

**DOI: 10.37000/abbsl.2026.118.04**

**UDC 638.12:638.138:637.055**

**Svitlana Furman,**

PhD, Associate Professor

Polissia National University, Zhytomyr, Ukraine

ORCID ID: 0000-0002-1079-5797

e-mail: [svitlana.furman@ukr.net](mailto:svitlana.furman@ukr.net)

**Leonora Adamchuk,**

DSc, Associate Professor

Institute of Veterinary Medicine of the National Academy  
of Agrarian Sciences of Ukraine, Kyiv, Ukraine

ORCID ID: 0000-0003-2015-7956

e-mail: [leonora.adamchuk@gmail.com](mailto:leonora.adamchuk@gmail.com)

**Jan Brindza,**

PhD, Associate Professor

Slovak University of Agriculture in Nitra, Nitra, Slovakia

ORCID ID: 0000-0001-8388-8233

e-mail [brindza.jan@gmail.com](mailto:brindza.jan@gmail.com)

**Dina Lisohurska,**

PhD, Associate Professor

Polissia National University, Zhytomyr, Ukraine

ORCID ID: 0000-0002-2559-6520

e-mail: [lisogurskadina@gmail.com](mailto:lisogurskadina@gmail.com)

**Olha Lisohurska,**

PhD, Associate Professor

Polissia National University, Zhytomyr, Ukraine

ORCID ID: 0000-0002-3553-9351

e-mail: [lisogurskaya2016@gmail.com](mailto:lisogurskaya2016@gmail.com)

## **ANALYSIS OF SAFETY INDICATORS AND BIOLOGICAL VALUE OF BEE POLLEN**

### ***Abstract***

*The article presents a synthesis of current scientific data on the safety, chemical composition, and biological value of bee pollen as a promising raw material for the development of functional food products, biologically active supplements, and pharmaceutical preparations. The results of numerous studies confirm that bee pollen is a concentrated source of proteins, amino acids, carbohydrates, lipids, minerals, vitamins, phenolic compounds, and flavonoids, which determine its antioxidant, anti-inflammatory, and antimicrobial properties. It has been established that the botanical and*

*geographical origin, season of collection, and technological conditions of drying and storage significantly affect the biochemical profile of the product, while contamination with heavy metals, pesticides, mycotoxins, and microorganisms reduces its nutritional suitability and safety.*

*Scientific approaches to determining the botanical authenticity of bee pollen using melissopalynological, spectroscopic, chromatographic, and microbiological analyses have been summarized. Special attention is given to innovative methods for improving the bioavailability of nutrients, particularly fermentation, ultrasonic destruction of cell walls, and optimization of drying regimes, which make it possible to preserve biologically active components without losing the natural properties of the product. Toxicological and microbiological risks associated with storage conditions and environmental factors in collection regions are considered, confirming the need for systematic quality control in accordance with international HACCP requirements and the principles of the “One Health” concept.*

*The obtained results prove that bee pollen is a unique natural product capable of exerting a complex effect on the human body – from antioxidant protection to maintaining immune homeostasis. It can be effectively used in the production of dietary supplements, therapeutic and prophylactic preparations, and specialized food products. The prospects for further research involve creating a national database on the chemical profile and bioactivity of samples of various botanical origins, harmonizing quality control standards, and scientifically substantiating biotransformation technologies to enhance nutrient bioavailability. Comprehensive studies of bee pollen will contribute to increasing the competitiveness of Ukrainian beekeeping products in the international market and expanding their application in the fields of healthy nutrition, medicine, and biotechnology.*

***Keywords:** bee pollen, safety, quality, biological value, standardization, honeybee, functional food products.*

**Introduction.** Modern trends in food science and technology have led to a growing interest in natural products that combine high nutritional value with therapeutic and preventive properties. One such product is bee pollen, which belongs to the unique gifts of beekeeping and has a complex effect on the human body. Formed as a result of honeybees (*Apis mellifera* L.) collecting floral pollen, moistening it with salivary secretions, and shaping it into granules, bee pollen acquires special physicochemical properties. As a result, it not only preserves the naturally rich composition of pollen but also demonstrates increased nutrient bioavailability.

The chemical composition of bee pollen is extremely diverse and includes a significant number of compounds. Its basis consists of proteins and amino acids, among which are all those essential for the human body. In addition, the product contains a wide range of vitamins, mineral elements, polysaccharides, unsaturated fatty acids, phenolic compounds, flavonoids, and antioxidants. Due to this combination of bioactive ingredients, bee pollen has the ability to positively influence metabolism, the immune system, and the body's antioxidant status, as well as to contribute to the prevention of chronic diseases associated with the effects of free radicals.

Particular interest is drawn to the study of the therapeutic and preventive potential of bee pollen. The results of numerous studies indicate that it exhibits immunostimulating, anti-inflammatory, antioxidant, antibacterial, and hepatoprotective properties. The use of this product is recommended in dietary nutrition, restorative medicine, gerontology, and sports nutrition. In addition, bee pollen is considered a promising raw material for the development of new types of functional food products and biologically active supplements.

