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INTENSITY OF TRANSITION OF HEAVY METALS AND CONTENT OF NON-ESTERIFIED FORMS OF FATTY ACIDS IN NEWLY CONSTRUCTED BEE COMBS

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Background. There is a debate in the literature about the presence of heavy metals, including toxic ones, in freshly built bee combs (tongues). At the same time, heavy metals in the wax-synthesizing glands of bees are involved in the synthesis of various forms of fatty acids. There are also no data in the literature on the coefficients of the transition of heavy metals from bee pollen and abdominal tissues of bees to wax during its synthesis in the wax-synthesizing glands and the content of various forms of fatty acids in freshly built bee combs (tongues) in territories with different ecological situations.

Materials and Methods. The material for research was selected in the mountainous, foothill, and forest-steppe territories of the Carpathian region. The content of heavy metals in the selected material was determined, as well as the transition coefficients of heavy metals from bee pollen and bee abdomen tissues to wax during its synthesis in the wax-synthesizing glands of bees. Heavy metals in wax-synthesizing glands of bees are involved in the metabolic processes of fatty acids. In connection with the above, the content of non-esterified forms of fatty acids was determined in freshly built bee combs. The obtained research results were statistically processed.

Results. It was established that the content of heavy metals in bee pollen, abdominal tissues of bees, and in freshly built bee combs increases in the direction from the mountain to the foothills and further to the forest-steppe territories of the Carpathian region. At the same time, the transition coefficients of heavy metals from bee pollen and the abdominal tissues of honey bees to bee combs are increasing in the above direction. At the same time, the content of non-esterified forms of fatty acids decreases in freshly built bee combs. Given that studies on the ecological state of the environment are being conducted worldwide, we propose using the content of heavy metals in newly constructed bee combs as an indicator.

Conclusion. In the direction from the mountains to the foothills and further to the forest-steppe territories of the Carpathian region, the content of heavy metals in bee pollen, bee abdomen tissues, and in newly constructed bee combs increases. In the above direction, the transition coefficients of heavy metals from bee pollen and bee abdomen tissues to bee combs are increasing. The total content of non-esterified fatty acids in bee combs from the foothills, and especially from the forest-steppe area of the Carpathian region, is lower than in the combs from the mountain area. Additionally, in the above direction, the total content of non-esterified fatty acids, which exhibit antimicrobial activity, decreases. All over the world, the search for means of bioindication of the ecological state of the environment is underway. We found that freshly built bee combs can serve as bioindicators of the ecological state of the environment.

Keywords: bee pollen, bee abdominal tissues, bee combs, content and transition of heavy metals, non-esterified fatty acids, territories of the Carpathian region

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INTRODUCTION

The main purpose of wax creation by the bee family is the construction of honeycombs (Bogdanov, 2015; Gallo & Chittka, 2018; Fedak, 2022). Beeswax consists mainly of esters of monobasic fatty acids and higher monoatomic alcohols (Hepburn *et al*., 2014; Finley *et al*., 2018; Kastratović, 2022; Furse *et al*., 2023; Xu *et al*., 2024; Roy, 2024). The non-esterified forms of fatty acids present in the wax exhibit pronounced antimicrobial activity and the ability to bind heavy metals, while forming low-active anionic forms of fatty acids (de Carvalho & Caramujo, 2018; Krendlinger, 2023).

The quality indicators of the wax strongly depend on the region and the forage of the bees (Guimarães & Venâncio, 2022; Gałczyńska *et al*., 2025). The best wax is produced in steppe areas (Mischenko *et al*., 2020). Bee pollen, compared to sugar syrup, has a much stronger effect on the quality indicators of wax (Fedak, 2022).

The aim of this work was to determine the transition coefficients of heavy metals from bee pollen and abdominal tissues of bees, as well as the content of non-esterified fatty acids in newly constructed bee combs (tongues) in different territories of the Carpathian region with different ecological situations.

