protein content depended significantly on the natural and climatic zone of pollen origin and was characterized by substantial inter- and intrazonal variability. The lowest mean protein values were established in the Polissia zone (16.4 %), and the highest – in the Forest-Steppe zone (26.8 %), reflecting the influence of the botanical composition of pollen, agroecological conditions, and the diversity of pollen resources. In the Steppe zone, the crude protein content was 19.3 %, and in the Carpathian zone – 23.1 %. On average across Ukraine, the crude protein content was 21.5 %, which corresponds to literature data, but a significant proportion of samples, especially from Polissia and the Steppe, did not reach the minimum regulatory values of DSTU. The obtained results confirm the appropriateness of a zonal approach to assessing the quality and nutritional value of bee-collected pollen and indicate the decisive role of technological factors of post-harvest processing in ensuring its compliance with standards. Comprehensive monitoring of physicochemical parameters combined with the harmonization of national requirements with international standards is a necessary condition for increasing the competitiveness of Ukrainian bee-collected pollen.

Keywords: bee-collected pollen, natural and climatic zones, moisture content, active acidity (pH), crude protein, organoleptic characteristics.

Екологічні детермінанти якості бджолиного обніжжя в Україні

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У статті наведено результати моніторингу органолептичних і фізико-хімічних показників бджолиного обніжжя залежно від природно-кліматичних умов України. Матеріалом дослідження слугували 126 проб бджолиного обніжжя, відібраних у регіонах, що репрезентують Полісся, Лісостеп, Степ та Українські Карпати. Оцінювання якості здійснювали відповідно до вимог ДСТУ 3127–95 із урахуванням положень міжнародного стандарту ISO 24382:2023 та застосуванням методів варіаційної статистики (усі відмінності вважали статистично значущими при $p<0,05$). Встановлено, що 100 % досліджених зразків відповідали нормативним вимогам за органолептичними показниками (зовнішній вигляд, колір, смак, специфічний запах та консистенція гранул масою 5–20 мг). Масова частка води у бджолиному обніжжі всіх природно-кліматичних зон не перевищувала гранично допустимого рівня у 10 %, проте найвищі середні значення зафіксовано у Поліській (9,01 %) та Степовій (8,97 %) зонах. У Лісостеповій та Карпатській зонах зафіксовано нижчий середній вміст вологи – 8,52 % та 8,55 % відповідно. Аналіз активної кислотності виявив чіткі міжзональні відмінності: найнижчі значення pH характерні для Лісостепової зони (4,82), тоді як у Степу показник становив 4,96. У Поліській (5,08) та Карпатській (5,17) зонах показник наближався до гранично допустимого рівня (pH≤5,3), формуючи потенційний ризик зниження мікробіологічної стабільності окремих партій продукції. У цілому по Україні середнє значення активної кислотності становило 5,01, а 7–9 % досліджених зразків не відповідали нормативним вимогам за показником pH (мали значення pH > 5,3). Масова частка сирого протеїну істотно залежала від природно-кліматичної зони походження обніжжя та характеризувалася значною між- і внутрішньозональною варіабельністю. Найнижчі середні значення протеїну встановлено у Поліській зоні (16,4 %), найвищі – у Лісостеповій (26,8 %), що відображає вплив ботанічного складу пилку, агроекологічних умов і різноманіття пилкових ресурсів. У Степовій зоні вміст сирого протеїну становив 19,3 %, а в Карпатській – 23,1 %. У середньому по Україні вміст сирого протеїну становив 21,5 %, що відповідає літературним даним, проте істотна частка зразків, особливо з Полісся та Степу, не досягала мінімальних нормативних значень ДСТУ. Отримані результати підтверджують доцільність зонального підходу до оцінювання якості та поживної цінності бджолиного обніжжя і свідчать про визначальну роль технологічних чинників післязбиральної обробки у забезпеченні його відповідності стандартам. Комплексний моніторинг фізико-хімічних показників у поєднанні з гармонізацією національних вимог із міжнародними стандартами є необхідною умовою підвищення конкурентоспроможності українського бджолиного обніжжя.