At the same time, ensuring the safety and quality of bee pollen remains a pressing issue. Its quality is significantly influenced by the botanical origin of the pollen, the region and conditions of collection, as well as harvesting and storage technologies. In view of current environmental challenges, the risks of contamination with heavy metals, pesticides, mycotoxins, and other xenobiotics pose a particular threat. It is also necessary to consider the possibility of microbiological contamination that may occur during the collection or storage stages of the product. These factors reduce food safety and may pose a potential risk to consumer health.

An important component of bee pollen research is its melissopalynological analysis, which makes it possible to determine the botanical origin of the pollen and to assess the specificity of its biological activity depending on the plant source. The use of modern methods of analytical chemistry, microbiology, and toxicology provides the scientific basis for a comprehensive assessment of the safety and biological value of this product. This approach complies with international food safety standards and the “One Health” concept, which emphasizes the interconnection between the health of humans, animals, and the environment.

Thus, the study of the safety and biological value of bee pollen is a relevant and multifaceted task that integrates aspects of food science, medicine, toxicology, and ecology. The scientific justification of the product’s nutritional suitability, the identification of potential risks, and the confirmation of its therapeutic and preventive potential form the basis for the broad use of bee pollen in healthy nutrition systems and preventive medicine.

The aim is to analyze scientific sources concerning the safety of bee pollen, to identify the factors influencing its quality, and to assess its biological value as a promising raw material for the development of innovative technologies for functional food products.

Analysis of recent studies and publications. In the current context of market globalization and the expansion of bee product exports, the issue of standardizing the quality and safety of bee pollen has become particularly important. The growing demand for natural ingredients with high biological activity requires the implementation of innovative quality control technologies, as well as the establishment of unified regulatory approaches to the evaluation of this product at the international level. This opens up broad prospects for the development of the beekeeping industry and for its deeper integration into the global system of functional food production.

Researchers have found that monofloral bee pollen collected during the flowering of *Acer* spp. is characterized by a high level of homogeneity of pollen pellets, a regular morphological shape, and a dense structure that ensures the stability of the product’s physicochemical parameters. The protein content in such pollen is on average 8% lower than in polyfloral pollen; however, it contains higher concentrations of polyphenols, flavonoids, and phenolic acids, which determine its stronger antioxidant activity. No deviations from the standards were detected according to microbiological, toxicological, and radiological criteria. Therefore, *Acer* spp. monofloral pollen meets DSTU requirements, possesses high biological and functional value, and can be used

as a raw material for the production of food supplements and pharmaceutical preparations [1].

In the authors' previous studies, similar patterns were observed regarding the quality and safety of *Acer* spp. bee pollen. Its high uniformity and stability of sanitary and hygienic parameters were confirmed. Although the protein level is somewhat lower compared to polyfloral samples, the increased content of phenolic compounds and antioxidants indicates its significant biofunctional potential and the feasibility of its use in the production of therapeutic and preventive products [2].

A comprehensive analysis of the accumulation of heavy metals in bee pollen collected from various natural zones of the Carpathian region was conducted. Significant variability in the content of lead, cadmium, copper, and zinc was revealed, which is determined by geographical and climatic factors. The highest concentrations of these elements were recorded near industrial facilities and transport routes, while in mountainous areas the values were close to the natural background. It was proven that bee pollen can serve as an effective bioindicator of environmental conditions, as it accumulates information about the level of ecological safety within the bees' foraging area. The practical significance of these findings lies in the use of the obtained data for creating environmental monitoring maps, identifying risk zones, and providing recommendations for the safe placement of apiaries [3].

Further studies were aimed at examining the relationship between the composition of bee pollen – particularly the content of heavy metals and fatty acids – and the reproductive capacity of queen bees. It was found that an increased concentration of toxic elements negatively affects physiological processes related to oogenesis, while a balanced fatty acid profile contributes to maintaining the reproductive function of queens. This confirms the relevance of a comprehensive approach to assessing pollen quality, which should include simultaneous monitoring of microbiological, toxicological, and lipid parameters. The authors emphasize the need to develop an environmental monitoring system for apiaries located in regions with intensive anthropogenic load [4].

Bee pollen is considered a promising functional product due to its combination of high nutritional value and bioactive properties. It has been established that bee pollen contains complete proteins, essential amino acids, carbohydrates, lipids, a wide range of vitamins and minerals, as well as phenolic compounds and flavonoids that determine its antioxidant, anti-inflammatory, immunomodulatory, and antimicrobial effects. The obtained results confirm the need for further standardization of this product and for the scientific substantiation of its therapeutic effectiveness [5].

A comprehensive characterization of the physicochemical properties of bee pollen reflecting its botanical origin was carried out. The combination of classical parameters (moisture, ash content, protein, fat, and sugar levels) with modern analytical technologies made it possible to establish objective criteria for the standardization and authentication of the product. The study's conclusions emphasize the importance of integrating spectroscopic and chromatographic methods into the

quality control of beekeeping products, ensuring greater analytical accuracy and reliability of the results [6].

