

This study quantifies the translocation factor (TF) for heavy metals transferred from wild honey plants to beekeeping products. The research area is located near the war zone, so its contamination with heavy metals is possible.

Analysis of honey plants and bee products can make it possible to establish their safety. Field studies were conducted in July 2025 in the village of Stepanivka (Ukraine). The concentration of Cd, Pb, As, as well as the TF for these heavy metals transferred from wild honey plants to beekeeping products (bee pollen and honey), were determined using generally accepted methods.

It was found that the concentration of Pb in wild honey plants is 1.64 ± 0.44 mg/kg, which exceeds the level permitted in Europe and Ukraine for plants by 5.5–8.2 times. However, in bee bread and honey, the concentration of Pb is within the normal range (0.15 ± 0.01 mg/kg and 0.09 ± 0.01 mg/kg, respectively). This indicates that pollen is less contaminated compared to vegetative parts of the plant, acting as a barrier for heavy metals, and bees have the ability to reduce the concentration of pollutants. This is also confirmed by the fact that the concentration of Pb in bee bread is higher than in honey, which may indicate the ability of bees to act as a biofilter. The same effect is observed with other toxins. The level of Cd in honey (0.007 ± 0.01 mg/kg) was lower than its concentration in bee bread (0.01 ± 0.05 mg/kg). The concentration of As in honey is also 0.1 mg/kg lower than its concentration in bee bread. At the same time, it was found that the concentration of As in wild honey plants (< 0.0001 mg/kg) is significantly lower than its concentration in beekeeping products. The highest bioaccumulation of Cd was registered in bee bread (TF = 0.13). Considering that the translocation factor of heavy metals does not exceed 1, honey and bee bread collected in the study area can be considered safe for consumption

Keywords: bee pollen, heavy metals, translocation factor, military operations, safety of apiproducs

UDC 638.162

DOI: 10.15587/1729-4061.2026.354695

REVEALING THE BIOACCUMULATION OF HEAVY METALS IN HONEY PLANTS AND THEIR TRANSLOCATION INTO APIPRODUCTS

Maryna Samilyk

Corresponding author

Doctor of Technical Sciences, Professor

Department of Technology and Food Safety**

E-mail: maryna.samilyk@snu.edu.ua

ORCID: <https://orcid.org/0000-0002-4826-2080>

Svetlana Tkachuk

Doctor of Veterinary Sciences, Professor

Department of Veterinary Hygiene named after professor A. K. Skorokhodko

National University of Life and Environmental Sciences of Ukraine

Heroiv Oborony str., 15, Kyiv, Ukraine, 03041

ORCID: <https://orcid.org/0000-0002-6923-1793>

Volodymyr Onoprienko

Doctor of Pedagogical Sciences, Professor*

ORCID: <https://orcid.org/0000-0002-6825-1899>

Larysa Yepyk

PhD, Associate Professor*

ORCID: <https://orcid.org/0000-0001-5160-6529>

Oleh Bakhmat

Doctor of Agricultural Sciences, Professor

Department of Ecology and General Biological Subjects***

ORCID: <https://orcid.org/0000-0002-8015-1567>

Danylo Plahtiy

PhD, Associate Professor

Department of Ecology and General Biological Subjects***

ORCID: <https://orcid.org/0000-0002-2014-9748>

Tetiana Krachan

PhD, Associate Professor, Head of Department

Department of Chemistry***

ORCID: <https://orcid.org/0000-0002-0618-4483>

Anna Hotvianska

PhD, Associate Professor

Department of Plant Production

Dnipro State Agrarian and Economic University

Serhiya Yefremova str., 25, Dnipro, Ukraine, 49600

ORCID: <https://orcid.org/0000-0003-3887-3192>

Dmytro Kisil

Doctor of Philosophy (PhD), Senior Lecturer

Department of Veterinary and Sanitary Inspection, Microbiology, Hygiene and Pathological Anatomy**

ORCID: <https://orcid.org/0000-0003-3088-951X>

Dmytro Nahirnyy

Assistant

Department of Ecology

Separated Subdivision of National University of Life and Environmental Sciences of Ukraine

«Berezhany Agrotechnical Institute»