Ключові слова: бджолине обніжжя, природно-кліматичні зони, масова частка води, активна кислотність (pH), сирий протеїн, органолептичні показники.

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Introduction

Bee-collected pollen is one of the most valuable apicultural products and is widely used in human nutrition. Its high content of proteins, essential amino acids, lipids, vitamins, mineral elements, and biologically active compounds determines its significant functional potential and the growing demand in both domestic and international markets [1].

The regulatory framework for quality control of bee-collected pollen in Ukraine is based on the national standard DSTU 3127-95 "Bee pollen (flower pollen) and its mixtures. Technical specifications" [2], which establishes requirements for organoleptic, physicochemical, and microbiological parameters, as well as rules for sampling and control methods. In parallel, at the international level, ISO 24382:2023 **"**Bee pollen – Specifications" [3] has been introduced, setting unified approaches to assessing the quality and safety of bee-collected pollen, taking into account its natural variability and the requirements of international trade. Harmonization of national research with the provisions of international standards is a necessary prerequisite for ensuring the comparability of results and enhancing the competitiveness of products.

In the context of environmental safety, studies on the effects of pesticides on bees and apicultural products are particularly relevant. Omelchun et al. (2025) [4] analyzed the impact of pesticides on the mortality of honey bees (*Apis mellifera*) and their ability to persist for prolonged periods in apicultural products, particularly honey. The authors demonstrated that chronic exposure of bees to agrochemicals is systemic in nature and is associated both with reduced colony viability and with risks to the safety of products produced by bees.

An equally important factor is the availability and diversity of pollen resources for bees, which determines the stability of bee-collected pollen formation in terms of nutritional characteristics, including protein content, amino acid composition, lipid profile, and bioactive compounds [5, 6].

The nutritional and biological value of bee-collected pollen was emphasized in the study by Klym et al. (2023) [7], which substantiated the prospects of its use in animal husbandry. The authors focused on the high protein content and the presence of essential amino acids, fatty acids, vitamins, and microelements that determine the functional value of the product. It is also important that this value is largely determined by the botanical origin and harvesting conditions, and therefore requires clearly defined regulatory control criteria and unified assessment methods.

Fundamental approaches to the assessment of the nutritional value of bee-collected pollen are presented in the works of researchers [8, 9]. These studies systematized the understanding of pollen as the primary source of proteins, lipids, vitamins, and minerals required for brood development, emphasizing that the evaluation of pollen quality cannot be reduced to a single indicator. The authors [9] highlighted a key methodological issue: different analytical approaches to the determination of protein and lipid content may yield systematically divergent results, which complicates the comparability of data across studies. The unification of analytical approaches proposed by the researchers is therefore of particular importance for investigations of bee-collected pollen.

A separate research direction involves the use of morphological characteristics of bee-collected pollen to assess its authenticity and technological quality. Researchers [10] demonstrated that monofloral bee-collected pollen of *Brassica napus* L. is characterized by high morphological uniformity and stable morphometric parameters of pollen pellets, which can be used as an additional criterion for batch quality control. This approach is consistent with primary quality control practices, where organoleptic and morphological characteristics (pellet shape, uniformity, color) serve as the first indicators of technological stability and the absence of foreign impurities.

Modern tools for advanced quality and authenticity control of bee-collected pollen are summarized in the works of researchers [11–13].

Bee-collected pollen quality is largely determined by its botanical origin, which influences the morphological characteristics of pollen pellets, their physicochemical properties, and biochemical composition [14].

Researchers [15] substantiated the concept of the protein-to-lipid ratio in pollen as a key indicator of the nutritional value of floral resources for bees and an important factor shaping their foraging preferences. The study results indicate that the protein-to-lipid ratio is an informative parameter that is relatively stable with respect to pollen collection and sample preparation methods. The authors emphasize the necessity of using unified analytical protocols to ensure correct comparison of the nutritional value of pollen of different botanical origins.