The study addressed this particular combination of indicators because heavy metals, specifically zinc, copper, and cobalt, are part of enzymes and are involved in the synthesis, transformation, and oxidation of fatty acids in the body of bees (Rai *et al.*, 2019).

Transition coefficient is a generally accepted term in beekeeping that indicates the ratio of the content of certain substances (in this case – heavy metals) in tissues of bees relative to their content in forage or other tissues.

MATERIALS AND METHODS

To determine the transition coefficients, the content of heavy metals in bee pollen, bee abdominal tissues, and in newly constructed bee combs selected from bee combs located in the mountain, foothill, and forest-steppe areas of Lviv region was studied (**Fig. 1**). The content of heavy metals in the selected samples was determined using an atomic absorption spectrophotometer (Vlizlo *et al*., 2012).

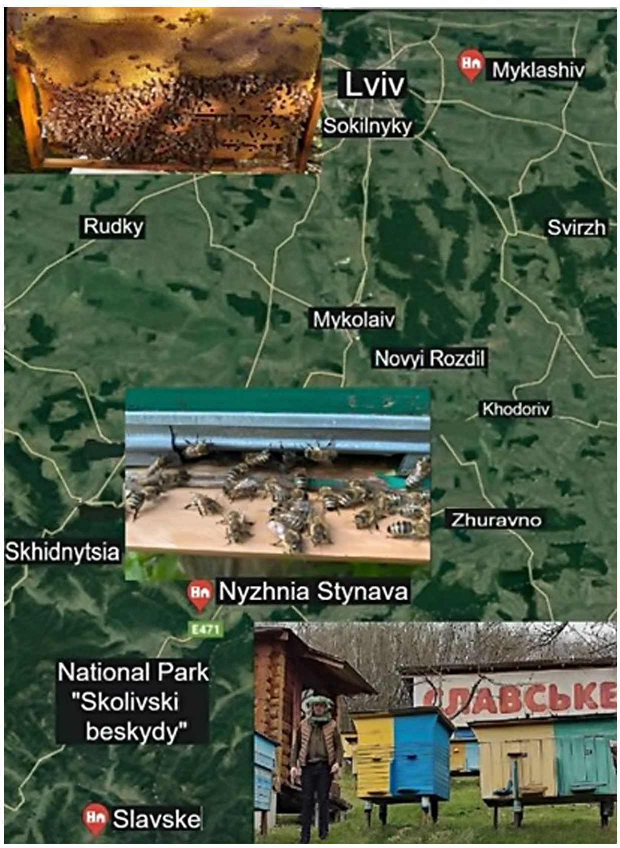


Fig. 1. Localization of model micropopulation ecosystems of bee apiaries (Slavske village – mountain micropopulation; Nyzhnia Stynava village – foothill micropopulation; Myklashiv village – forest-steppe micropopulation)

The content of heavy metals (iron, zinc, copper, cobalt, chromium, nickel, lead, and cadmium) in the collected samples of bee pollen loads, abdominal tissues of honey bees, and freshly built honeycombs was determined following the current national standard (DSTU 4405:2005) using a Selmi-115 atomic absorption spectrophotometer. For this purpose, the samples of bee pollen loads, abdominal tissues of honey bees, and freshly built honeycombs were introduced into the instrument in the form of solutions obtained by dry ashing followed by dissolution of the resulting ash in concentrated hydrochloric acid. During the analysis, weighed portions of the test material were placed into pre-calcined crucibles and dried in a drying oven at a temperature of 100–105 °C. The dried samples were then incinerated in a muffle furnace at a temperature of 450–500 °C until complete ashing. After ashing was complete, the crucibles were cooled, and the ash was dissolved in 10 mL of 10% hydrochloric acid (HCl). The resulting acidic ash solutions were analyzed spectrophotometrically at specific wavelengths using the aforementioned atomic absorption spectrophotometer, which was equipped with software that, taking into account the dilution factor, provided digital data on the concentrations of the studied heavy metals.

