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RESEARCH ON THE CONTENT OF HEAVY METALS AND SPECIFIC ACTIVITY OF RADIONUCLIDES IN BEE'S WAX DEPENDING ON THE CONDITIONS OF RAW MATERIAL PROCESSING

Relevance. *Beeswax is a biologically active product that is widely used in the pharmaceutical, food, and cosmetics industries due to its regenerative, antibacterial, anti-inflammatory, and antioxidant properties. However, beeswax can also accumulate radionuclides and heavy metals from the environment which, creates a need to develop effective methods for cleaning wax to ensure its safe use.*

The purpose *of the study to determine the influence of wax raw material processing conditions on the content of heavy metals and the specific activity of radionuclides in beeswax.*

Materials and methods. *In the conducted studies, two groups of bee colonies were formed according to the principle of analogues using different operating conditions of building frames. To assess the effect of pre-soaking of wax raw materials, three experimental batches were formed, which differed in water treatment modes. Studies of wax safety indicators were carried out taking into account the effect of the method of processing wax raw materials and the temperature of water during its soaking. To assess the quality of wax, generally accepted and special methods of physicochemical analysis, atomic absorption spectroscopy for determining the content of heavy metals, radiometric and radiochemical methods for assessing the specific activity of radionuclides, as well as mathematical and statistical methods for processing experimental data.*

Research results*. It has been proven that repeatedly soaking wax raw materials until the transfer of non-wax components stops significantly reduces the specific activity of radionuclides (for example, ^{137}Cs and ^{90}Sr) and the concentration of heavy metals (for example, Pb and Cd) in wax.*

The specific activity of ^{137}Cs decreased by 35.9%, ^{90}Sr by 2.0 times, the concentrations of Pb and Cd by 2.4 and 6.0 times, respectively, which ensures increased radiological and toxicological safety of the product. By increasing the water temperature to 60 °C and and using a dry processing method further improves the cleaning efficiency, reducing the levels of contamination and improving the quality of wax.

Conclusion. *It was found that among the studied technological operations for processing wax raw materials (soaking frequency, water and air temperature, wet and dry processing methods), the highest efficiency of reducing the specific activity of radionuclides (^{137}Cs and ^{90}Sr) and the content of heavy metals (Pb and Cd) in wax was observed with repeated washing of non-wax components from wax raw materials until their transition to water was stopped.*

Key words: *beeswax, radionuclides, heavy metals, wax purification, wax raw materials, soaking raw materials, temperature regime, dry and wet processing methods.*

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ДОСЛІДЖЕННЯ ВМІСТУ ВАЖКИХ МЕТАЛІВ ТА ПИТОМОЇ АКТИВНОСТІ РАДІОНУКЛІДІВ У БДЖОЛИНОМУ ВОСКУ ЗАЛЕЖНО ВІД УМОВ ОБРОБКИ СИРОВИНИ

Актуальність. *Бджолиний віск є важливим біологічно активним продуктом, що широко застосовується в медицині, фармації, харчовій та косметичній промисловості завдяки своїм регенеративним, антибактеріальним, протизапальним та антиоксидантним властивостям. Водночас він здатний накопичувати радіонукліди та важкі метали з навколишнього сере-*

довища, що створює потребу в опрацюванні ефективних методів очищення воску для забезпечення безпеки його використання.

***Мета дослідження** – з'ясування впливу умов обробки воскової сировини на вміст важких металів і питому активність радіонуклідів у бджолиному воску.*

***Матеріал і методи.** У проведених дослідженнях було сформовано дві групи бджолиних сімей за принципом аналогів із використанням різних умов експлуатації будівельних рамок. Для оцінки впливу попереднього вимочування воскової сировини сформували три експериментальні партії, які відрізнялися режимами обробки водою. Дослідження показників безпечності воску проводили з урахуванням впливу способу обробки воскової сировини та температури води під час її вимочування. Для оцінки якості воску застосовували загальноприйняті спеціальні методи фізико-хімічного аналізу, атомно-абсорбційної спектроскопії для визначення вмісту важких металів, радіометричні та радіохімічні методи для оцінки питомої активності радіонуклів, а також математично-статистичні методи обробки експериментальних даних.*