The nutritional potential of bee pollen and bee bread was investigated, with emphasis on the bioavailability of their macronutrients. The use of an *in vitro* gastrointestinal model made it possible to assess the degree of protein, fat, and carbohydrate digestion. It was shown that enzymatic treatment increases nutrient availability, while bee bread, due to natural fermentation in the hive, exhibits better digestibility. The obtained data confirm the high nutritional value of both products and substantiate their use as sources of functional ingredients in the food industry [7].

A detailed characterization of the chemical composition of bee pollen was presented, highlighting a wide range of biologically active compounds – from proteins and fatty acids to polyphenols and flavonoids. The antioxidant, anti-inflammatory, and antimicrobial activity of the extracts indicates the potential of bee pollen as a natural source of antioxidants and functional components for food and pharmaceutical products. At the same time, it was found that the level of bioactivity varies depending on the botanical origin and geographical collection conditions, which necessitates further harmonization of approaches to assessing the quality and safety of this product [8].

It has been proven that bee pollen possesses pronounced antioxidant properties due to its high content of polyphenols and flavonoids. Chemical analysis confirmed the presence of biologically active compounds responsible for the product's ability to neutralize free radicals. In addition, the effect of bee pollen extracts on the growth of probiotic and pathogenic microorganisms was studied: a stimulating effect on certain probiotic strains and inhibition of some pathogens were observed. The obtained results confirm the significant potential of bee pollen as a natural antioxidant and as a functional ingredient in food and pharmaceutical products, combining nutritional and probiotic value with properties that counteract pathogenic microflora [9].

It was determined that drying methods significantly affect the chemical composition and aromatic profile of bee pollen. The authors compared different drying technologies, including hot-air drying, lyophilization, and other methods, and revealed substantial differences in the preservation of proteins, carbohydrates, lipids, and volatile components. It was found that high temperatures cause the loss of thermolabile substances (particularly vitamins and phenolic compounds) and alter the profile of volatile compounds responsible for aroma. Lyophilization proved to be the most gentle method, ensuring the preservation of both the nutritional and sensory value of the product. The obtained results indicate that the proper choice of drying technology is critically important for maintaining the nutritional and biological value of bee pollen, as well as for ensuring its stability and authenticity during further use in food technologies and pharmaceuticals [10].

Based on the conducted studies, it was established that fermented bee pollen, in terms of its chemical composition and biological activity, can be comparable to natural bee bread. The authors examined the changes occurring during the controlled fermentation of bee pollen and compared the results with the parameters of natural bee

bread. It was found that the fermentation process increases the content of free amino acids, simple sugars, phenolic compounds, and flavonoids, which directly enhance the antioxidant activity of the product. At the same time, the bioavailability of nutrients in fermented pollen improves, making it more digestible for the body. The study showed that although natural bee bread exhibits higher biological activity due to complex processes in the beehive, laboratory-fermented pollen demonstrates similar properties and may become a promising alternative in the food and pharmaceutical industries. This approach makes it possible to obtain a product with controlled characteristics, which is important for standardization and commercial use [11].

Bee pollen can be regarded as a functional food product with pronounced therapeutic properties. The authors systematized data on its chemical composition, which includes proteins, essential amino acids, carbohydrates, unsaturated fatty acids, vitamins, minerals, and a wide range of biologically active compounds such as polyphenols, flavonoids, and carotenoids. These components determine its antioxidant, anti-inflammatory, antimicrobial, and immunomodulatory effects. It has been shown that regular consumption of bee pollen may contribute to strengthening the immune system and reducing the risk of cardiovascular and metabolic diseases. The product's potential as an adjunct in the prevention and treatment of chronic pathologies associated with inflammatory processes is particularly emphasized. The summarized research results indicate that bee pollen can be used as a functional component in dietary supplements and therapeutic-preventive preparations. At the same time, there is an emphasized need for further product standardization and for determining optimal doses to ensure its safe and effective application in human nutrition and medicine [12].

According to research [13], spectroscopic methods are an effective tool for distinguishing bee pollen based on its composition, color, and botanical origin. The study showed that the chemical profile, particularly the ratio of proteins, lipids, carbohydrates, and phenolic compounds, has clear correlations with the botanical origin of the pollen. The color of bee pollen, determined by the concentration of carotenoids and flavonoids, also demonstrated diagnostic significance in the classification of samples. The use of spectroscopic methods in combination with statistical models made it possible to achieve high accuracy in identifying the botanical origin of bee pollen. The obtained results confirm the prospects of introducing spectroscopic technologies into the quality control and authentication of beekeeping products. This opens up opportunities for rapid, non-destructive analysis of bee pollen without the need for labor-intensive classical melissopalynological methods.

It has been proven that bee pollen is a multicomponent product with high therapeutic potential. Current data on its chemical composition have been summarized, including proteins, essential amino acids, vitamins, minerals, flavonoids, and polyphenolic compounds. Particular attention is given to its antioxidant, anti-inflammatory, immunomodulatory, antimicrobial, and anticancer activity. The study emphasizes the importance of bee pollen as a promising raw material for the development of functional food products and biologically active supplements. The authors highlight the need for further standardization, investigation of bioavailability,

and determination of safe application doses, which are key prerequisites for the integration of this product into medical and pharmaceutical practice [14].