Akademichna str., 20, Berezhany, Ukraine, 47501

ORCID: <https://orcid.org/0009-0006-6789-272X>

*Department of Tourism**

**Sumy National Agrarian University

Herasyma Kondratieva str., 160, Sumy, Ukraine, 40021

***Higher Educational Institution «Podillia State University»

Shevchenko str., 12, Kamenets-Podolsky, Ukraine, 32316

Received 17.12.2025

Received in revised form 02.03.2026

Accepted 12.03.2026

Published

How to Cite: Samilyk, M., Tkachuk, S., Onoprienko, V., Yepyk, L., Bakhmat, O., Plahtiy, D., Krachan, T.,

Hotvianska, A., Kisil, D., Nahirnyy, D. (2026). Revealing the bioaccumulation of heavy metals in honey

plants and their translocation into apiproducs. *Eastern-European Journal of Enterprise Technologies,*

2 (10 (140)), 18–23. <https://doi.org/10.15587/1729-4061.2026.354695>

1. Introduction

One of the main issues that modern society has to resolve is environmental pollution. Given the global

nature of this problem, ecosystem monitoring methods must be suitable for use in regions with completely different ecological, infrastructural, social, and economic conditions.

One of the biomonitoring methods used to acquire accurate information about pollutants present in the territory, as well as about their biotoxic impact, is the analysis of honey bees and apiproducs [1].

Honey is an important biomarker for detecting environmental pollution. When honey bees forage in polluted areas, they are exposed to pollutants present in the atmosphere, soil, vegetation, and water. Toxins from bees enter beekeeping products, which can create potential risks for both their health and the safety of hive products.

As a natural bioindicator, apiproducs can accumulate and reflect environmental pollutants, providing an idea of the health of the ecosystem and the level of its pollution [2]. Thus, through apiproducs, it is possible to detect the presence of a significant concentration of heavy metals in the ecosystem [3], which in high concentrations are toxic to honey bees. The fact that toxins have the ability to accumulate is important, especially when there is a prolonged effect of external factors.

Environmental pollution is always observed in areas where there is active military activity. This is caused by the ingress of various toxins into the soil and water as a result of the use of weapons and military equipment. Considering that the full-scale war in Ukraine has been going for more than 4 years, it is important to monitor the pollution not only of soil and water but also of agricultural produce.

Analysis of the safety of apiproducs in the territories of the military conflict zone is relevant since an important principle of natural beekeeping is the absence of chemical treatments or other unnatural interventions.

2. Literature review and problem statement

It was reported in [4] that the increase in the scale of infrastructure projects, deforestation, as well as intensive agriculture, sharply reduce the areas on which honey bee populations can grow. The results of the study link this to the high level of pesticide use and excessive movement of hives. It has been shown that pesticides contaminate honey plants, and through them bee products, which are ultimately consumed by humans [5]. However, issues related to other factors that may affect the safety of the honey bee population remain unresolved. A likely reason is the complexity and cost of research related to other anthropogenic factors of influence. In addition, some toxins formed by other factors accumulate in the bee body, but only in small quantities enter honey, which reduces the priority of such studies for safety control.

Some studies [6] have shown that sources of contamination of bee products may be associated not only with agricultural activities because bees are the link between what gets to plants and beekeeping products through water, soil, and air. This is the approach used in work [7]. It has been shown that the transport of dust in the air containing heavy metals and their deposition on plants is enhanced in areas affected by mining activities. These particles can be carried by the wind over considerable distances and settle on the surface of leaves and flowers, which are honey plants. Bees can accumulate heavy metals from contaminated pollen, nectar, and water [8]. The level of bioaccumulation of heavy metals depends on many factors and is a poorly studied issue.

It is also known that other anthropogenic factors lead to progressive contamination of honey and other beekeeping products [9]. Industrial emissions, burning of fossil fuels, and

intensive road traffic contribute to the accumulation of heavy metals in the atmosphere and in the beekeeping ecosystem. However, many potential contaminants of beekeeping products remain unstudied.

Among the insufficiently studied sources of heavy metals entering the environment and bee products are military operations. It is known that heavy metals can enter the soil from weapon residues, during ground combat operations and bombings [10]. Therefore, at the sites of military equipment burning, the maximum permissible concentration of heavy metals is usually observed. However, the radius of contamination has not been established. Studies of bee products contamination with substances formed as a result of military aggression are still insufficient.