***Результати дослідження.** Доведено, що багаторазове вимочування воскової сировини до припинення переходу невоскових компонентів сприяє значному зниженню питомої активності радіонуклідів (на прикладі ^{137}Cs та ^{90}Sr) та концентрації важких металів (на прикладі Pb та Cd) у воску. Питома активність ^{137}Cs зменшилася на 35,9%, ^{90}Sr – у 2,0 рази, концентрація Pb знизилася у 2,4 раза, Cd – у 6,0 разів, що забезпечує підвищену радіологічну та токсикологічну безпеку продукту. Підвищення температури води до +60 °C та застосування сухого способу переробки додатково покращують ефективність очищення, знижуючи рівні забруднень і підвищуючи якість воску.*

***Висновок.** Установлено, що серед досліджених технологічних операцій обробки воскової сировини (кратність вимочування, температура води та повітря, вологий та сухий способи переробки) найвища ефективність зниження у воску питомої активності радіонуклідів (^{137}Cs та ^{90}Sr) та вмісту важких металів (Pb та Cd) спостерігалася за багаторазового вимивання невоскових компонентів із воскової сировини до призупинення їх переходу у воду.*

***Ключові слова:** бджолиний віск, радіонукліди, важкі метали, очищення воску, воскова сировина, вимочування сировини, температурний режим, сухий та вологий способи переробки.*

Introduction. Relevance. Beeswax is an important natural product that is widely used in phytotherapy, apitherapy, pharmacy, food and cosmetic industries. At the same time, the ability of wax raw materials to accumulate radionuclides and heavy metals creates potential risks for the safe use of wax, especially under conditions of anthropogenic environmental pollution. In this context, studies of the influence of wax raw material processing conditions on the content of heavy metals and specific activity of radionuclides in beeswax are relevant.

Beeswax is widely used in traditional and official medicine due to its unique composition and properties. Research indicates that the demand for wax is increasing annually, driven by advancements in medical practices. The composition of wax includes 80% carbon, 13% hydrogen, and 7% oxygen, with these elements forming almost 300 substances. The main component of wax is esters (70.4–74.7%), followed by hydrocarbons, which account for 12.5–15.5%, and free carboxylic acids, which account for 12–15%. It also contains small amounts of alcohols, vitamins, pigments, and other compounds. Complex wax esters are unsaturated (51–53%), saturated esters account for 10–13%, and oxyesters account for 5–18%. About 250 hydrocarbons have been identified in the composition of wax, of which 74% are normal paraffins, 4.7% are isoparaffins, and 21% are olefins (Polishchuk, 2001).

Beeswax is widely used to treat various pathological conditions. Preparations containing beeswax are used to treat burns, ulcers, wounds, boils, carbuncles, tonsillitis, sinusitis, frontal sinusitis, radiculitis, and rheumatism.

According to experimental studies by Illnait et al. (2013), a mixture of antioxidant-active beeswax alcohols (D-002) has hepatoprotective properties. Using D-002 at a daily dose of 100 mg improved ultrasound parameters, reduced insulin resistance, increased total antioxidant capacity in plasma, and improved the clinical course of non-alcoholic fatty liver disease in patients. A mixture of alcohols extracted from beeswax has shown high efficacy in modeling experimental osteoarthritis. Six weeks of use resulted in improved arthritis symptoms and good tolerability (Puente et al., 2014). Oral administration of D-002 simultaneously reduces inflammatory conditions that impair joint health and provides a gastroprotective effect (Molina et al., 2015). It also improves the quantitative and qualitative characteristics of gastric mucus, partly due to its gastroprotective effect (Carbajal et al., 2000).

The importance of beeswax is also evident in materials science and technology. Adding wax enhances the stiffness and elasticity of innovative biomaterials, as well as their hydrophobic properties. This expands their application possibilities in materials engineering and biotechnology (Ariati et al., 2024). Francisco et al. (2025) created a 3D-printed scaffold with promising physicochemical and biological properties by using wax in a composite mixture, which improved the strength of the scaffolds in wet conditions and optimized the surface properties, promoting the formation of apatite crystals and increasing cell adhesion.