According to studies [15], bee pollen demonstrates significant antioxidant activity, which is determined by its high content of polyphenolic compounds and flavonoids. The analysis indicates that the product's antioxidant effectiveness depends on its botanical origin and collection conditions. The obtained data show that the concentration of biologically active compounds accounts for the variability of the product's antioxidant properties. The study results confirm that bee pollen can serve as a valuable ingredient for enhancing the body's antioxidant defense, making it attractive for use in food technologies, dietary supplements, and pharmaceutical products.

The carbohydrate composition of bee pollen also determines its functional properties and nutritional value. The authors summarized data on mono- and disaccharides, polysaccharides, and dietary fiber, which together form the product's energy potential. Special attention was given to the role of simple sugars (glucose, fructose, sucrose) that provide a readily available source of energy, as well as complex carbohydrates that affect the bioavailability of other nutrients and the functionality of the product within food systems. It was noted that the carbohydrate profile of bee pollen depends on its botanical origin and the environmental conditions of its formation. Carbohydrate components interact with proteins, phenolic compounds, and minerals, determining the antioxidant, prebiotic, and structural properties of the product. The authors emphasize that the carbohydrate fraction is largely responsible for the functionality of bee pollen as a food additive and its potential in the food industry and biotechnology [16].

The authors [17] systematically demonstrated that the nutritional and biochemical properties of bee pollen significantly depend on its botanical origin. The study emphasizes the necessity of considering botanical variability when standardizing the quality indicators and nutritional value of bee pollen.

The studies [18] systematized current data on the chemical profile of pollen (carbohydrates, proteins/amino acids, lipids, and phenolic compounds), analytical methodologies, and the variability factors determined by botanical and geographical origin, phenology, drying/storage, and processing. The data on antioxidant, antimicrobial, and immunomodulatory properties, safety aspects (contaminants, pesticides, heavy metals, allergens), and potential applications in functional food products, pharmaceuticals, and biomaterials were summarized.

The study [19] summarizes current understanding of the role of amino acids in shaping the nutritional value of pollen and maintaining the physiological functions of the honeybee. Essential and conditionally essential amino acids are discussed, along with their influence on larval growth and development, immune protection, and the synthesis of proteins and enzymes. Particular attention is given to the dependence of the amino acid composition on the botanical origin of pollen, as well as on seasonal, climatic, and technological factors related to collection and storage. Modern analytical methods for determining the amino acid profile are evaluated, and the need for standardization to enable accurate comparison of research results is emphasized. The

review demonstrates the critical importance of a high-quality amino acid composition of pollen for bee health and apiary productivity.

A comprehensive comparison of the physicochemical composition and functional properties of bee pollen collected from different geographical regions of Brazil was conducted. The authors analyzed the content of proteins, lipids, sugars, ash, moisture, and energy value, as well as determined the levels of phenolic compounds, flavonoids, and antioxidant activity. It was shown that the botanical and geographical origin significantly influence the qualitative parameters, particularly the concentration of macro- and microelements and the antioxidant potential. The results highlight the importance of regional specificity in evaluating the nutritional value of pollen and in developing quality standards [20].

The study [21] comprehensively evaluated the nutritional value of bee pollen based on its palynological composition, antioxidant and antimicrobial activity, as well as the content of macro- and microelements. The authors showed that the botanical origin determines the levels of phenolic compounds, flavonoids, and mineral elements, which directly affect the antioxidant and antimicrobial properties of the product. The research results emphasize the importance of combining melissopalynological analysis with biochemical and microbiological methods for a comprehensive assessment of the quality and nutritional value of bee pollen.

Seasonal variations in the chemical composition of bee pollen were analyzed. The authors determined the content of crude protein, lipids, sugars, ash, and moisture in samples collected throughout the year and demonstrated a significant dependence of these indicators on the season and plant diversity. The highest protein and fat values were recorded in spring, while the carbohydrate composition and ash content varied under the influence of climatic factors and the phenology of melliferous plants. The study emphasizes the importance of considering seasonal dynamics when assessing the nutritional value of pollen [22].

A unified approach to assessing the nutritional composition of pollen for studying the nutritional ecology of bees has been proposed. The authors substantiated a standardized methodology for determining key macronutrients and demonstrated how the ratio of these components affects the development, immunity, and reproductive performance of bees. Particular attention was given to integrating analytical measurements with ecological factors, which allows for a more accurate modeling of the relationship between available pollen resources and the nutritional needs of pollinators. The proposed concept ensures the comparability of results across different studies and may serve as a basis for optimizing the forage resources of bees [23].

The study [24] examined the chemical composition, antioxidant, and anticancer properties of bee pollen collected from various floral sources in Taiwan. The authors identified a wide range of phenolic compounds and flavonoids, determined the content of major macronutrients, and assessed antioxidant activity using several analytical methods. In addition, tests on cancer cell growth inhibition were conducted, revealing the potential of certain samples as promising sources of biologically active substances.

The results highlight the significant influence of botanical origin on the biochemical profile and biofunctional properties of bee pollen.

