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SAFETY OF PROTEIN-BASED BEEKEEPING PRODUCTS AND THE IMPACT OF GROCHEMICAL SOIL AMELIORATION ON RADIONUCLIDE ACCUMULATION

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The article presents the results of a comprehensive study on the toxicological and microbiological indicators of beekeeping products – in particular, bee pollen and propolis – collected from private apiaries in the Vinnytsia region of Ukraine. The aim of the study was to assess the safety and quality of protein-based bee products for their potential application in the food, pharmaceutical, cosmetic, and veterinary sectors. According to the results of laboratory analyses, the content of heavy metals (lead, cadmium, copper, and zinc) in most of the studied samples did not exceed the maximum permissible concentrations established by current Ukrainian and international safety standards. However, certain bee pollen samples failed to meet microbiological safety criteria due to excessive levels of mesophilic aerobic and facultative anaerobic microorganisms, which may indicate contamination during collection, transportation, or storage of the products. These findings highlight the need for adherence to proper hygiene conditions and the implementation of regular quality control measures at all stages of production. A separate section of the study was devoted to examining the effect of liming acidic soils on the accumulation of radionuclides ^{137}Cs and ^{90}Sr) in protein-rich apicultural products formed from the pollen of winter oilseed rape (Brassica napus L.). The study confirmed that the applied agrochemical measure – soil liming – is effective in reducing the bioaccumulation of radionuclides in bee products and contributes to increased yields and productivity of apicultural resources. The presented results are of significant practical value for ensuring the environmental safety of bee products and enhancing consumer trust. They can also serve as a scientific basis for the development of recommendations regarding safe and sustainable beekeeping practices in regions affected by man-made or radiological pollution and requiring ecological restoration.

Keywords: *bee pollen, propolis, microbiological safety, cadmium, lead, ^{137}Cs, ^{90}Sr, liming, winter rapeseed.*

Table 2., Lit.15.

Formulation of the problem. Beekeeping plays a crucial role not only in agricultural production but also in maintaining ecological balance through pollination. Its products – pollen, propolis, honey, and bee bread – are valued for their high biological activity and are widely applied in the food industry, medicine, and cosmetics. However, the growing anthropogenic pressure on ecosystems, including soil, air, and water pollution with hazardous substances such as heavy metals and radionuclides, poses a serious risk of contaminant transfer into bee-derived products. Toxic elements such as cadmium (Cd), lead (Pb), cesium (^{137}Cs), and strontium (^{90}Sr) may accumulate in apicultural products through contaminated melliferous plants, reducing product quality and potentially threatening consumer health. Equally important is the microbiological safety of bee products, as they may provide favorable conditions for the growth of pathogenic bacteria, molds, and yeasts, thus influencing both food safety and storage stability. In Ukraine, especially in territories affected by radioactive fallout from the Chornobyl disaster, continuous monitoring of contaminants in apicultural products remains a pressing necessity. Agro-technical practices such as liming acidic soils are considered an effective approach to limit radionuclide transfer into crops and, consequently, into bee products. Despite the availability of separate studies, a comprehensive evaluation of toxicological and microbiological safety of pollen and propolis under Ukrainian conditions remains insufficient. Therefore, this research aims to conduct a thorough assessment of the toxicological and microbiological indicators of bee products, alongside evaluating the effect of soil liming on the accumulation of radionuclides in protein-rich apicultural products. In the face of intensifying anthropogenic pressure and environmental contamination with heavy metals and radionuclides, ensuring the safety of bee products is of critical importance. Pollen and propolis, as protein-enriched products of apiculture, are highly valued for their nutritional and medicinal properties, yet they are vulnerable to both toxic and microbiological contamination.

Although some previous studies have explored chemical and biological safety aspects of bee products, the majority have primarily focused on honey or royal jelly, leaving pollen and propolis less investigated. Furthermore, limited attention has been paid to the potential of agrochemical measures, particularly soil liming, in mitigating radionuclide accumulation in bee products under Ukrainian environmental conditions.

This research seeks to address these gaps by providing a comprehensive assessment of the toxicological and microbiological safety of bee pollen and propolis, as well as by examining the impact of soil liming on the reduction of ^{137}Cs and ^{90}Sr in protein-rich apicultural products derived from rapeseed pollen.