In study [16], the technological and organizational features of bee-collected pollen production under the conditions of the Forest-Steppe zone of Ukraine are examined, which is directly related to the subject of the present article. The authors demonstrated that natural and climatic conditions, as well as the structure of melliferous and pollen-bearing flora, determine the intensity of pollen collection, its morphological characteristics, and potential nutritional value. The importance of pollen trap usage regimes and sampling periods for obtaining high-quality raw material without adverse effects on the condition of honey bee colonies was substantiated. The conclusions obtained provide a theoretical and methodological basis for further research into the quality indicators of bee-collected pollen depending on natural and climatic conditions, which is fully consistent with the aim and objectives of the present scientific study.

Conducted in-depth studies of bee pollen demonstrate a complex relationship between its morphological characteristics, the level of contamination, and biological value, as confirmed by the results of contemporary scientific research [17–20].

A key element in ensuring the quality of bee-collected pollen is the availability of clear regulatory requirements and standardized control methods. In national practice, the basic regulatory document is DSTU 3127-95 "Bee pollen (flower pollen) and its mixtures. Technical

specifications" [2], which defines terminology, classification, quality requirements, sampling rules, control methods, as well as conditions for packaging, labeling, transportation, and storage.

Importantly, DSTU has an applied character and is oriented toward product control on the domestic market; therefore, it provides detailed regulation of primary batch acceptance criteria, including appearance (granulated form), absence of spoilage signs, conformity of color to botanical origin, and a characteristic odor and taste without foreign off-flavors. Specific requirements are aimed at minimizing technological risks – primarily those related to moisture content and secondary rehydration – which determine the microbiological stability of the product during storage. At the international level, a unified framework for the assessment of bee-collected pollen quality is provided by ISO 24382:2023 "Bee pollen-Specifications" [3]. Unlike DSTU, which is historically oriented toward the domestic market and has a long tradition of application in Ukraine, ISO adopts a harmonized approach aimed at international trade. The standard defines terminology, scope of application, general requirements for quality and safety, as well as approaches to labeling, packaging, transportation, and storage of bee-collected pollen.

Thus, the literature analysis indicates that the formation of high-quality bee-collected pollen is determined by a complex of ecological, botanical, technological, and regulatory factors. Studies addressing the risks of pesticide exposure confirm the need to strengthen safety control, while research on the forage base and nutritional ecology of bees substantiates the variability of the nutritional composition of bee-collected pollen depending on its botanical origin. At the same time, the standards DSTU 3127-95 and ISO 24382:2023 establish a regulatory framework for the comparability of results and for ensuring the reproducibility of laboratory studies, which is critically important when assessing the nutritional value, safety, and authenticity of bee-collected pollen of different origins [2, 3].

The aim of the study

The purpose of the study is to monitor the quality indicators of bee-collected pollen depending on the natural and climatic conditions of Ukraine.

Materials and methods

The research material consisted of samples of bee-collected pollen collected from different regions of Ukraine representing the main natural and climatic zones – Polissia, the Forest-Steppe, the Steppe, and the Ukrainian Carpathians. Such spatial representativeness made it possible to account for the influence of environmental conditions, the floristic composition of melliferous vegetation, and regional beekeeping practices on the formation of quality characteristics of bee-collected pollen.

Sampling was carried out in accordance with the requirements of the current standard, which regulates the procedures for sample collection, preparation, and quality assessment of products. Bee-collected pollen samples were obtained during specialized beekeeping events where products from different regions of Ukraine were represented, ensuring the representativeness of the sample set and the diversity of botanical origins of the samples.

Prior to laboratory analyses, all samples underwent preliminary visual inspection and sorting in order to detect mechanical impurities and assess the integrity of pollen pellets. Sample storage was carried out in hermetically sealed containers under conditions that prevented secondary moisture uptake, the development of microbiological processes, and deterioration of the organoleptic properties of the product.

Organoleptic analyses were carried out in accordance with the requirements of the standard. During the assessment, the external appearance and consistency of pollen pellets, uniformity and color characteristics, intensity and specificity of odor, taste properties, as well as the presence of damage by harmful insects and signs of fermentation were evaluated. Organoleptic assessment served as the primary stage of quality control and as the basis for subsequent physicochemical analyses.