The physical and microbiological parameters of bee pollen were also characterized, and its antioxidant activity was evaluated. It was found that the botanical origin and drying method significantly affect the content of phenolic compounds, flavonoids, and overall antioxidant potential. The obtained results emphasize the necessity of controlling physical and microbiological parameters to ensure the stable quality and safety of bee pollen during storage and processing [25].

An amino acid analysis of *Apis andreniformis* honey and the corresponding bee pollen was conducted using chemometric methods. The content of essential and conditionally essential amino acids was determined, and their contribution to nutritional value and possible biological effects was elucidated. Statistical analysis made it possible to differentiate samples according to their botanical and geographical origin and to trace the relationship between the amino acid composition of pollen and honey. The study emphasizes the importance of the amino acid profile as a marker of botanical authenticity and an indicator of the nutritional value of bee products [26].

The effect of the fermentation process on the composition of polyphenolic compounds in bee pollen was investigated. The authors evaluated changes in the content of phenolic acids and flavonoids, as well as determined antioxidant activity after different stages of fermentation. It was found that controlled lactic acid fermentation enhances the bioavailability of certain polyphenols and can improve the antioxidant properties of the product. The results highlight the potential of fermentation as a technological approach to increasing the functional value of bee pollen [27].

A comprehensive comparison of bee pollen collected from different countries was carried out. The profiles of major amino acids, organic acids, sugars, phenolic compounds, and other metabolites were determined, enabling the identification of geographical and botanical differences in the product. The obtained results demonstrate the high efficiency of combining spectroscopic and chromatographic methods for authenticity control, nutritional value assessment, and detection of possible adulteration of bee products [28].

The study [29] presents modern approaches to determining the botanical origin of honey. The possibilities and limitations of the melissopalynological method are analyzed. The review emphasizes the need to standardize methods and create reference databases for quality control and authenticity verification of honey.

The studies [30] analyzed the quality of bee bread (perga) of different botanical origins and production technologies. Organoleptic characteristics (appearance, odor, taste, color, consistency) and physicochemical parameters (moisture, acidity, content of bee products, wax impurities), as well as the degree of sanitary-microbiological safety and flavonoid content, were evaluated. It was shown that the production technology has a significant impact: bee bread produced using artificial combs or collected manually demonstrates higher quality and fewer impurities. Botanical origin also influences the content of bioactive compounds and antioxidant activity. The work

highlights the need to apply standardized production technologies and clear botanical identification to ensure high-quality bee bread.

Methods for identifying bee products by their botanical and geographical origin have been improved through the morphological analysis of pollen grains. The technique of scanning electron microscopy was adapted for studying the pollen of entomophilous plants of Ukraine. The obtained results can be used to create a national database of pollen images [31].

The study [32] analyzed bee pollen samples from 28 countries for the presence of common mycotoxins. The ELISA method was used for the quantitative determination of mycotoxins. The study also included a risk assessment related to the consumption of one or more mycotoxins.

Researchers have presented a harmonized set of standard methods for studying bee pollen. The authors describe procedures for collection, storage, sample preparation, identification of botanical origin (palynology, microscopy), as well as measurement of key qualities: moisture content, chemical composition (proteins, lipids, carbohydrates, phenolic and flavonoid compounds), antioxidant activity, physical characteristics, and microbiological safety. The methodological guidelines include standardized analytical procedures with examples that can be applied in many countries to ensure comparability of results [33].

The chronic effects of pesticides on larval development and pupal survival in *Osmia cornifrons* were evaluated. It was found that in all cases, the consumption of contaminated pollen led to delayed development and reduced larval and adult mass; additionally, the fungicide caused abnormal defecation patterns and increased mortality at the pupal stage. The study emphasizes that even low and moderate levels of pesticides in pollen pose a significant risk to solitary bee species and should be considered in regulatory standards and pollinator protection strategies [34].

The effect of ultrasonic treatment aimed at disrupting the cell wall on the physicochemical properties of pollen protein isolates was studied. The researchers emphasize that optimizing the parameters of ultrasonic exposure makes it possible to intensify the extraction of biologically active substances without the use of aggressive reagents. Thus, the technology of ultrasonic cell wall disruption is considered a promising method for enhancing the nutritional and functional value of bee pollen, including its use in the production of protein isolates and specialized food ingredients [35].

The authors [36] used spectrophotometric and chromatographic methods combined with high-performance liquid chromatography and mass spectrometry, which enabled the identification of key phenolic compounds, particularly flavonoids, responsible for pronounced antioxidant activity. The results indicate the significant potential of bee pollen as a source of natural antioxidants and natural inhibitors of enzymatic browning, thereby expanding its applications in functional foods, cosmetology, and food technology. The study highlights the importance of the botanical origin of pollen as a factor determining the level of its biological activity.

At the same time, alongside the study of natural bioactive components of bee pollen, an important aspect of assessing the quality of bee products is the analysis of anthropogenic factors, particularly pesticide load, which can reduce the safety and biological value of the products. In the researchers' work, it is emphasized that the use of pesticides in agriculture remains one of the main factors contributing to the mortality of honey bees. The authors note that even at low concentrations, residues of chemical substances can persist in bee products for a long time, posing a potential threat to consumers and necessitating stricter control over the use of agrochemicals. The obtained results confirm the need to harmonize national safety standards for bee products with European requirements and to develop a monitoring system for pesticide residues in beekeeping products [37].