To determine the transfer coefficients of heavy metals from bee pollen loads and abdominal tissues of honey bees into the honeycombs, we calculated the ratio of the heavy metal content in the honeycombs to their content in the bee pollen loads and abdominal tissues of honey bees (Rivis *et al.*, 2024).

The concentrations of esterified, non-esterified, and anionic forms of long-chain fatty acids in the studied biological material were determined by gas-liquid chromatography according to the method of J. F. Rivis (Rivis *et al*., 2024). Specifically, the content of esterified forms of fatty acids was determined by lipid extraction using a chloroform–methanol mixture (2:1, v/v). Lipids freed from chloroform were dissolved in hexane in a test tube. A solution of sodium methylate in methanol was then added to the tube, followed by vigorous shaking. After phase separation, approximately 1 µL of the upper hexane layer was injected into the evaporator of the gas-liquid chromatograph.

The concentration of non-esterified fatty acids in the examined bee pollen loads and pollen was determined through lipid extraction using a chloroform–methanol mixture (2:1, v/v). From the chloroform lipid extract, non-esterified fatty acids were isolated using a solution of sodium methylate in methanol. The isolated fatty acids were methylated with methanol in the presence of a catalyst – acetyl chloride. The resulting methyl esters of fatty acids were then injected into the evaporator of the gas-liquid chromatograph.

To determine the content of anionic forms of fatty acids, the bee pollen and pollen samples were treated with two different extraction mixtures: in one case, a mixture of chloroform–methanol–hydrochloric acid (200:100:1, v/v), and in the other, a mixture of chloroform–methanol (2:1, v/v). Lipids extracted and freed from chloroform in both cases were saponified with sodium methylate, and the resulting fatty acids were methylated with methanol in the presence of acetyl chloride as a catalyst. The resulting methyl esters of fatty acids were injected into the evaporator of the gas-liquid chromatograph. The difference in fatty acid content between the two extracts represented their anionic components.

Separation of fatty acid methyl esters was carried out using the method of J. F. Rivis *et al*. on a “Chrom-5” gas-liquid chromatograph (“Laboratorni pristroje”, Prague). A stainless steel column, 3700 mm in length and 3 mm in internal diameter, was packed with Chromaton-N-AW (60–80 mesh), silanized with HMDS (hexamethyldisilazane), and coated with 10% polyethylene glycol adipate as the stationary liquid phase. The flow rate of the carrier gas, chemically pure and dried nitrogen (mobile phase), through the column at an inlet pressure of $1.5 \cdot 10^5$ Pa, was approximately 65 mL/min. Flame combustion was maintained with hydrogen (25 mL/min) and air (380 mL/min). The isothermal operation of the packed column with a polar liquid phase was maintained at 196 °C, while the temperatures of the evaporator and detector were set at 245 °C. A flame ionization detector (FID) was used.

Under these conditions, the column ensured good separation of fatty acid methyl esters. Column efficiency, determined according to McNair and Bonelli for the commonly accepted reference peak on the chromatogram – methyl ester of palmitic acid – was 1827±118 theoretical plates.

Peak identification on the chromatogram was performed using the "carbon number" calculation method, as well as through the use of chemically pure standard solutions of fatty acid methyl esters. The content of individual fatty acids, based on the results of gas chromatographic analysis (chromatograms), was calculated using a formula incorporating correction factors for each acid. These correction factors were determined as the ratio of peak areas (or peak heights) of heptadecanoic acid (used as an internal standard) and the analyzed acids at a 1:1 concentration ratio under isothermal conditions on the gas-liquid chromatograph.