Analysis of recent research and publications. The safety of apicultural products has been widely studied both in Ukraine and abroad, with particular focus on the presence of heavy metals, microbial contamination, residues of antibacterial substances, and radionuclides. Much of the available literature is devoted to examining the influence of anthropogenic and technological factors on the quality of honey, bee bread, pollen, propolis, and other bee-derived products [1, 2, 14, 15].

For instance, Skrypka H.A. and co-authors [2, 14] investigated the safety and quality of sunflower honey, propolis, and pollen. Their research emphasized the frequent exceedance of microbiological norms, particularly in relation to mesophilic aerobic and facultative anaerobic microorganisms, coliform bacteria, and molds, as well as the detection of residual antibacterial substances in both domestic and imported products [15]. The authors stress the necessity of continuous monitoring to ensure that products entering the consumer market meet established safety standards.

Other scholars have explored the impact of agro-ecological conditions, soil properties, and nectar-bearing flora on the accumulation of contaminants and trace elements in bee products. For example, Mishchenko O.A. and colleagues [11] examined how pollen-collecting methods influence bee behavior, which indirectly affects the quality of collected apicultural products.

Kalynychenko O.O. [10] analyzed the effect of probiotics on the productivity of bee colonies, thereby linking colony performance with the quality characteristics of pollen and other bee-derived resources. Radioecological aspects of protein bee products have received comparatively less attention, yet they remain highly relevant, especially in relation to agrochemical practices such as soil liming aimed at reducing radionuclide bioaccumulation. At the same time, the potential of such measures to improve the yield of apicultural products also holds significant practical importance. Nevertheless, most existing studies tend to examine safety parameters only in fragments–for example, focusing predominantly on honey or bee bread–while overlooking other protein-rich bee products such as pollen and propolis. Comprehensive investigations that combine toxicological and microbiological safety assessments with an evaluation of agrochemical soil management practices and their influence on radionuclide accumulation remain scarce. Addressing these research gaps defines both the relevance and novelty of the present study.

Research methods. The toxicological and microbiological analyses of bee pollen and propolis were carried out at the Zhytomyr branch of the State Institution «State Soil Protection». A total of 80 samples were collected from private apiaries in Vinnytsia region, following the standard requirements for sampling raw food materials.

Toxicological testing involved the determination of heavy metals (cadmium and lead) through dry mineralization, followed by atomic absorption spectrophotometry. The results were compared against the maximum permissible concentrations (MPCs) established by national standards (DSTU 3127-95, DSTU 4662:2006).

Microbiological assessment was performed using selective nutrient media produced by Himedia (India), in accordance with widely accepted microbiological techniques. Parameters examined included the total microbial count (TMC), the presence of coliform bacteria (Escherichia coli group), pathogenic microorganisms (such as *Salmonella spp.* and *Staphylococcus aureus*), as well as molds and yeasts. Results were interpreted in line with regulatory requirements for the respective apicultural products. In parallel, a field experiment was conducted to evaluate the effect of an agrochemical practice–soil liming–on the accumulation of radionuclides (^{137}Cs and ^{90}Sr) in protein-based bee products. The trials were organized on the agricultural lands of the Dzyaliv farm (Kamianohirka village, Zhmerynka district, Vinnytsia region). Winter rapeseed was cultivated on acidic soils with a natural pH of 4.7, containing 31.0 Bq/kg of ^{137}Cs and 2.7 Bq/kg of 90Sr. Liming was applied at a rate of 7–9 t/ha of limestone materials, which were incorporated into the soil. This treatment raised soil pH to 6.8. Pollen collected from rapeseed flowers under these conditions served as the basis for bee-colony protein products (pollen loads and bee bread). Bee colonies were maintained at apiary sites in compliance with the principle of analogues and spatial separation (minimum distance of 5 km). Pollen samples were obtained using pollen traps during the mass flowering stage of rapeseed, while bee bread was collected after a 15-day fermentation period.

Soil samples were taken using the «envelope» method, and bee products were collected through spot sampling. Radionuclide activity was measured with established techniques: gamma spectrometry was used for ^{137}Cs, and the oxalate method was applied for ^{90}Sr, in accordance with environmental monitoring and veterinary radiology guidelines.