**Conclusions and prospects for further research.** The analysis of scientific sources has shown that bee pollen is a unique natural product of high biological value, combining the properties of both a food and a therapeutic-preventive agent. Owing to its complex composition, which includes proteins, amino acids, carbohydrates, lipids, vitamins, minerals, phenolic compounds, flavonoids, organic acids, and enzymes, this product exhibits a wide range of biological activities. Its scientifically proven properties determine its potential for use in the food, medical, and pharmaceutical sectors.

It has been proven that the chemical composition and biological activity of bee pollen depend significantly on its botanical and geographical origin, as well as on the conditions of collection, drying, storage, and technological processing. It was found that the levels of proteins, carbohydrates, and phenolic compounds determine not only the nutritional but also the antioxidant and prebiotic functionality of the product. At the same time, the need for systematic safety control has been identified, since contamination with heavy metals, pesticides, mycotoxins, or microorganisms can significantly limit its suitability for consumption.

The application of modern analytical control methods ensures a comprehensive assessment of the product's authenticity, nutritional value, and sanitary safety. Particular attention is drawn to innovative technological approaches for preserving bioactive components, such as fermentation, ultrasonic cell wall disruption, and controlled drying, which contribute to increasing the bioavailability of nutrients and the stability of the product.

Thus, the synthesis of current data confirms that bee pollen is a promising source of biologically active substances capable of playing an important role in shaping the concept of functional nutrition and human biosecurity. Its systematic study aligns with the priorities of sustainable development, the "One Health" concept, and the European Green Deal strategy.

Further research on bee pollen should focus on an in-depth study of its biochemical composition, structure, and functional activity, taking into account botanical and geographical differentiation. Particular attention should be given to developing a national database on the amino acid, phenolic, and mineral profiles of samples from various origins, which will enable the creation of a standardized system

for product identification and geographical labeling. An important direction is the improvement of biotechnological processing methods.

### **ACKNOWLEDGEMENTS**

The authors Dina Lisohurska (ID 52510347) and Svitlana Furman (ID 52510356) express their sincere gratitude to the International Visegrad Fund for the fellowships and research stays during which the results presented in this article were obtained. The author, Leonora Adamchuk, gratefully acknowledges that the results presented in this article were achieved during a research stay in Slovakia supported by the National Scholarship Programme of the Slovak Republic (NSP), ID 57381.

### **FUNDING**

The research was carried out with the financial support of the International Visegrad Fund, whose grants were awarded to Dina Lisohurska (grant ID 52510347) and Svitlana Furman (grant ID 52510356). Part of the research was funded by the National Scholarship Programme of the Slovak Republic (NSP), awarded to Leonora Adamchuk under application ID 57381.

### **References**

1. Adamchuk L., Sukhenko V. Monofloral bee pollen from *Acer* spp.: its quality and safety in nutrition /Applied scientific and technical research: materials of the 5th International scientific and practical conference (Ivano-Frankivsk, April 5–7, 2021). Ivano-Frankivsk: Kushnir H. M. Publisher, 2021. P. 259–260.
2. Adamchuk L. O., Sukhenko V. Yu. Safety and quality of monofloral bee pollen from *Acer* spp. /Proceedings of the conference dedicated to the 122nd anniversary of the National University of Life and Environmental Sciences of Ukraine. Kyiv: NUBiP of Ukraine, 2020. P. 20.
3. Peculiarities of accumulation of heavy metals in bee pollen (plant pollen) in different natural zones of the Carpathian region [Electronic resource] / Y. F. Ravis, I. I. Saranchuk, O. Ya. Klym, O. B. Dyachenko, O. I. Stadnytska, V. D. Fedak, O. O. Gopanenko /*Agricultural Science and Practice*. 2022. Issue 1, Part 1. P. 36–43. Access mode: ([http://nbuv.gov.ua/UJRN/agnipr\\_2022\\_1\\_1\\_8](http://nbuv.gov.ua/UJRN/agnipr_2022_1_1_8)).
4. Peculiarities of the influence of heavy metals and fatty acids of bee pollen on the reproductive capacity of queen bees [Electronic resource] / Y. F. Ravis, V. O. Postoienko, O. I. Stadnytska, I. I. Saranchuk, O. Ya. Klym, O. B. Dyachenko, V. D. Fedak, A. V. Shelevach, O. O. Gopanenko /*Agricultural Science and Practice*. 2023. Issue 2, Part 3. P. 24–33. Access mode: [[http://nbuv.gov.ua/UJRN/agnipr\\_2023\\_2\\_3\\_6](http://nbuv.gov.ua/UJRN/agnipr_2023_2_3_6)]([http://nbuv.gov.ua/UJRN/agnipr\\_2023\\_2\\_3\\_6](http://nbuv.gov.ua/UJRN/agnipr_2023_2_3_6)).
5. Alshallash K. S., Abolaban G., Elhamamsy S. M., Zaghlool A., Nasr A., Nagib A., Taha I. M. Bee pollen as a functional product – chemical constituents and nutritional properties / *Journal of Ecological Engineering*. 2023. Vol. 24, No. 2. P. 173–183. <https://doi.org/10.12911/22998993/156611>
6. Prđun S., Svečnjak L., Valentić M., Marijanović Z., Jerković I. Characterization of bee pollen: Physico-chemical properties, headspace composition and FTIR spectral