The question of whether military activities can affect the safety of bee products remains unresolved. All this gives grounds to argue that it is advisable to conduct a study aimed at determining the safety of apiproducs collected within the 30-kilometer zone of military operations on the territory of Ukraine.

3. The aim and objectives of the study

The purpose of our study is to determine the level of bioaccumulation of heavy metals in beekeeping products within a 30-kilometer zone of active hostilities. This will make it possible to establish the safety of beekeeping products in these territories.

To achieve this aim, the following objectives were accomplished:

- to determine the concentration of heavy metals in wild honey plants;
- to determine the concentration of heavy metals in honey and bee bread;
- to quantify the translocation factor for heavy metals transferred from wild honey plants to beekeeping products.

4. The study materials and methods

4.1. The object and hypothesis of the study

The object of our study is the translocation factor (TF) of heavy metals transferred from wild honey plants to beekeeping products. The subject of the study is the mass concentration of heavy metals in wild honey plants and beekeeping products; translocation factor of heavy metals transferred from plants to beekeeping products.

It is hypothesized that since plants are bioaccumulators of toxic metals, an increase in the concentration of heavy metals in them may indicate contamination of the ecosystem (soil, water). Thus, nectar and pollen of honey plants may also be contaminated. Since honey bees are a highly effective means of conducting ground research, analysis of their apiproducs could allow us to determine whether they are subject to contamination.

Wild honey plants collected within a 30-kilometer combat zone can accumulate excess heavy metals, which may pose risks of contamination of bees and beekeeping products. Bees visit almost all sectors of the environment (soil, vegetation, water, and air) within a circular area with a radius of approximately 12 km² around the hive, providing numerous randomly collected samples. Once in the hive, these products are easily selected and analyzed for the presence of pollutants.

Therefore, it is advisable not only to determine the concentration of heavy metals in honey plants but also quantify the coefficient of their transition to beekeeping products. The study will make it possible to prove or disprove the impact of hostilities on the safety of beekeeping products produced in the 30-kilometer zone from the border with the aggressor state.

4. 2. Materials

Our field research was conducted in July 2025 in the vilage of Stepanivka, Sumy oblast (Ukraine), which is located within a 30-kilometer combat zone (Fig. 1).



Fig. 1. Map of the study area (Sumy region, Sumy oblast, Ukraine), represented as a Google map image

Planes, helicopters, missiles, unmanned aerial vehicles, guided bombs, etc., are constantly moving above this territory.

4. 3. Investigating wild honey plants

Sampling of wild honey plants was carried out in the area within a radius of 2 km from the site of a private household, in which samples of bee bread and honey were taken. A 10 kg batch was collected, from which an average sample weighing 1 kg was selected for analysis. The composition of the collected sample was dominated by red clover, common blueberry, and white yam. The selected plant samples were washed with distilled water to remove dust and soil particles. The washed plants were dried in a drying oven at a temperature of 60°C until a constant weight was reached and ground into powder. Then 1 g of powder was placed in flasks and digested in a solution of chloric and nitric acid (in a ratio of 1:3) at a temperature of 200–300°C. The samples were cooled at room temperature and filtered through filter paper. The filtrate was analyzed using an AAS-30 atomic absorption spectrophotometer (Germany).

4. 4. Investigating apiproducs

Pollen samples (bee bread) were taken from a pollen trap installed on a hive at a private household. An average pollen sample (100 g) was taken from five different hives of one household. Raw pollen was cleaned of debris and dried at a temperature not exceeding 40°C in a drying cabinet. A honey sample (500 g) was taken from the total batch of honey collected at this household in July. The content of heavy metals in bee bread and honey was determined by atomic absorption spectrometry using a PinAAcle900T spectrometer (USA).

4. 5. Quantifying the translocation factor of heavy metals

The translocation factor (TF) for heavy metals transferred from wild honey plants to bee bread was determined from the following formula [11]

$$TF = \frac{C_h}{C_{hp}}, \tag{1}$$

where C_{hp} – concentration of heavy metals in wild honey plants, mg/kg; C_h – concentration of heavy metals in bee bread, mg/kg.

The translocation factor for heavy metals transferred from wild honey plants to honey was calculated as the ratio of the concentration of heavy metals in honey to their concentration in wild honey plants.

The value of $TF \geq 1$ means that the product can accumulate heavy metals. $TF \leq 1$ indicates that the bioaccumulation of heavy metals is low.