Beeswax is widely used in the food, chemical, cosmetic and pharmaceutical industries, and is also a key material in beekeeping, where it is used to form honeycomb cells by bees, which store honey and royal jelly, and provide space for the development of brood. In the agri-food sector, it is used as a food additive (E901), a glazing component in the manufacture of confectionery, a coating for some fruits, and as a carrier for flavorings (Navarro-Hortal et al., 2019; Amin et al., 2017; Szulc et al., 2020). It is also widely used in food packaging, as a protective coating for cheese during ripening, as a polishing agent E901 and as a component of food coatings mixed with polylactic acid (Fratini et al., 2016).

In the pharmacies wax performs functions auxiliary substance, thickener and carrier of drugs, as well as a regulator of their release rate. Its components, in particular flavonoids and antioxidants, contribute to skin regeneration. Topical application shows antibacterial and antifungal effects, which can affect the synthesis of cytokines by skin cells (Karabey et al., 2019). In addition, beeswax has anti-inflammatory, antimicrobial, antistress and antioxidant properties, which makes it a promising component for wound care (Zhang et al., 2018). Significant effectiveness has also been demonstrated in clinical practice. Aboul Nasr et al. demonstrated that moisturizing ointment with a beeswax-based thickener helps accelerate reparative processes, reduce the incidence of complications, and increase patient satisfaction in the treatment of superficial facial burns.

The antibacterial and antifungal properties of beeswax have been demonstrated by data on its activity against several bacterial strains and the yeast Candida albicans (Ghanem, 2011). The antifungal activity of a combination of honey, beeswax and olive oil in vivo was demonstrated by Al-Waili (2004) in patients with dermatomycoses. This mixture has also shown high efficacy in the treatment of atopic dermatitis, psoriasis and diaper dermatitis (Al-Waili, 2003, 2005; Al-Waili et al., 2006; Lewis et al., 2012). Beeswax is used to manufacture and models and is an ingredient in materials for dental prosthetics and practices (Bernardini et al., 2012; Saralaya et al., 2021). It is added to cleansing ointments, face masks, plasters, whitening creams, lipsticks, and in the production of honey-wax candies, which stimulate the secretion of saliva and gastric juice and help clean teeth from tartar.

Given that beeswax is widely used in medicine and food technology, its quality control is extremely important.

In modern medical practice and healthcare systems, the quality and safety of natural raw materials are assessed from the standpoint of evidence-based medicine and traditional approaches. In the Western scientific paradigm, the main attention is paid to the standardization of the composition, toxicological control, analytical determination of impurities (heavy metals, pesticides, radionuclides) and clinical evaluation of the effectiveness of beeswax-based preparations (Bilko, & Holovetskyi, 2025; Li, & Wu, 2023; Sharma et al., 2023). In contrast, in traditional Eastern medical systems, beekeeping products are considered as complex biologically active substances with harmonizing and restorative properties, with less attention paid to the control of contaminants.

The combination of modern analytical control methods with the concept of using beekeeping products as environmental bioindicators forms an interdisciplinary approach that has a number of advantages. First, it allows for the simultaneous assessment of the quality of raw materials and the state of the ecosystem. Second, this approach provides an objective quantitative characteristic of the anthropogenic load on products. Third, the research results can be integrated into apimonitoring and environmental management systems, which increases the predictive value of the data obtained.

Compared to traditional methods of assessing the safety of beekeeping products, which are limited to organoleptic, physicochemical or microbiological indicators, the proposed approach allows taking into account long-term environmental risks associated with the accumulation of radionuclides and heavy metals in wax raw materials. This expands the possibilities of quality control and provides a scientifically sound basis for the use of beeswax in medicine, pharmacy and food technology.

It has been established that bees carry harmful substances into their nests at concentrations that can exceed those in the external environment by 1,000 to 100,000 times (Zavrtnik et al., 2024; Végh et al., 2023). In addition to radionuclides, heavy metals, in particular lead, cadmium, zinc and copper, accumulate in wax, especially in long-term combs (Zafeiraki et al., 2022). Researchers suggest that radionuclides are concentrated mainly in non-wax components, cocoons, undigested food residues, propolis and bee pollen residues (Sorokin, 2025).