- profiles / *Foods*. 2021. Vol. 10, No. 9. P. 2103.  
<https://doi.org/10.3390/foods10092103>
7. Aylanc V., Falcao S. I., Vilas-Boas M. Bee pollen and bee bread nutritional potential: Chemical composition and macronutrient digestibility under in vitro gastrointestinal system / *Food Chemistry*. 2023. Vol. 413. P. 135597. DOI: <https://doi.org/10.1016/j.foodchem.2023.135597>
  8. Rodríguez-Pólit C., Gonzalez-Pastor R., Heredia-Moya J., Carrera-Pacheco S. E., Castillo-Solis F., Vallejo-Imbaquingo R., Guamán L. P. Chemical properties and biological activity of bee pollen / *Molecules*. 2023. Vol. 28, No. 23. P. 7768. DOI:(<https://doi.org/10.3390/molecules28237768>).
  9. Ilie C-I, Oprea E, Geana E-I, Spoiala A, Buleandra M, Gradisteanu Pircalabioru G, Badea IA, Ficai D, Andronescu E, Ficai A, et al. Bee Pollen Extracts: Chemical Composition, Antioxidant Properties, and Effect on the Growth of Selected Probiotic and Pathogenic Bacteria/*Antioxidants*. 2022; 11(5):959. <https://doi.org/10.3390/antiox11050959>
  10. Keskin M., Özkök A. Effects of drying techniques on chemical composition and volatile constituents of bee pollen / *Czech Journal of Food Sciences*. 2020. Vol. 38, No.4. P.202–210. DOI: <https://doi.org/10.17221/79/2020-CJFS>
  11. Miłek M., Mołoń M., Kula-Maximenko M., Sidor E., Zagula G., Dżugan M. Chemical composition and bioactivity of laboratory-fermented bee pollen in comparison with natural bee bread / *Biomolecules*. 2023. Vol. 13, No. 7. P. 1025. DOI:(<https://doi.org/10.3390/biom13071025>).
  12. El Ghouzi A., Bakour M., Laaroussi H., Ousaaid D., El Menyiy N., Hano C., Lyoussi B. Bee pollen as functional food: Insights into its composition and therapeutic properties / *Antioxidants*. 2023. Vol. 12, No. 3. P. 557. DOI: (<https://doi.org/10.3390/antiox12030557>)
  13. Bleha R., Shevtsova T. V., Živčáková M., Korbářová A., Ježková M., Saloň I., Snytytsya A. Spectroscopic discrimination of bee pollen by composition, color, and botanical origin / *Foods*. 2021. Vol. 10, No. 8. P. 1682. DOI: <https://doi.org/10.3390/foods10081682>).
  14. Khalifa, S. A. M., Elashal, M. H., Yosri, N., Du, M., Musharraf, S. G., Nahar, L., Sarker, S. D., Guo, Z., Cao, W., Zou, X., Abd El-Wahed, A. A., Xiao, J., Omar, H. A., Hegazy, M.-E. F., & El-Seedi, H. R. (2021). Bee pollen: Current status and therapeutic potential. *Nutrients*, 13(6), 1876. <https://doi.org/10.3390/nu13061876>
  15. Tutun H., Kaya M. M., Usluer M. S., Kahraman H. A. Bee pollen: Its antioxidant activity / *Uludağ Arıcılık Dergisi*. 2021. Vol. 21, No. 1. P. 119–131. DOI: 10.31467/uluaricilik.896045.
  16. Bertonceļ J., Lilek N., Korošec M. Bee pollen carbohydrates composition and functionality / *Pollen Chemistry & Biotechnology*. Cham : Springer International Publishing, 2024. P. 51–69. DOI: [https://doi.org/10.1007/978-3-031-47563-4\\_3](https://doi.org/10.1007/978-3-031-47563-4_3)
  17. Kolayli, S., Birinci, C., Kanbur, E. D., Ucurum, O., Kara, Y., & Takma, C. (2024). Comparison of biochemical and nutritional properties of bee pollen samples