4. 6. Statistical analysis

The end results are represented as the mean ± standard deviation obtained within three parallel studies. To assess the statistical significance of the difference between groups, the Student’s *t*-test was used. Differences were considered significant at a probability level of $p \leq 0.05$. All data are represented in tabular and graphical forms using a bar chart.

5. Results investigating the level of heavy metal contamination of wild honey plants and apiproducs

5. 1. Results of investigating the concentration of heavy metals in wild honey plants

The results of the analysis of the level of contamination of honey plants are shown in Fig. 2.

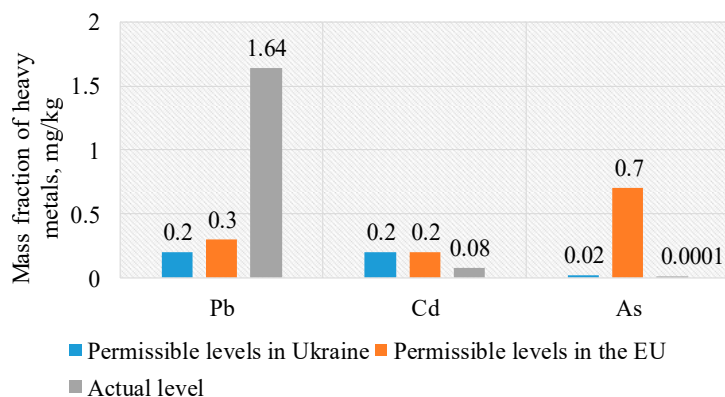


Fig. 2. Concentration of heavy metals in experimental samples of wild honey plants

The Pb content in the tested samples ranged from 1.58 to 1.7 mg/kg with an average statistical value of 1.64 ± 0.44 mg/kg. According to the recommendations from the World Health Organization (WHO) [12], the permissible level of Pb in plants is 0.3 mg/kg. In Ukraine [13], a safe concentration of Pb in plants is considered to be 0.2 mg/kg. In view of this, the level of lead in honey plants exceeds the established maximum permissible standards by 5.5–8.2 times.

The concentration of Cd in wild honey plants in the studied area did not exceed the recommended maximum permis-

sible concentrations and was within 0.07–0.09 mg/kg with an average value of 0.08 ± 0.04 mg/kg.

The actual level of As (< 0.0001 mg/kg) also indicates its low bioaccumulation in vegetation in areas within the 30-kilometer combat zone.

5. 2. Results of investigating the concentration of heavy metals in honey and bee bread

The results of investigating the beekeeping products are shown in Fig. 3, 4.

The results of our study showed that the concentration of heavy metals in bee bread is within the permissible levels [14]. The closest to the upper permissible level is the content of As (0.27 ± 0.05 mg/kg). The concentration of Cd in bee bread is quite high (0.01 ± 0.05 mg/kg), which is only 0.04 mg/kg lower than the permissible level in Ukraine [15]. In view of this, the determined content of heavy metals in bee bread can be considered low.

The results of our study showed that the concentration of heavy metals in honey does not exceed the established maximum permissible standards. However, the level of Pb (0.09 ± 0.01 mg/kg) is close to the maximum permissible limits established in the European Union (EU) [16]. Also, the concentration of Cd (0.007 ± 0.01 mg/kg) in honey is close to the EU maximum limits. However, since the norm is not exceeded, the product can be considered safe.