Physicochemical parameters were determined in accordance with the methods regulated by the standard. The analyzed parameters included moisture content, which characterizes product stability and storage capacity; the pH of a 2 % aqueous solution, reflecting the acidity of bee-collected pollen; and crude protein content, which is one of the main indicators of the nutritional value of bee-collected pollen.

The combined application of organoleptic and physicochemical research methods ensured an objective assessment of the quality of bee-collected pollen, taking into account the natural and climatic characteristics of its origin. Statistical processing of the experimental data was performed using methods of variation statistics. Differences were considered statistically significant at a significance level of $p < 0.05$. Data processing was carried out using standard statistical analysis software.

Results and discussion

Organoleptic evaluation of bee-collected pollen included the assessment of appearance, consistency, color, odor, and taste. A total of 126 samples of bee-collected pollen were analyzed. According to the results of organoleptic assessment, all examined samples complied with the regulatory requirements of the standard.

The pollen was characterized by pellets of irregular shape with a mass of 5–20 mg and a granular, friable consistency; the pollen granules were firm and did not crumble when pressed between the fingers. Color varied over a wide range, which was determined by the botanical origin of the pollen. The odor was specific, pleasant, and characteristic of bee-collected pollen, without foreign impurities. The taste was typical and pleasant, predominantly sweet, sometimes with slight bitterness or acidity.

During the analyses, no signs of damage by harmful insects, foreign odors typical of spoiled protein products, manifestations of fermentation, or the presence of

mechanical impurities were detected. Thus, the organoleptic parameters of the examined bee-collected pollen samples met the requirements of the standard, indicating an appropriate level of product quality.

Figure 1 presents the results of the analysis of moisture content in bee-collected pollen depending on the natural and climatic zone of Ukraine, showing the mean values of the parameter and the standard error of the mean. The maximum permissible moisture content (10 %), established by the requirements of the current national standard, was used as a regulatory reference and is indicated by a dashed horizontal line.

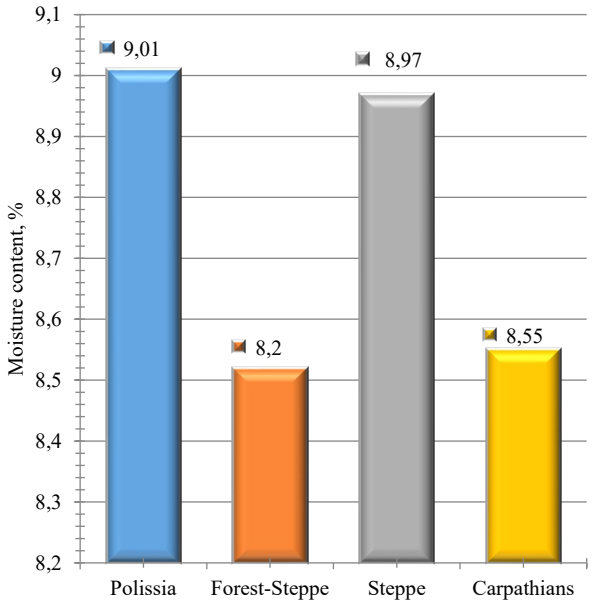

Fig. 1. Moisture content of bee-collected pollen by natural and climatic zones of Ukraine

The obtained results indicate that the mean moisture content of bee-collected pollen in all natural and climatic zones remained within the regulatory limits. In the Polissia zone, the mean moisture content was 9.01±0.22 %, which was the highest value among the studied zones and may be attributed to higher climatic humidity and more challenging post-harvest drying conditions. In the Steppe zone, the mean moisture content was 8.97±0.23 %, which also approaches the maximum permissible value of the standard and indicates the need for particular attention to technological drying regimes of bee-collected pollen.

For the Forest-Steppe zone, a lower mean moisture content was recorded – 8.52±0.16 %, indicating more stable conditions of product formation and post-harvest processing. In the Carpathian zone, the mean moisture content of bee-collected pollen was 8.55±0.19 %, which corresponds to the national average values despite the higher air humidity typical of mountainous areas.