Statistical analysis of the obtained results was carried out using MS Excel 2016 and Statistica programs (Ibatullin & Zhukorskyi, 2017; Wilcox, 2022). The data on the content of heavy metals, summarized in **Table 1**, were analyzed by two-way ANOVA, where one factor was the area of sample collection (has three levels: mountain, foothill, and forest-steppe regions) and the second factor was the biomaterial (has three levels: bee pollen, abdominal tissues, and bee combs). The data summarized in **Fig. 1** (heavy metal exchange coefficients) and **Table 2** (content of non-esterified fatty acids in bee combs) were analyzed by one-way ANOVA, where the independent factor was the area of sample collection (has three levels: mountain, foothill, and forest-steppe regions). All data are presented as a mean (M) ± standard error of mean (SE), $n = 3$. P values of <0.05 or lower were interpreted as statistically significant.

Manipulations with animals were carried out under the principles of the "General Ethical Principles of Experimentation on Animals" approved by the First National Congress on Bioethics (Kyiv, Ukraine, 2001).

RESULTS AND DISCUSSION

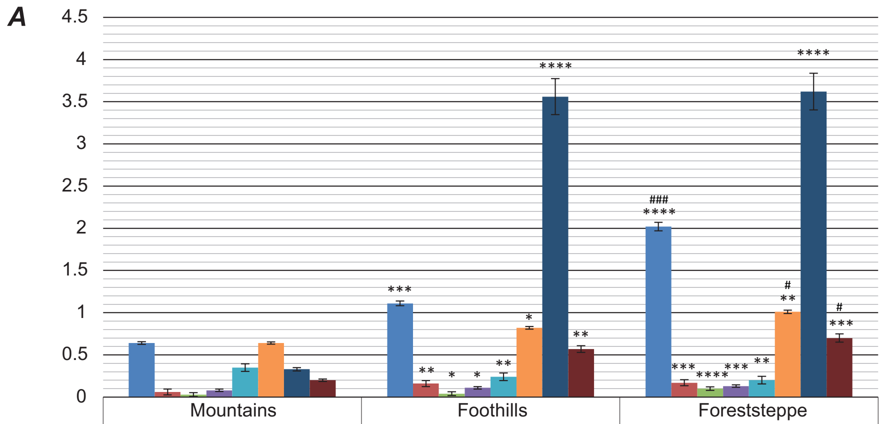
It was established (**Table 1**) that in the direction from the mountain to the foothills and further to the forest-steppe territories of the Carpathian region, the content of heavy metals in bee pollen, bee abdomen tissues and in newly constructed bee combs increases as well as the transition coefficients of heavy metals from bee pollen and abdominal tissues of honey bees to bee combs (**Fig. 2**). The above indicates that bee pollen through the alimentary canal and its wall and further through the lymph has a strong influence on the transition coefficients and the content of heavy metals in bee combs.

It is noteworthy that some heavy metals have high transition coefficients from bee pollen and bee abdomen tissues to bee combs, while others average and still others – low. It can be seen that the bee's body can regulate the interstitial transition of heavy metals to some extent.

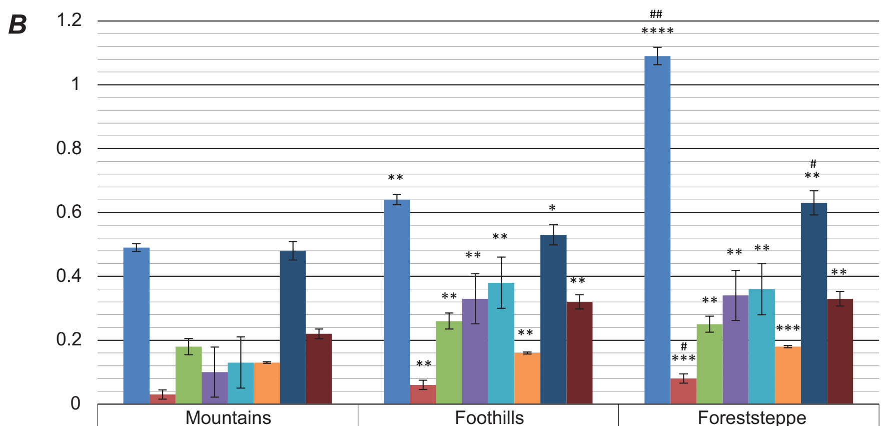
Table 1. **The content of heavy metals, including toxic ones, in bee pollen, bee abdominal tissues, and honeycombs (M±SE, n = 3)**