- according to botanical differences. *European Food Research and Technology*, 250(3), 799–810. <https://doi.org/10.1007/s00217-023-04428-1>
18. Bayram, N. E., Kostić, A. Ž. & Gercek, Y. C. (ред.). *Pollen Chemistry & Biotechnology*. Cham : Springer, 2024. 347 с. <https://doi.org/10.1007/978-3-031-47563-4>
19. Bryś, M. S., & Strachecka, A. (2024). The key role of amino acids in pollen quality and honey bee physiology — A review. *Molecules*, 29(11), 2605. <https://doi.org/10.3390/molecules29112605>)
20. Melo, B. K. C. D., Silva, J. A. D., Gomes, R. D. D. S., Custódio, P. P., Lira, G. A. D., Ramalho, A. M. Z., ... & Bezerra, M. D. F. (2023). Physicochemical composition and functional properties of bee pollen produced in different locations. *Brazilian Journal of Food Technology*, 26, e2022006. (<https://doi.org/10.1590/1981-6723.00622>)
21. Çobanoğlu, D. N., Kizilpınar Temizer, İ., Candan, E. D., Yolcu, U., & Güder, A. (2023). Evaluation of the nutritional value of bee pollen by palynological, antioxidant, antimicrobial, and elemental characteristics. *European Food Research and Technology*, 249(2), 307–325. <https://doi.org/10.1007/s00217-022-04117-5>
22. Al-Kahtani, S., & Taha, E. K. A. (2021). Seasonal variations in nutritional composition of honeybee pollen loads. *Journal of the Kansas Entomological Society*, 93(2), 105–112. [<https://doi.org/10.2317/0022-8567-93.2.105>](<https://doi.org/10.2317/0022-8567-93.2.105>)
23. 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), 20210510. <https://doi.org/10.1098/rstb.2021.0510>)
24. Nguyen, H. C., Liu, L.-C., Wu, M.-C., Lin, T.-P., Yang, C.-Y., & Huang, M. Y. (2022). Chemical constituents, antioxidant, and anticancer activities of bee pollen from various floral sources in Taiwan. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, 50(2), 12644. <https://doi.org/10.15835/nbha50212644>)
25. Straumite, E., Bartule, M., Valdovska, A., Kruma, Z., & Galoburda, R. (2022). Physical and microbiological characteristics and antioxidant activity of honey bee pollen. *Applied Sciences*, 12(6), 3039. <https://doi.org/10.3390/app12063039>)
26. Sommano, S. R., Bhat, F. M., Wongkeaw, M., Sriwichai, T., Sunanta, P., Chuttong, B., & Burgett, M. (2020). Amino acid profiling and chemometric relations of black dwarf honey and bee pollen. *Frontiers in Nutrition*, 7, 558579. <https://doi.org/10.3389/fnut.2020.558579>)
27. 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>](<https://doi.org/10.3390/antiox11040645>)
28. Lu, P., Takiguchi, S., Honda, Y., Lu, Y., Mitsui, T., Kato, S., ... & Nagata, K. (2022). NMR and HPLC profiling of bee pollen products from different countries.

- Food Chemistry: Molecular Sciences*, 5, 100119.  
<https://doi.org/10.1016/j.fochms.2022.100119>)
29. Adamchuk, L., Sukhenko, V., Akulonok, O., Bilotserkivets, T., Vyshniak, V., Lisohurska, D., ... & Galyasnyj, I. (2020). Methods for determining the botanical origin of honey. *Potravinarstvo Slovak Journal of Food Sciences*, 14(1), 1018–1025. <https://doi.org/10.5219/1386>
30. Adamchuk L., Sukhenko V., Tysevych Ye. Bee bread quality: botanical identification and production technology. *International scientific-practical journal "Commodities and markets"*. 2021. N 2. P.70-84. <https://doi.org/10.31617/tr.knute.2021%2838%2907>)
31. Адамчук, Л. О., Сухенко, В. Ю., & Скорик, М. А. (2020). Адаптація методів електронної скануючої мікроскопії для дослідження пилоквих зерен. *Продовольчі ресурси*, 8(14), 20–28. <https://doi.org/10.31073/foodresources2020-14-02>)
32. 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>)
33. Campos, M. G., Anjos, O., Chica, M., Campoy, P., Nozkova, J., Almaraz-Abarca, N., ... & Carreck, N. L. (2021). Standard methods for pollen research. *Journal of Apicultural Research*, 60(4), 1–109. (<https://doi.org/10.1080/00218839.2021.1948240>)
34. Phan, N. T., Joshi, N. K., Rajotte, E. G., Zhu, F., Peter, K. A., López-Urbe, 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>
35. Xue, F. & Li, C. Effects of ultrasound assisted cell wall disruption on physicochemical properties of camellia bee pollen protein isolates. *Ultrasonics Sonochemistry*, 2023, vol. 92, article 106249. <https://doi.org/10.1016/j.ultsonch.2022.106249>
36. Su, J., Yang, X., Lu, Q., & Liu, R. (2021). Antioxidant and anti-tyrosinase activities of bee pollen and identification of active components. *Journal of Apicultural Research*, 60(2), 297–307. <https://doi.org/10.1080/00218839.2020.1722356>
37. Pesticides as a cause of honeybee (*Apis mellifera*) mortality and their persistence in honey / Y. A. Omelchun, L. V. Shevchenko, L. M. Nikitina, V.V. Solomon, V.M. Mykhalska, S.V. Furman, D.V. Lisohurska, O.V. Lisohurska / *Biosystems Diversity*. 2025. Vol. 33, No. 1. P. e2501. (<https://doi.org/10.15421/012501>).

Стаття надійшла до редакції 15 січня 2026 року

Стаття пройшла рецензування 17 лютого 2026 року

Стаття опублікована 30 березня 2026 року