Overall, the obtained data confirm that the moisture content of bee-collected pollen is determined not only by natural and climatic conditions but primarily by compliance with production technology, in particular timely harvesting, drying efficiency, and storage conditions. Adherence to these requirements ensures the stability of the moisture parameter and the compliance of bee-collected pollen with the requirements of the current standard, which is an important factor for its quality and safety.

Analysis of the mean values of active acidity (pH) of bee-collected pollen, taking into account statistical error, revealed interzonal differences that are both statistically and practically significant. Overall, the majority of the analyzed samples complied with the regulatory requirements (pH ≤ 5.3).

In the Forest-Steppe natural and climatic zone, the lowest mean values of active acidity were recorded, amounting to 4.82±0.04. The small magnitude of the error indicates high homogeneity of the analyzed samples and stability of technological approaches to post-harvest processing of bee-collected pollen. Within this zone, all examined samples complied with the regulatory requirements for pH.

In the Steppe natural and climatic zone, the mean pH value was 4.96±0.06. Compared with the Forest-Steppe zone, greater variability of values was observed, which may be attributed to the influence of elevated air temperatures during pollen harvesting and uneven drying processes. Nevertheless, the vast majority of samples remained within the permissible regulatory range (pH ≤ 5.3).

The Polissia natural and climatic zone was characterized by higher mean values of active acidity – 5.08±0.07. The mean pH values in this zone approached the maximum permissible level, and the magnitude of the error indicated the presence of a proportion of samples with a tendency to exceed this threshold. This feature is likely associated with higher air humidity and more challenging conditions for drying and storage of bee-collected pollen.

The highest mean pH values were recorded in the Carpathian natural and climatic zone – 5.17±0.14. A substantial proportion of samples in this zone exhibited values close to the maximum regulatory pH level of 5.3, indicating an increased risk of reduced microbiological stability of the product. The combination of high air humidity and a prolonged post-harvest stabilization period creates conditions conducive to pH elevation, even when basic technological requirements are observed.

Overall across Ukraine, the mean pH value of bee-collected pollen was 5.01±0.19. It was established that approximately 7–9 % of the analyzed samples did not comply with the regulatory requirements for active acidity (pH > 5.3). These samples constituted a group of increased microbiological risk, since at such pH values favorable conditions are created for the development of acid-tolerant and putrefactive microflora.

The obtained results indicate that the interzonal differences in active acidity are statistically and technologically substantiated; however, the decisive factor in the formation of elevated pH values remains compliance with drying regimes, the duration of post-harvest stabilization, and storage conditions rather than the region of origin of bee-collected pollen alone. This confirms the appropriateness of using pH as a threshold criterion for quality control of bee-collected pollen.

Crude protein content is one of the key indicators of the nutritional value of bee-collected pollen, reflecting the botanical origin of pollen, agroecological conditions of the area, and soil status. Analysis of the mean crude protein values, taking into account the standard error of the mean, revealed interzonal differences as well as substantial intrazonal variability of this parameter.

In the Polissia natural and climatic zone, the mean crude protein content was 16.4±3.8 %, indicating pronounced intrazonal variability. A substantial proportion of samples were characterized by reduced protein content that did not reach the regulatory minimum values, whereas individual samples met the minimum requirements or only slightly exceeded them. Such variability is consistent with literature data and is обусловлена acidic, low-fertility soils of Polissia, limited species diversity of high-protein pollen sources, and the dominance of forest and wetland phytocenoses.

In the Steppe natural and climatic zone, the mean crude protein content was moderately higher, amounting to 19.3±4.2 %, and this zone exhibited one of the largest standard errors. This indicates substantial fluctuations in the parameter – from samples with low protein content to those approaching the upper regulatory limits. Such instability is typical of steppe regions and is associated with arid conditions, pronounced seasonality of pollen production, monocultural farming systems, and the predominance of certain entomophilous agricultural crops.