Metal and its symbol	Territories of the Carpathian region		
	mountains	foothills	forest-steppe
Bee pollen, g·10^{-3}/kg of air-dry mass			
Iron, Fe	33.1±1.0^{bbbb}	37.3±0.9	43.4±2.3**
Zinc, Zn	33.6±0.8^{bbbb}	39.2±0.9$^{*,\ bbbb}$	44.3±1.8$^{**,\ bbbb}$
Copper, Cu	2.07±0.12^{bbbb}	3.02±0.17$^{*,\ bbbb}$	4.17±0.20$^{***,\ bbbb}$
Cobalt, Co	1.08±0.09^{bbbb}	1.16±0.04^{bbbb}	1.37±0.02$^{*,\ bbbb}$
Chromium, Cr	4.10±0.17^{bbbb}	5.03±0.18$^{*,\ bbbb}$	6.67±0.15$^{****,\ \#\#,\ bbbb}$
Nickel, Ni	0.58±0.01^{bb}	0.65±0.01*	0.73±0.02$^{**,\ \#}$
Lead, Pb	0.13±0.01^{bbbb}	0.17±0.01^{bbbb}	0.21±0.01$^{**,\ \#,\ bbbb}$
Cadmium, Cd	0.04±0.003	0.07±0.01	0.10±0.01$^{**,\ \#}$
Abdomen tissues of bees, g·10^{-3}/kg of raw mass			
Iron, Fe	44.8±0.8$^{aaaa,\ bbbb}$	63.7±1.0****	75.0 ±1.0****. $^{\#\#\#}$
Zinc, Zn	77.1±1.2$^{aaaa,\ bbbb}$	91.3±1.5$^{***,\ aaaa,\ bbbb}$	105.8±1.0$^{****,\ \#\#\#,\ aaaa,\ bbbb}$
Copper, Cu	0.34±0.01^{aaaa}	0.47±0.01$^{**,\ aaaa}$	0.57±0.02$^{***,\ \#,\ aaaa}$
Cobalt, Co	0.31±0.01^{aaa}	0.36±0.01$^{*,\ aaaa,\ bbb}$	0.44±0.01$^{***,\ \#,\ aaaa,\ bbbb}$
Chromium, Cr	2.43±0.04$^{aaaa,\ bbbb}$	3.21±0.10$^{**,\ aaaa,\ bbbb}$	3.79±0.10$^{****,\ \#\#,\ aaaa,\ bbbb}$
Nickel, Ni	2.83±0.05$^{aaaa,\ bbbb}$	3.40±0.07$^{**,\ aaaa,\ bbbb}$	4.13±0.06$^{****,\ \#\#\#,\ aaaa,\ bbbb}$
Lead, Pb	0.71±0.02$^{aaaa,\ bbbb}$	1.23±0.04$^{***,\ aaaa,\ bbbb}$	1.50±0.05$^{****,\ \#\#,\ aaa,\ bbbb}$
Cadmium, Cd	0.09±0.01$^{aa,\ bbb}$	0.15±0.01$^{*,\ aaa,\ bbb}$	0.21±0.01$^{***,\ \#\#,\ aa,\ bbb}$
Bee combs, g·10^{-3}/kg of natural weight			
Iron, Fe	20.9±0.3^{aaaa}	43.1±0.4**	86.5±4.1****. $^{\#\#\#\#}$
Zinc, Zn	2.15±0.12^{aaaa}	4.85±0.28$^{***,\ aaaa}$	7.95±0.25****, $^{\#\#\#,\ aaaa}$
Copper, Cu	0.06±0.003^{aaaa}	0.13±0.02$^{*,\ aaaa}$	0.17±0.01$^{**,\ aaaa}$
Cobalt, Co	0.08±0.01^{aaaa}	0.12±0.01$^{**,\ aaaa}$	0.18±0.01$^{****,\ \#\#\#,\ aaaa}$
Chromium, Cr	0.85±0.02^{aaaa}	1.17±0.03$^{***,\ aaaa}$	1.36±0.02$^{****,\ \#\#,\ aaaa}$
Nickel, Ni	0.38±0.01^{aaaa}	0.53±0.02$^{*,\ aaaa}$	0.84±0.04$^{****,\ \#\#\#,\ aaaa}$
Lead, Pb	0.42±0.01^{aaaa}	0.70±0.02$^{**,\ aaaa}$	0.97±0.06$^{***,\ \#\#,\ aaaa}$
Cadmium, Cd	0.02±0.01	0.06±0.01	0.09±0.01**