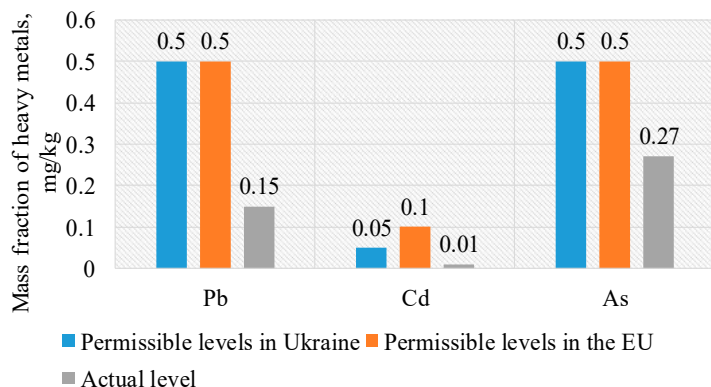


Fig. 3. Concentration of heavy metals in a sample of bee bread

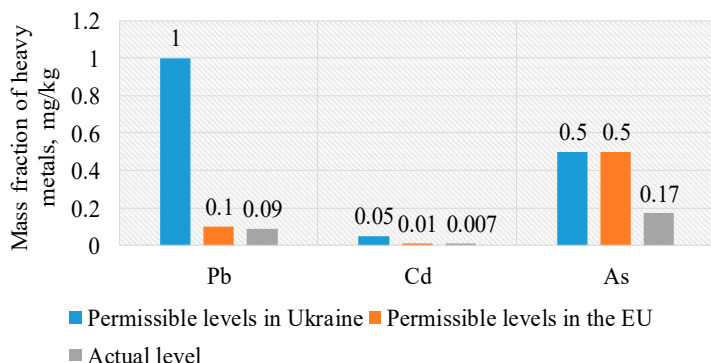


Fig. 4. Concentration of heavy metals in a test sample of honey

5. 3. Results of quantifying the translocation factors of heavy metals transferred from wild honey plants to beekeeping products

The results of calculating the translocation factors of heavy metals transferred from wild honey plants to bee bread and from bee bread to honey are given in Table 1.

Table 1

Heavy metal concentration, mg/kg	Pb	Cd	As
Wild honey plants	1.64 ± 0.44	0.08 ± 0.04	<0.0001
Bee pollen	0.15 ± 0.01	0.01 ± 0.05	0.27 ± 0.05
TF	0.09	0.13	–
Honey	0.09 ± 0.01	0.007 ± 0.01	0.17 ± 0.11
TF	0.06	0.09	–

The highest translocation factor is observed for Pb transferred from wild honey plants to bee bread, and for Cd – from honey plants to honey. The concentration of As in honey plants was lower (<0.0001) than in bee bread and honey. Considering that the translocation factor for all heavy metals is $TF \leq 1$, this indicates that the bioaccumulation of heavy metals in the studied bee products is low.

6. Discussion of results based on investigating the safety of beekeeping products within the 30-kilometer zone of military operations

The absorption of heavy metals by plants depends on their bioavailability and concentration. According to the data obtained (Fig. 2), the mass fraction of Cd (0.08 ± 0.04 mg/kg) and As (< 0.0001) in wild honey plants is moderate. This concentration of Cd is slightly higher than the typical concentration for wildflowers (0.04 mg/kg) collected in safe areas [17]. However, it cannot be stated that the Cd level in honey plants is critically high.

The Pb content in honey plants ranged from 1.58 to 1.7 mg/kg, which is consistent with previous studies conducted in the villages of Tovsta [18], Ulyanivka, and Sulske [19], which are located within the 50-kilometer zone of military operations. Considering the recommended maximum concentrations of Pb [12, 13], the concentration of this heavy metal in honey plants is 5.5–8.2 times higher than the recommended maximum concentrations. Since Pb is used in the production of bullets and other ammunition, in the construction of military vehicles and aircraft [10], it can be assumed that the reason for its accumulation in plants is the proximity of the studied area to the combat zone. Since similar studies were not conducted before the war, it is impossible to confirm this assumption.

Since plants are the only source of food for bees, the main cause of the accumulation of toxins is direct contact and consumption of pollutants present in pollen and/or nectar [20]. Honey plants serve as an intermediate link for the transfer of metals from water, air, and soil to human and animal organisms [21].

According to the results of our study (Fig. 3), it was found that the concentration of heavy metals in the bee bread is within permissible levels [14]. The mass fraction of As in it is 0.27 ± 0.05 mg/kg, which significantly exceeds the concentration of As in wild honey plants (< 0.0001 mg/kg). Bee bread is mainly composed of flower pollen, which by its nature has a high adsorption capacity. It easily bioaccumulates heavy metals and toxins not only from the cell sap of plants but also directly from the atmosphere. Plants absorb As mainly through their roots from the soil. However, bees and their products of life

are exposed to additional effects. They collect water to cool the hive and dissolve food. If this water is contaminated, the toxin gets into honey and bee bread regardless of how much it is contained in honey plants.

It is also interesting that the mass fraction of As in honey (0.17 ± 0.11 mg/kg) is significantly higher than in honey plants (< 0.0001 mg/kg) collected for the study. A probable reason may be the fact that bees evaporate a significant part of the water from nectar to make honey. If there was a microscopic dose of As in nectar, then after condensation its concentration per unit mass increases.