Presentation of the main research material. The research examined the safety of protein-rich apicultural products–namely bee pollen and propolis–collected from private apiaries in Vinnytsia region. In addition, the effect of soil liming as an agrochemical measure on the accumulation of radionuclides in pollen- and propolis-based products derived from winter rapeseed was evaluated. The toxicological analysis revealed that the concentrations of heavy metals (lead, cadmium, mercury, and arsenic) in all tested samples remained below the maximum permissible limits set by current legislation. However, microbiological assessment indicated that several pollen samples showed an excessive number of mesophilic aerobic and facultative anaerobic microorganisms. Such findings point to the necessity of strict compliance with veterinary and sanitary standards during collection, storage, and preliminary processing of bee products. The experiments also demonstrated that liming acidic soils significantly reduces radionuclide bioaccumulation in bee products. In particular, a marked decrease in ^{137}Cs levels was observed in bee bread from limed plots compared to control sites. These results confirm the effectiveness of agrochemical amelioration practices as a means of enhancing radiation safety in agroecosystems historically exposed to radioactive contamination.

Toxicological testing (Table 1) showed that cadmium and lead concentrations in bee pollen and propolis remained within acceptable ranges. Cadmium was found in 20% of pollen samples, ranging between 0.013 ± 0.001 and 0.028 ± 0.001 mg/kg, while lead was detected in 27.5% of samples, with values between 0.28 ± 0.01 and 0.74 ± 0.01 mg/kg.

Table 1

The content of toxic elements in bee leg, mg/kg

№ of the sample	Mg/kg		№ of the sample	Mg/kg	
	cadmium	lead		cadmium	lead
1	0,013± 0,001	0.34± 0.01	21	<0,01	<0,05
2	<0,01	<0,05	22	<0,01	<0,05
3	<0,01	<0,05	23	<0,01	<0,05
4	<0,01	0.41± 0.01	24	<0,01	<0,05
5	<0,01	<0,05	25	0,021± 0,001	<0,05
6	<0,01	<0,05	26	<0,01	0.31± 0.01
7	<0,01	<0,05	27	0,018± 0,001	<0,05
8	0,028± 0,001	<0,05	28	<0,01	0.3± 0.01
9	<0,01	0.74± 0.01	29	<0,01	<0,05
10	<0,01	0.28± 0.01	30	<0,01	<0,05
11	<0,01	<0,05	31	<0,01	<0,05
12	<0,01	<0,05	32	<0,01	<0,05

Continuation of Table 1

13	0,022± 0,001	<0,05	33	<0,01	0.54± 0.01
14	<0,01	<0,05	34	<0,01	<0,05
15	<0,01	0.68± 0.01	35	<0,01	<0,05
16	<0,01	<0,05	36	<0,01	<0,05
17	0,016± 0,001	0.37± 0.01	37	0,015± 0,001	<0,05
18	<0,01	0.29± 0.01	38	<0,01	<0,05
19	0,019± 0,001	<0,05	39	<0,01	0.62± 0.01
20	<0,01	<0,05	40	<0,01	<0,05

Source: Based on own research.

The toxicological analysis of propolis indicated cadmium presence in 17.5% of samples, with concentrations between 0.018 ± 0.001 and 0.046 ± 0.001 mg/kg, remaining below the MPC of 0.05 mg/kg. Lead was detected in 12.5% of propolis samples, with concentrations from 0.28 ± 0.01 to 0.62 ± 0.01 mg/kg, also below the permissible limit of 1.0 mg/kg. Despite the occurrence of these toxic elements, the recorded levels suggest that propolis can generally be considered safe with respect to heavy-metal contamination. Nevertheless, ongoing monitoring is recommended, since even trace amounts of such elements in biologically active substances may pose long-term risks through trophic chain accumulation (Table 2).