Comments: Here and further, the differences are likely compared to the mountainous area: * – $p < 0.05$; ** – $p < 0.01$; *** – $p < 0.001$; **** – $p < 0.0001$; to the foothills area: $^{\#}$ – $p < 0.05$; $^{\#\#}$ – $p < 0.01$; $^{\#\#\#}$ – $p < 0.001$; $^{\#\#\#\#}$ – $p < 0.0001$; to the bee pollen: ^{a} – $p < 0.05$; ^{aa} – $p < 0.01$; ^{aaa} – $p < 0.001$; ^{aaaa} – $p < 0.0001$; to the bee combs: ^{b} – $p < 0.05$; ^{bb} – $p < 0.01$; ^{bbb} – $p < 0.001$; ^{bbbb} – $p < 0.0001$



	Mountains	Foothills	Foreststeppe
Fe	0.64	1.11	2.02
Zn	0.06	0.16	0.17
Cu	0.03	0.04	0.1
Co	0.08	0.11	0.13
Cr	0.35	0.24	0.2
Ni	0.64	0.82	1.01
Pb	0.33	3.56	3.62
Cd	0.2	0.57	0.7



	Mountains	Foothills	Foreststeppe
Fe	0.49	0.64	1.09
Zn	0.03	0.06	0.08
Cu	0.18	0.26	0.25
Co	0.1	0.33	0.34
Cr	0.13	0.38	0.36
Ni	0.13	0.16	0.18
Pb	0.48	0.53	0.63
Cd	0.22	0.32	0.33

Fig. 2. Transition coefficients of heavy metals, including toxic ones, from bee pollen to bee combs (***A***) and bee abdominal tissues to bee combs (***B***)

Comments: Here the differences are likely compared to the mountainous area: * – p <0.05; ** – p <0.01; *** – p <0.001; **** – p < 0.0001 ; to the foothills area: $^{\#}$ – p < 0.05; $^{\#\#}$ – p <0.01; $^{\#\#\#}$ – p < = 0.001

Non-esterified forms of fatty acids are very active. It was found (**Table 2**) that in bee combs collected from hives located in the foothills and especially forest-steppe areas of the Carpathian region, compared to the bee combs of the mountain area, the content of non-esterified fatty acids decreases (respectively, 252.84 and 202.88 vs. 328.88 g/kg of natural weight), which affects their antimicrobial activity (Guimarães & Venâncio, 2022).