In the Carpathian natural and climatic zone, the mean crude protein content was 23.1±4.0 %. Elevated mean values were combined with a very wide range of variation, which is typical of mountainous ecosystems. The high protein value of certain samples is explained by rich floristic diversity, a substantial proportion of wild-growing high-protein nectar- and pollen-bearing plants, as well as minimal anthropogenic pressure.

The highest mean crude protein values were recorded in the Forest-Steppe natural and climatic zone – 26.8±3.1 %. Even in the presence of some variability, the majority of samples from this zone clearly exceeded the minimum regulatory requirements. The difference between the Forest-Steppe and Polissia zones exceeded 10 %, which convincingly indicates the decisive influence of soil and climatic conditions, agrofloristic structure, and the diversity of pollen resources on the formation of the protein composition of bee-collected pollen.

Figure 2 presents the crude protein content of bee-collected pollen depending on the natural and climatic zone of Ukraine. The obtained data indicate an increase in crude protein content from the Polissia to the Forest-Steppe zone, as well as the presence of substantial inter- and intrazonal variability of this parameter.

Overall across Ukraine, the mean crude protein content of bee-collected pollen was 21.5±4.5 %, which corresponds to literature data on the average nutritional value of this product but at the same time highlights its high chemical heterogeneity. Analysis of compliance with regulatory requirements showed that a substantial proportion of samples, particularly from the Polissia and Steppe zones, did not meet the requirements of the current DSTU standard. The obtained results confirm that the crude protein content of bee-collected pollen largely depends on the natural and climatic zone, the botanical origin of pollen, and agroecological conditions, which substantiates the appropriateness of a zonal approach to product quality assessment and the interpretation of chemical analysis results.

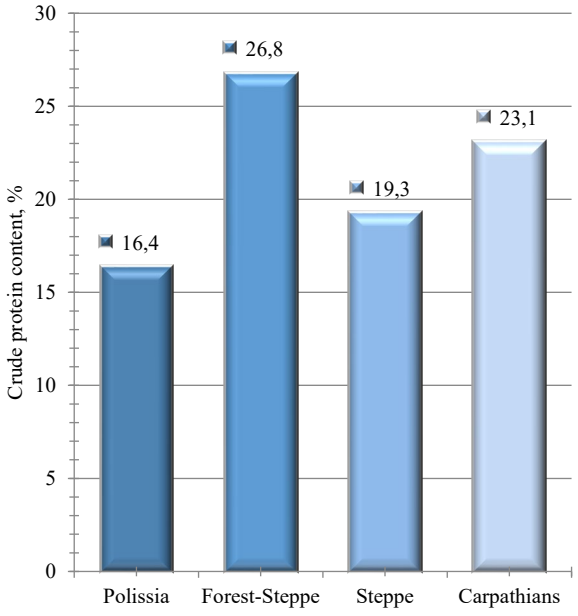

Fig. 2. Crude protein content (%) of bee-collected pollen depending on the natural and climatic zone of Ukraine

Conclusions

All 126 examined samples of bee-collected pollen complied with the requirements of DSTU 3127–95 for organoleptic characteristics, and the moisture content in all zones remained within the regulatory limit (≤ 10 %), though the highest values were characteristic of the Polissia (9.01 %) and Steppe (8.97 %) zones compared to the lower levels in the Forest-Steppe (8.52 %) and Carpathian (8.55 %) zones. The active acidity (pH) indicator exhibited statistically significant interzonal differences ($p<0.05$), where values closest to the maximum threshold of 5.3 were recorded in the Carpathian (5.17) and Polissia (5.08) zones, increasing the risk of microbiological instability, while the lowest pH was observed in the Forest-Steppe zone (4.82); overall across Ukraine, the mean pH was 5.01, with 7–9 % of samples failing to comply with the standard (pH>5.3). The crude protein content depended significantly on natural and climatic conditions and botanical origin, averaging 21.5 % nationwide, with the highest values observed in the Forest-Steppe zone (26.8 %) and the lowest in the Polissia zone (16.4 %), followed by the Steppe (19.3 %) and Carpathian (23.1 %) zones, while a substantial proportion of samples from Polissia and the Steppe did not meet the minimum regulatory requirements. The obtained results confirm the appropriateness of a zonal approach to assessing the quality and nutritional value of bee-collected pollen, as well as the necessity of comprehensive control of physicochemical parameters in accordance with current standards.