According to the results of our analysis (Table 1), it was found that the mass fraction of Cd in bee bread is 0.01 ± 0.05 mg/kg, which is only 0.04 mg/kg lower than the permissible level established in Ukraine [15]. At the same time, the coefficient of Cd transfer from honey plants to bee bread is the highest among the obtained results (0.13) but does not indicate a critical level of bioaccumulation. Some researchers associate the accumulation of Cd in bee pollen with military aircraft [22]. Therefore, it is advisable to continue monitoring its level in areas that are in military conflict zones.

The mass fraction of Pb in bee bread is 0.15 ± 0.01 mg/kg, which is higher than its concentration in honey (0.09 ± 0.01 mg/kg). The bioaccumulation of this heavy metal in honey is 0.03 lower than in bee bread. The higher concentration of heavy metals in bee bread compared to honey is due to the fact that pollen is a direct product of collection from plant anthers, which absorb toxic substances from the air, soil, and precipitation. Pollen is not purified and accumulates heavy metals directly from the environment, unlike honey, which undergoes a fermentation process by bees. Honey undergoes complex physiological processes in the bee, which act as a kind of filter, reducing the concentration of pollutants compared to pollen.

This confirms the results of previous studies [23], which indicate that bees act as biofilters for toxic metals and prevent contamination of honey.

Heavy metal contamination of honey plants did not affect the mineral composition of honey, which is consistent with the results reported by other researchers [21]. The concentration of Cd in honey (0.007 ± 0.01 mg/kg) is significantly lower than in bee bread and honey plants but is close to the maximum limits established in the EU and Ukraine. This indicates that honey bees have the ability to remove Cd from honey.

Based on the results of our study (Table 1), the coefficient of transfer of Cd from wild honey plants to honey (0.09) is lower than the coefficient of its transfer to bee bread. Due to these features, pollen is more often used as a bioindicator of the ecological state of the area than honey [24].

Taking into account all the results obtained, beekeeping products produced within the 30-kilometer zone of military operations are safe but require further monitoring.

The practical significance of our study is that the results will be useful for beekeepers and consumers of beekeeping products. The results could be used to further assess the ecological state of this area. The limitations of this study include the fact that there are no maximum permissible concentrations specifically for honey plants. When analyzing the data, the norms of permissible concentrations of heavy metals in plants were used. This does not make it possible to fully establish whether there is currently a problem of accumulation of heavy metals in beekeeping products as a result of military aggression.

The disadvantage of this study is that the samples collected at only one private household in this settlement were

analyzed. In addition, honey plants within a radius of 2 km from the household plot were analyzed, as the most likely place for bees to collect nectar and pollen, but it is known that the radius of bee work is much larger.

Therefore, there is a need for further research aimed at monitoring the level of safety of beekeeping products in this area.

7. Conclusions

1. We have found that the mass fraction of Pb in honey plants exceeds the maximum permissible level by 5.5–8.2 times, which may be associated with military influence on the studied area. The mass fraction of Cd (0.08 ± 0.04 mg/kg) and As (< 0.0001 mg/kg) are within the permissible limits.

2. The mass fraction of heavy metals in bee bread and honey is within the permissible limits. However, the content of As (0.27 ± 0.05 mg/kg) in bee bread and Pb (0.09 ± 0.01 mg/kg) and Cd (0.007 ± 0.01 mg/kg) in honey is quite high. Considering that the content of heavy metals in honey is lower than their content in bee bread, it can be stated that bees are capable of reducing the concentration of pollutants in apiproducs.

3. The translocation factor for heavy metals transferred from honey plants to bee products does not exceed 1. Their translocation is not critical. However, given the high bioaccumulation of Pb in honey plants in the studied area, it is advisable to monitor the safety indicators of bee products.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study, as well as the results reported in this paper.

Funding

This study was funded by the National Research Foundation of Ukraine within the framework of scientific topic 0125U001049 “Studying the impact of hostilities on the possibility of obtaining safe agricultural products.”

Data availability

All data are available, either in numerical or graphical form, in the main text of the manuscript.