Due to its high sorption capacity and lipid composition, wax functions as a natural bioindicator of environmental pollution (Ćirić et al., 2021). Zhukorskyi and Atarshchykova (2022) emphasize the need to improve the methodology for identifying sources of environmental pollution by analyzing bee tissues and products, as well as developing an apimonitoring system.

The long-term presence of radionuclides in ecosystems continues to be a pressing problem of radiological safety. Honey bees collect nectar and pollen, as well as pollen and plant secretions, which are used to produce honey, wax, bee pollen, propolis, royal jelly and other products. Radionuclides enter these products through trophic transfer and accumulate in them, which allows the use of bees and their products as effective bioindicators of radioactive contamination (Szarłowicz et al., 2025; Sorokin, 2025). Use of beekeeping products as bioindicators allows not only to assess the level of radioactive contamination, but also to track its dynamics over time, which is extremely important for managing environmental risks and ensuring the safety of food products, cosmetic and pharmaceutical materials that contain beeswax.

The purpose of the study to determine the influence of wax raw material processing conditions on the content of heavy metals and the specific activity of radionuclides in beeswax.

Materials and methods. Research on the safety of bee products and methods to improve them was conducted in apiaries located in areas contaminated with radionuclides and heavy metals across various ecological zones in Ukraine. These zones include the villages of Pershotravneve and Kamianivka in the Ovruch district; the town of Narodychi in the Narodychi district of the Zhytomyr region (Polissia); the village of Novomykolaivka in the Verkhnodniprovsk district of the Dnipropetrovsk region (Steppe); the village of Vasylivka in the Tyvriv district; the village of Agronomichne in the Vinnytsia district (Forest-Steppe).

The assessment of the effectiveness of reducing the specific activity of radionuclides (^{137}Cs, ^{90}Sr) and the concentration of heavy metals (Pb, Cd) in beeswax was based exclusively on instrumental quantitative methods of analytical control that meet the requirements of evidence-based analytical practice and current regulatory documents. The study did not involve the use of clinical criteria, but standardized instrumental methods of quantitative analysis were applied.

Fore valuation to test the effectiveness of reducing the specific activity of radionuclides and the concentration of heavy metals in wax, experimental groups of bee colonies were formed according to the principle of analogues. In one group, during the active season, each colony had 2 building frames, from which the wax cells built by the bees were removed after the larvae of drones and bees were grown in them. In the second group, 4 of the same building frames were used.frames, and during intensive honey collection their number was increased to 6; in this group, wax cells were removed from the building frames during the period of absence of brood or at the egg stage.

To evaluate the effectiveness of reducing the activity of radionuclides and the concentration of heavy metals in wax, experimental groups of bees were formed based on the principle of analogies. During the active season, each family in the first group had two frames. The wax cells built by the bees were removed from these frames after the drones and bees had been raised in them. The second group used four frames, increasing to six during the intensive honey collection period. In this group, wax cells were removed from the frames when the brood was absent or at the egg stage.

The next experiment involved separating the building frames from the brood part of the nest with a separating grid in the extensions and the upper body. After the bees rebuilt the frames in the broodless and brood parts of the nest, they were removed, the wax raw material was cut out and processed into wax.

To study the effect of preliminary removal of soluble non-wax components from wax raw materials on the specific activity of radionuclides and the concentration of heavy metals, combs were used in which up to 15 generations of bees were grown, without perga and honey. Three batches of wax raw materials were formed from these combs: the first was soaked in water for 48 hours with a single water change; the second – with three water changes during the same period; the third – with water changes until the change in its color stopped, which indicated the cessation of the transition of soluble non-wax components into the solvent. After that, the wax raw materials of the first and second batches were processed in a steam wax furnace to obtain wax, in which the specific activity of radionuclides and the concentration of heavy metals were determined.