Prospects for further research. Further scientific research will be focused on an in-depth study of the relationships between natural and climatic conditions, the botanical origin of pollen, and the formation of physicochemical and biological quality indicators of bee pollen. It is promising to expand the range of studied parameters by determining microbiological safety indicators, antioxidant activity, the content of biologically active compounds, as well as the amino acid and mineral composition depending on the zone of origin.

DECLARATIONS

Ethical Statement

The authors declare that the sampling and analysis of bee-collected pollen samples were conducted in accordance with international ethical norms and veterinary guidelines. Since this study was based on the analysis of finished apiary products and did not involve experiments or harm to honeybee (*Apis mellifera*) colonies, formal institutional bioethics committee approval was not required.

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Conflict of interest

The authors state that there is no conflict of interest.

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Declaration of AI and AI-assisted technologies

The author declare that no artificial intelligence or AI-assisted technologies were used in the preparation of this manuscript.

References

1. Komosinska-Vassev, K., Olczyk, P., Kaźmierczak, J., Mencner, L., & Olczyk, K. (2015). Bee pollen: Chemical composition and therapeutic application. *Evidence-Based Complementary and Alternative Medicine*, 2015, 1–6. https://doi.org/10.1155/2015/297425
2. Derzhavnyi Standart Ukrainy. (1995). *Obnizhzhia bdzholyne (pylok kvitkovyi) i yoho sumishi. Tekhnichni umovy* [Pollen load and compositions (flower pollen). Specifications] (DSTU 3127–95). DP «UkrNDNTs». https://online.budstandart.com/ua/catalog/doc-page.html?id_doc=91436 [in Ukrainian]
3. International Organization for Standardization. (2023). *Bee pollen – Specifications* (ISO Standard No. 24382:2023). https://www.iso.org/standard/78544.html
4. Omelchun, Y. A., Shevchenko, L. V., Nikitina, L. M., Solomon, V. V., Mykhalska, V. M., Furman, S. V., Lisohurska, D. V., & Lisohurska, O. V. (2025). Pesticides as a cause of honeybee (Apis mellifera) mortality and their persistence in honey. *Biosystems Diversity*, 33 (1), e2501. https://doi.org/10.15421/012501
5. Campos, M. G. R., Bogdanov, S., de Almeida-Muradian, L. B., Szczesna, T., Mancebo, Y., Frigerio, C., & Ferreira, F. (2008). Pollen composition and standardisation of analytical methods. *Journal of Apicultural Research*, 47 (2), 154–161. https://doi.org/10.1080/00218839.2008.11101443
6. Thakur, M., & Nanda, V. (2020). Composition and functionality of bee pollen: A review. *Trends in Food Science & Technology*, 98, 82–106. https://doi.org/10.1016/j.tifs.2020.02.001
7. Klym, O., Vorobel, M., Kovalskyi, Y., Rivis, Y., Kaplinskyi, V., & Androshulik, R. (2023). Nutritional value and modern approaches to the usage of the bee pollen. *Foothill and Mountain Agriculture and Stockbreeding*, 73 (1), 134–149. https://doi.org/10.32636/01308521.2023-(73)-1-9
8. Nicolson, S. W. (2011). Bee food: the chemistry and nutritional value of nectar, pollen and mixtures of the two. *African Zoology*, 46 (2), 197–204. https://doi.org/10.1080/15627020.2011.11407495
9. Lau, P., Lesne, P., Grebenok, R. J., Rangel, J., & Behmer, S. T. (2022). Assessing pollen nutrient content: a unifying approach for the study of bee nutritional ecology. *Philosophical Transactions of the Royal Society B*, 377 (1853). https://doi.org/10.1098/rstb.2021.0510