Table 2. **The content of non-esterified forms of fatty acids in bee combs (tongues), g/kg of natural weight (M±SE, n = 3)**

Fatty acid and its code	Territories of the Carpathian region		
	mountains	foothills	forest-steppe
Caprylic, 8:0	0.67±0.04	0.42±0.02***	0.34±0.02****, ##
Caprynic, 10:0	0.28±0.02	0.14±0.02***	0.10±0.01****, ##
Lauric, 12:0	0.34±0.01	0.23±0.01**	0.14±0.01****, #
Myristic, 14:0	0.36±0.35	0.21±0.01*	0.16±0.01**
Pentadekanic, 15:0	0.15±0.01	0.07±0.01**	0.05±0.01***
Palmitic, 16:0	0.28±0.20	0.18±0.01*	0.15±0.01**
Palmitoleic, 16:1	0.49 ±0.01	0.30±0.01***	0.26±0.01****, #
Stearic, 18:0	5.47±0.26	3.84±0.08***	3.32±0.34***
Oleic, 18:1	23.77±1.44	16.48±1.22*	13.65±0.80**
Linoleic, 18:2	2.55±0.25	1.36±0.03***	0.98±0.08****, #
Linolenic, 18:3	40.14±1.17	26.20±1.05***	17.87±1.56***, #

Comments: Here and further, the differences are likely compared to the mountainous area: * – p <0.05; ** – p <0.01; *** – p <0.001; **** – p <0.0001; to the foothills area: # – p <0.05; ## – p <0.01; ### – p <0.001; #### – p <0.0001

The decrease in the content of non-esterified forms of fatty acids in newly constructed bee combs (tongues) is accompanied by a strong increase in the ratio of the level of non-esterified forms of polyunsaturated fatty acids of the ω-3 family to the ω-6 family (19.26 and 18.23 vs. 15.74, respectively), which appears to be related to the protective function of the wax-synthesizing glands with regard to the future comb.

Non-esterified forms show antimicrobial activity (Fratini *et al*., 2016). The antimicrobial activity of saturated fatty acids in bee combs is due to their low concentration of hydrogen ions, and this property of unsaturated fatty acids is due to the ability, thanks to double bonds, to affect the cell membranes of microorganisms (Fratini *et al*., 2016). Thus, their total content in bee combs of the foothills and especially forest-steppe areas of the Carpathian region, compared to combs selected from bee combs located in the mountainous area, decreases (respectively to 239.04 and 198.86 against 323.13 g/kg of natural weight).

Non-esterified forms of fatty acids in beeswax have the most pronounced ability to bind heavy metals, primarily divalent (de Carvalho & Caramujo, 2018; Kumar *et al*., 2019). Binding of non-esterified forms of long-chain fatty acids to heavy metals takes place in the wax glands of honey bees (Hu *et al*., 2017). At the same time, less active anionic forms of fatty acids are formed (Blanco *et al*., 2019).

Thus, the content of heavy metals and non-esterified fatty acids in freshly built bee combs can serve as an indicator of technogenic pollution of the territory (Didukh, 2012).

CONCLUSIONS

In the direction from the mountains to the foothills and further to the forest-steppe territories of the Carpathian region, the content of heavy metals in bee pollen, bee abdomen tissues, and in newly constructed bee combs increases. In the above direction, the transition coefficients of heavy metals from bee pollen and bee abdomen tissues to bee combs are increasing. The total content of non-esterified fatty acids in bee combs from the foothills, and especially from the forest-steppe area of the Carpathian region, is lower than in the combs from the mountain area. Additionally, in the above direction, the total content of non-esterified fatty acids, which exhibit antimicrobial activity, decreases. All over the world, the search for means of bioindication of the ecological state of the environment is underway. We found that freshly built bee combs can serve as bioindicators of the ecological state of the environment.

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COMPLIANCE WITH ETHICAL STANDARDS

Conflict of Interest: the authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Human Rights: this article does not contain any studies with human subjects performed by any of the authors.

Animal studies: all international, national, and institutional guidelines for the care and use of laboratory animals were followed.