Table 2

Content of toxic elements in propolis, mg/kg

№ of the sample	Mg/kg		№ of the sample	Mg/kg	
	cadmium	lead		cadmium	lead
1	0,018± 0,001	<0,05	21	<0,01	0.51± 0.01
2	0,046± 0,001	<0,05	22	<0,01	<0,05
3	<0,01	<0,05	23	<0,01	<0,05
4	<0,01	<0,05	24	0,024± 0,001	<0,05
5	<0,01	<0,05	25	<0,01	<0,05
6	<0,01	0.28± 0.01	26	<0,01	<0,05
7	<0,01	0.62± 0.01	27	<0,01	<0,05
8	<0,01	<0,05	28	0,021± 0,001	<0,05
9	<0,01	<0,05	29	<0,01	<0,05
10	<0,01	<0,05	30	<0,01	<0,05
11	<0,01	<0,05	31	<0,01	0.35± 0.01
12	0,027± 0,001	<0,05	32	<0,01	<0,05
13	<0,01	<0,05	33	<0,01	<0,05
14	<0,01	0.39± 0.01	34	<0,01	<0,05
15	<0,01	<0,05	35	<0,01	<0,05
16	<0,01	<0,05	36	<0,01	<0,05
17	0,035± 0,001	<0,05	37	<0,01	<0,05
18	<0,01	<0,05	38	<0,01	<0,05
19	<0,01	<0,05	39	<0,01	<0,05
20	<0,01	<0,05	40	0,036± 0,001	<0,05

Source: Based on own research.

Microbiological assessment of propolis showed compliance with regulatory standards: no pathogenic microorganisms were detected, coliform counts were within permissible values, and the total microbial count was normal. In contrast, bee pollen partially failed to meet sanitary requirements: 15% of samples showed excessive mesophilic bacteria, 10% tested positive for coliforms, 7.5% contained molds, and 10% had excessive yeast counts. These findings highlight potential violations during harvesting, transport, or storage.

A separate set of studies concerned the impact of soil acidity on the accumulation of radionuclides in bee protein products. Field studies were carried out on lands with soil pH 4.7 and specific activity of ^{137}Cs – 31.0 and ^{90}Sr – 2.7 Bq/kg. Liming (9 t/ha $CaCO_3$) for winter rape contributed to an increase in pH to 6.8, which reduced the bioaccumulation of radionuclides in bee products.

Another important focus was the effect of soil acidity on radionuclide accumulation in protein bee products. Field trials confirmed that liming acidic soils (pH 4.7) increased soil pH to 6.8, thereby reducing radionuclide bioaccumulation in bee pollen and bee bread. Specifically, liming decreased the specific activity of ^{137}Cs in bee pollen by 40.0% and of ^{90}Sr by 42.9%. Similar reductions were recorded in bee bread and related products.

The highest efficiency of liming was observed for 137Cs reduction in bee pollen (66.7% decrease) and for 90Sr in bee bread (3.4-fold decrease). Moreover, the specific activity of both radionuclides was found to be substantially higher in bee bread than in pollen–2.8 times greater for ^{137}Cs and seven times greater for ^{90}Sr.

Besides mitigating radiological risks, liming also improved the productivity of bee colonies. Compared to control plots, the number of pollen loads increased by 18.2% and the amount of bee bread rose by 6.0% in colonies placed on limed soils.

Discussion. The results obtained confirm that the concentrations of cadmium and lead in the analyzed pollen and propolis samples did not exceed maximum permissible levels, indicating a relatively favorable ecological status of the melliferous areas within the study region. These findings align with earlier research [6, 22], which demonstrated that the content of heavy metals in bee products varies depending on both geographical location and anthropogenic influence.

At the same time, microbiological analysis revealed notable challenges related to sanitary and hygienic conditions during the collection and storage of pollen. Instances of excessive counts of mesophilic bacteria, coliforms, molds, and yeasts suggest that insufficient sterilization of equipment, inadequate storage, or improper transportation may be contributing factors. This highlights the importance of stricter control at every stage of the production and distribution chain.

A particularly important outcome of the study is the demonstrated effectiveness of soil liming as an agro-technical practice. The measure significantly reduced the concentrations of ^{137}Cs and ^{90}Sr in protein bee products. Since soil acidity is a key factor influencing radionuclide migration, these findings support previous reports on the usefulness of liming as a strategy to enhance environmental safety in apicultural systems [1, 9].

Moreover, the observed increase in colony productivity under limed conditions emphasizes that this intervention benefits not only the safety but also the yield of bee products. The results carry practical implications for improving quality assurance and environmental safety of apicultural production. They provide a basis for developing recommendations aimed at protecting consumer health while simultaneously promoting the sustainable growth of beekeeping in Ukraine. Future investigations should extend to other potential contamination factors and explore improved techniques for the collection and preservation of bee products.