10. Redina, N. M., Adamchuk, L. O., Nikolaieva, N. V., & Brindza, J. (2016). Morphological characteristics of bee pollen obtained from *Brassica napus* L. *Scientific Messenger of LNU of Veterinary Medicine and Biotechnologies*, 18 (2), 73–78. https://doi.org/10.15421/nvlvet6814
11. Prđun, S., Svečnjak, L., Valentić, M., Marijanović, Z., & Jerković, I. (2021). Characterization of bee pollen: Physico-chemical properties, headspace composition and FTIR spectral profiles. *Foods*, 10 (9), 2103. https://doi.org/10.3390/foods10092103
12. Pasarin, D., & Rovinaru, C. (2022). Chemical analysis and protein enzymatic hydrolysis of poly-floral bee pollen. *Emirates Journal of Food and Agriculture*, 35 (1), 59–69. https://doi.org/10.9755/ejfa.2023.v35.i1.2928
13. Giampieri, F., Quiles, J. L., Cianciosi, D., Forbes-Hernández, T. Y., Orantes-Bermejo, F. J., Alvarez-Suarez, J. M., & Battino, M. (2022). Bee products: An emblematic example of underutilized sources of bioactive compounds. *Journal of Agricultural and Food Chemistry*, 70 (23), 6833–6848. https://doi.org/10.1021/acs.jafc.1c05822
14. Castiglioni, S., Astolfi, P., Conti, C., Monaci, E., Stefano, M., & Carloni, P. (2019). Morphological, physicochemical and FTIR spectroscopic properties of bee pollen loads from different botanical origin. *Molecules*, 24 (21), 3974. https://doi.org/10.3390/molecules24213974
15. Vaudo, A. D., Tooker, J. F., Patch, H. M., Biddinger, D. J., Coccia, M., Crone, M. K., Fiely, M., Francis, J. S., Hines, H. M., Hodges, M., Jackson, S. W., Michez, D., Mu, J., Russo, L., Safari, M., Treanore, E. D., Vanderplanck, M., Yip, E., Leonard, A. S., & Grozinger, C. M. (2020). Pollen protein: Lipid macronutrient ratios may guide broad patterns of bee species floral preferences. *Insects*, 11 (2), 132. https://doi.org/10.3390/insects11020132
16. Sych, I. V., Losiev, O. M., & Holovetskyi, I. I. (2015). Osoblyvosti vyrobnytstva bdzholynoho obnizhzhia v umovakh Lisostepu Ukrainy [Features of bee-collected pollen production under the conditions of the Forest-Steppe of Ukraine]. *Naukovyi Visnyk Natsionalnoho Universytetu Bioresursiv i Pryrodokorystuvannia Ukrainy. Seriia: Tekhnolohiia Vyrobnytstva i Pererobky Produktsii Tvarynytstva*, 223, 184–189. [in Ukrainian]
17. Denisow, B., & Denisow-Pietrzyk, M. (2016). Biological and therapeutic properties of bee pollen: a review. *Journal of the Science of Food and Agriculture*, 96 (13), 4303–4309. https://doi.org/10.1002/jsfa.7729
18. Carrera, M. A., Miguel, E., Fernández-Alba, A. R., & Hernando, M. D. (2023). First survey on the presence of mycotoxins in commercial bee pollen sourced from 28 countries. *Food Control*, 152, 109816. https://doi.org/10.1016/j.foodcont.2023.109816

19. Phan, N. T., Joshi, N. K., Rajotte, E. G., Zhu, F., Peter, K. A., López-Uribe, M. M., & Biddinger, D. J. (2024). Systemic pesticides in a solitary bee pollen food store affect larval development and increase pupal mortality. *Science of the Total Environment*, 915, 170048. https://doi.org/10.1016/j.scitotenv.2024.170048
20. Adaškevičiūtė, V., Kaškonienė, V., Barčauskaitė, K., Kaškonas, P., & Maruška, A. (2022). The impact of fermentation on bee pollen polyphenolic compounds composition. *Antioxidants*, 11 (4), 645. https://doi.org/10.3390/antiox11040645

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