AUTHOR CONTRIBUTIONS

Conceptualization, [Y.R.; V.P.]; methodology, [Y.R.]; validation, [O.H.; A.Sh.; I.S.]; formal analysis, [O.S.; O.D.; U.F.].; investigation, [Y.R.; O.K.; A.Sh.]; resources, [O.H.; A.Sh.; O.D.; O.B.]; data curation, [O.H.; A.Sh.; O.S.]; writing – original draft preparation, [Y.R.; V.P.; A.Sh.; O.H.]; writing – review and editing, [A.Sh.; O.H.; O.S.; O.D.; U.F.]; visualization, [Y.R.; A.Sh.; O.D.]; supervision, [Y.R.; V.P.; A.Sh.; O.H.]; project administration, [Y.R.; V.P.]; funding acquisition, [Y.R.;D.Z].

All authors have read and agreed to the published version of the manuscript.

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ІНТЕНСИВНІСТЬ ПЕРЕХОДУ ВАЖКИХ МЕТАЛІВ І ВМІСТ НЕЕСТЕРИФІКОВАНИХ ЖИРНИХ КИСЛОТ У СВІЖОПОБУДОВАНИХ БДЖОЛИНИХ СТІЛЬНИКАХ

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Актуальність. У літературі точиться дискусія щодо наявності важких металів, зокрема, токсичних, у свіжопобудованих бджолиних стільниках (язиках). Одночасно важкі метали у воскосинтезувальних залозах бджіл причетні до синтезу неестерифікованих жирних кислот. У літературі немає також даних щодо коефіцієнтів переходу важких металів із бджолиного обніжжя (пилку рослин) і тканин черевця бджіл у віск під час його синтезу у воскосинтезувальних залозах та вмісту неестерифікованих жирних кислот у свіжопобудованих бджолиних стільниках (язиках) на територіях із різною екологічною ситуацією.

Матеріали і методи. Матеріал для досліджень відбирали на гірській, передгірній і лісостеповій територіях Карпатського регіону. У відібраному матеріалі визначали вміст важких металів, а за ним – перехід важких металів із бджолиного обніжжя і тканин черевця бджіл у віск під час його синтезу у воскосинтезувальних залозах бджіл. Важкі метали у воскосинтезувальних залозах бджіл беруть участь в обмінних процесах жирних кислот. У зв'язку з вищенаведеним у свіжопобудованих бджолиних стільниках визначали вміст неестерифікованих жирних кислот. Отримані результати досліджень оброблені статистично.

Результати. Встановлено, що в напрямку від гірської до передгірної та далі до лісостепової територій Карпатського регіону зростає вміст важких металів у бджолиному обніжжі, тканинах черевця медоносних бджіл і у свіжопобудованих бджолиних стільниках. Одночасно в наведеному вище напрямку зростають коефіцієнти переходу важких металів із бджолиного обніжжя і тканин черевця медоносних бджіл у бджолині стільники. Водночас у свіжопобудованих бджолиних стільниках зменшується вміст неестерифікованих жирних кислот. У зв'язку з тим, що в усьому світі ведуться дослідження екологічного стану довкілля, ми пропонуємо використовувати вміст важких металів у свіжопобудованих бджолиних стільниках як індикатор.

Висновки. У напрямку від гір до передгір'їв і далі до лісостепових територій Карпатського регіону вміст важких металів у бджолиному обніжжі, тканинах черевця бджіл і у щойно збудованих стільниках зростає. У зазначеному напрямку також зростають коефіцієнти переходу важких металів із бджолиного обніжжя та тканин черевця бджіл у стільники. Загальний вміст неестерифікованих жирних кислот у стільниках із передгір'їв, а особливо з лісостепової зони Карпатського регіону, є нижчим, ніж у стільниках із гірської місцевості. Крім того, у вказаному напрямку знижується загальний вміст неестерифікованих жирних кислот, що характеризуються антимікробною активністю. У всьому світі тривають пошуки засобів біоіндикації екологічного стану довкілля. Ми встановили, що щойно збудовані бджолині стільники можуть слугувати біоіндикатором екологічного стану навколишнього середовища.

Ключові слова: бджолине обніжжя, тканини черевця бджіл, бджолині стільники, вміст і перехід важких металів, неестерифіковані жирні кислоти, території Карпатського регіону

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