Overall, this study demonstrates the necessity of a holistic approach to assessing the safety of bee products, integrating both toxicological and microbiological aspects. Agro-technical practices such as liming acidic soils have proven effective as tools for ecological management of melliferous landscapes. Expanding research on pollutant dynamics under varying climatic, edaphic, and anthropogenic conditions will allow for the development of regional risk maps and optimization of veterinary and sanitary monitoring systems.

Conclusions and prospects for further research. The samples of bee pollen and propolis collected from beekeeping farms in Odesa region did not exceed the maximum permissible concentrations of cadmium and lead defined by the current regulations.

1. Propolis demonstrated stable microbiological safety. While bee pollen in some cases did not meet the requirements of DSTU for such indicators as CAFAnM, BCCP, moulds and yeasts.

2. Liming of acidic soils (pH 4.7) to pH 6.8 significantly reduced the accumulation of radionuclides in bee protein products: specific activity of ^{137}Cs by 40- 43%, ^{90}Sr by 42-43%, and the accumulation coefficient by up to 35%, depending on the type of product.

3. The use of liming also contributed to an increase in the productivity of bee colonies in terms of protein production.

4. The obtained results confirm the expediency of continuous monitoring of the environmental safety of apiary products and the use of agrotechnical measures to improve it.

5. The effectiveness of the agrochemical measure - liming of acidic soils - in reducing the radiological load on bee protein products has been proven. Liming of soils reduced the specific activity of ^{137}Cs and ^{90}Sr in bee leg and pergium by 40 to 43 %.

6. It was determined that the microbiological parameters of propolis mostly meet the regulatory requirements, while bee pollen in some cases exceeds the permissible values for CMAFanM, yeast, moulds and Bacterial GCP. This requires strengthening of sanitary control during the collection and storage of apiary products.

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АНОТАЦІЯ
БЕЗПЕЧНІСТЬ БІЛКОВОЇ ПРОДУКЦІЇ БДЖІЛЬНИЦТВА ТА ВПЛИВ АГРОХІМІЧНОЇ МЕЛІОРАЦІЇ ҐРУНТІВ НА НАКОПИЧЕННЯ РАДІОНУКЛІДІВ

У статті представлено результати комплексного дослідження токсикологічних і мікробіологічних показників продуктів бджільництва – зокрема бджолиного обніжжя та прополісу, зібраних на приватних пасіках Вінницької області. Метою роботи було оцінити безпечність і якість білкової продукції бджільництва для подальшого використання в харчовій, фармацевтичній, косметичній і ветеринарній галузях. За результатами лабораторних аналізів встановлено, що вміст важких металів (свинцю, кадмію, міді, цинку) у більшості досліджених зразків не перевищував гранично допустимих концентрацій, встановлених відповідно до чинних українських і міжнародних нормативів. Разом із тим, окремі зразки бджолиного обніжжя не відповідали мікробіологічним критеріям безпечності через перевищення допустимого рівня мезофільних аеробних та факультативно-анаеробних мікроорганізмів, що свідчить про можливе забруднення під час збирання, транспортування або зберігання продукції. Це підкреслює необхідність дотримання належних гігієнічних умов та впровадження регулярного контролю якості на всіх етапах виробництва. Окрему увагу в дослідженні приділено впливу вапнування кислих ґрунтів на накопичення радіонуклідів (^{137}Cs і ^{90}Sr) у білковій продукції бджільництва, що формувалась за участі пилку озимого ріпаку (Brassica napus L.). Доведено, що застосування агрохімічного заходу – вапнування – є ефективним у зниженні біоакумуляції радіонуклідів у продукції та сприяє підвищенню урожайності апіпродуктів.

Представлені результати мають важливе практичне значення для забезпечення екологічної безпеки бджолопродуктів та формування споживчої довіри, а також можуть бути використані як наукове підґрунтя для розробки рекомендацій щодо ведення безпечного й сталого бджільництва в регіонах, що зазнають техногенного або радіологічного навантаження і потребують відновлення.

Ключові слова: *бджолине обніжжя, прополіс, мікробіологічна безпека, кадмій, свинець, ^{137}Cs, ^{90}Sr, вапнування, ріпак озимий.*

Табл. 2., Літ. 15.

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