Use of artificial intelligence

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

Authors' contributions

Maryna Samilyk: Conceptualization, Investigation, Resources, Writing – Reviewing and Editing, Supervision, Project Administration; **Svetlana Tkachuk:** Resources, Writing – Drafting, Funding; **Volodymyr Onoprienko:** Verification, Formal Analysis, Funding; **Larysa Yepyk:** Methodology, Data

Curation, Funding; **Oleh Bakhmat**: Verification, Formal Analysis, Funding; **Danylo Plahitiy**: Methodology, Writing – Drafting, Funding; **Tetiana Krachan**: Writing – Drafting, Funding;

Anna Hotvianska: Writing – Drafting, Funding; **Dmytro Kisił**: Writing - Drafting, Funding; **Dmytro Nahirnyy**: Writing – Drafting, Visualization, Funding.

References

- Girotti, S., Ghini, S., Ferri, E., Bolelli, L., Colombo, R., Serra, G. et al. (2020). Bioindicators and biomonitoring: honeybees and hive products as pollution impact assessment tools for the Mediterranean area. *Euro-Mediterranean Journal for Environmental Integration*, 5 (3). <https://doi.org/10.1007/s41207-020-00204-9>
- Fuente-Ballesteros, A., Ciulu, M., Haque, S. M., Syrgabek, Y., Basaran, B. (2025). Honeybees as active bioindicators of plastic pollution: Environmental exposure, analytical strategies, and monitoring perspectives. *Science of The Total Environment*, 1003, 180722. <https://doi.org/10.1016/j.scitotenv.2025.180722>
- Glevitzky, M., Corcheș, M.-T., Popa, M., Vică, M. L. (2025). Honey as a Bioindicator: Pollution's Effects on Its Quality in Mining vs. Protected Sites. *Applied Sciences*, 15 (13), 7297. <https://doi.org/10.3390/app15137297>
- Margaoan, R., Papa, G., Nicolescu, A., Cornea-Cipcigan, M., Kösoğlu, M., Topal, E., Negri, I. (2024). Environmental pollution effect on honey bees and their derived products: a comprehensive analysis. *Environmental Science and Pollution Research*, 32 (16), 10370–10391. <https://doi.org/10.1007/s11356-024-33754-4>
- Zavrtnik, S., Loborec, J., Kapelj, S., Grčić, I. (2024). Environmental Biomonitoring of Heavy and Toxic Metals Using Honeybees and Their Products – An Overview of Previous Research. *Sustainability*, 16 (19), 8526. <https://doi.org/10.3390/su16198526>
- Tong, D. Q., Gill, T. E., Sprigg, W. A., Van Pelt, R. S., Baklanov, A. A., Barker, B. M. et al. (2023). Health and Safety Effects of Airborne Soil Dust in the Americas and Beyond. *Reviews of Geophysics*, 61 (2). <https://doi.org/10.1029/2021rg000763>
- Borsuk, G., Sulborska, A., Stawiarz, E., Olszewski, K., Wiącek, D., Ramzi, N. et al. (2021). Capacity of honeybees to remove heavy metals from nectar and excrete the contaminants from their bodies. *Apidologie*, 52 (6), 1098–1111. <https://doi.org/10.1007/s13592-021-00890-6>
- Godebo, T. R., Stoner, H., Taylor, P., Jeuland, M. (2025). Metals in honey from bees as a proxy for environmental contamination in the United States. *Environmental Pollution*, 364, 125221. <https://doi.org/10.1016/j.envpol.2024.125221>
- Demková, L., Hauptvogel, M., Oboňa, J., Bobuľská, L., Jančo, I., Harangozo, L. et al. (2024). Comprehensive assessment of mercury contamination in bees, bee products and moss and lichen bags. *Ecotoxicology and Environmental Safety*, 285, 117132. <https://doi.org/10.1016/j.ecoenv.2024.117132>
- Altahaan, Z., Dobsław, D. (2024). The Impact of War on Heavy Metal Concentrations and the Seasonal Variation of Pollutants in Soils of the Conflict Zone and Adjacent Areas in Mosul City. *Environments*, 11 (11), 247. <https://doi.org/10.3390/environments11110247>
- Samilyk, M. (2025). Assessment of the state of lead contamination of soil and agricultural products in the territory near the combat zone. *EUREKA: Life Sciences*, 4, 30–38. <https://doi.org/10.21303/2504-5695.2025.004071>
- Zolfaghari, G., Akhgarı Sang Atash, Z., Sazgar, A. (2018). Baseline heavy metals in plant species from some industrial and rural areas: Carcinogenic and non-carcinogenic risk assessment. *MethodsX*, 5, 43–60. <https://doi.org/10.1016/j.mex.2018.01.003>
- Tsytsiura, Ya. H., Shkatula, Yu. M., Zabarna, T. A., Pelekh, L. V. (2022) Innovatsiyni pidkhody do fitoremediatsiyi ta fitorekultyvatsiyi u suchasnykh systemakh zemlerobstva. Vinnitsia: TOV «Druk», 1200. Available at: <https://repository.vsau.org/getfile.php/31038.pdf>
- Aldgini, H. M. M., Abdullah Al-Abbadi, A., Abu-Nameh, E. S. M., Alghazeer, R. O. (2019). Determination of metals as bio indicators in some selected bee pollen samples from Jordan. *Saudi Journal of Biological Sciences*, 26 (7), 1418–1422. <https://doi.org/10.1016/j.sjbs.2019.03.005>
- Skrypka, G., Naidich, O., Timchenko, O., Dankevych, N. (2023). Toxicological and microbiological criteria for the safety of pollen load and propolis. *Agrarian Bulletin of the Black Sea Littoral*, 109, 95–102. <https://doi.org/10.37000/abbsl.2023.109.15>
- Šerevičienė, V., Zigmontienė, A., Paliulis, D. (2022). Heavy Metals in Honey Collected from Contaminated Locations: A Case of Lithuania. *Sustainability*, 14 (15), 9196. <https://doi.org/10.3390/su14159196>
- Anderson, C. W. N., Smith, S. L., Jeyakumar, P., Thompson-Morrison, H., Cavanagh, J.-A. E. (2022). Forage crops and cadmium: How changing farming systems might impact cadmium accumulation in animals. *Science of The Total Environment*, 827, 154256. <https://doi.org/10.1016/j.scitotenv.2022.154256>
- Samilyk, M., Bokovets, S., Kovalenko, O., Ryzhkova, T., Hnoievyi, I., Hrinchenko, D. et al. (2025). Revealing the impact of military activities on the safety of agricultural produce. *Eastern-European Journal of Enterprise Technologies*, 6 (11 (138)), 47–53. <https://doi.org/10.15587/1729-4061.2025.343273>
- Samilyk, M., Synenko, T., Bolgova, N., Lukhanin, B., Borozenets, N. (2025). Assessment of the risk of pollution of the ecosystem and agricultural products in the zone of military conflict. *Technology Audit and Production Reserves*, 5 (3 (85)), 23–28. <https://doi.org/10.15587/2706-5448.2025.341902>
- Scott, S. B., Gardiner, M. M. (2025). Trace Metals in Nectar of Important Urban Pollinator Forage Plants: A Direct Exposure Risk to Pollinators and Nectar-Feeding Animals in Cities. *Ecology and Evolution*, 15 (4). <https://doi.org/10.1002/ece3.71238>
- Tomczyk, M., Zaguła, G., Kaczmarek, M., Puchalski, C., Dżugan, M. (2023). The Negligible Effect of Toxic Metal Accumulation in the Flowers of Melliferous Plants on the Mineral Composition of Monofloral Honeys. *Agriculture*, 13 (2), 273. <https://doi.org/10.3390/agriculture13020273>
- Végh, R., Csóka, M., Sörös, C., Sipos, L. (2021). Food safety hazards of bee pollen – A review. *Trends in Food Science & Technology*, 114, 490–509. <https://doi.org/10.1016/j.tifs.2021.06.016>
- Dżugan, M., Wesolowska, M., Zaguła, G., Kaczmarek, M., Czernicka, M., Puchalski, C. (2018). Honeybees (*Apis mellifera*) as a biological barrier for contamination of honey by environmental toxic metals. *Environmental Monitoring and Assessment*, 190 (2). <https://doi.org/10.1007/s10661-018-6474-0>
- Li, D., Liu, J., Yuan, Y., Chen, J., Mu, J. (2025). Cadmium Contaminants in Pollen and Nectar Are Variably Linked to the Growth and Foraging Behaviors of Honey Bees. *Insects*, 16 (3), 306. <https://doi.org/10.3390/insects16030306>