The influence of the method of processing wax raw materials on the specific activity of radionuclides and the concentration of heavy metals was studied using two groups of combs with the same number of reared bee generations. The wax raw materials of each group were formed into two batches: one was processed in a steam wax furnace (wet method), the other – in a dry method in a solar wax furnace with the use of artificial thermal energy.

To evaluate the effect of water temperature when soaking wax raw materials was formed into three batches: the first was treated with water at +20 ºC, the second at +40 ºC, and the third at +60 ºC. The water temperature during soaking of the wax raw materials was maintained at the appropriate values, which was maintained using a bath.water VB-4 with a thermostat. After processing the wax raw materials the specific activity of radionuclides and the concentration of heavy metals were determined on a steam wax furnace.

Wax settling at different air temperatures (+20 and +45 ºC) was carried out in a TC-80 thermostat. The water temperature during wax settling corresponded to the air temperature in the thermostat.

To assess the content of heavy metals and radionuclides, atomic absorption spectroscopy and gamma spectrometry were used, which are analytical methods in the toxicological and radiological control of food and pharmaceutical raw materials. Heavy metal content(Cd, Pb) were determined by atomic absorption method in accordance with the methodological guidelines for the determination of toxic elements in food products and raw materials (Methodological guidelines for atomic absorption methods for the determination of toxic elements in food products and food raw materials;State Pharmacopoeia of Ukraine)on an AAnalyst 200 atomic absorption spectrophotometer.Atomic absorption spectroscopy is a method used forevaluationlevels of heavy metals in honey bees and their waste products (Pohl, 2009). Specific activity ^{137}Cs the volumetric and specific activity of cesium in wax was estimated by the express radiometric method using gamma radiation, and the specific activity ^{90}Sr– by radiochemical method according to the methodology«Sampling, primary processing and determination of ^{137}Cs and ^{90}Sr in food products». The specified equipment was used exclusively for laboratory analytical control of samples and did not have any therapeutic or corrective effect on the human body. The devices are operated in accordance with the requirements of metrological verification and the current legislation of Ukraine regarding the use of analytical and radiometric equipment.

The suitability assessment of beeswax was carried out in accordance with the requirements of the State Pharmacopoeia of Ukraine, the European Pharmacopoeia and ICH Q3D recommendations for elemental impurities. Radiological safety was assessed in accordance with the current hygienic standards of Ukraine and the radiation safety standards of Ukraine (NRBU-97).

A statistical analysis of the results was performed using Statistica software to calculate the arithmetic mean (x) and standard deviation (±SD). ANOVA was used to determine statistically significant differences between the mean values of the respective groups. Results were considered statistically significant at $p < 0.05$.

Research results. Research conducted regarding evaluation the impact of the preliminary partial removal of soluble non-wax components from the wax raw material by washing them out until their transition into the solvent is stopped on the level of specific activity of radionuclides and the concentration of heavy metals in the wax made from this raw material.

Zavrtnik et al. (2024) showed that honeycombs accumulate radionuclides. According to the results of Sorokin (2025), the main accumulation of radionuclides occurs in non-wax impurities, cocoons and perga. The analysis shows that pre-soaking of wax raw materials with different water replacement rates significantly affects specific activity radionuclides (^{137}Cs, ^{90}Sr)in wax (table 1).

As shown in the table 1, the results indicate a pronounced influence of the multiplicity of soaking of the wax raw material on the specific activity of radionuclides in wax. After a single water change within 48 hours, the specific activity of ^{137}Cs decreased by 86.2-fold, ^{90}Sr – by 127.3-fold, three-time soaking within 48 hours provided a decrease in the radionuclide load by 109.4 and 206.2-fold, respectively. The best effect was obtained with multiple water changes until the transition of soluble impurities ceased, during which the level of ^{137}Cs decreased by 130.9-fold, ^{90}Sr – by 240.7-fold. After the transition of soluble impurities of wax raw materials into water is suspended, its further replacement is almost did not affect to reduce the specific activity of ^{137}Cs and ^{90}Sr in beeswax compared to the previous version.

Three water changes within 48 hours (every 16 hours) during soaking of wax raw materials compared to a single replacement, reduced the specific activity of ^{137}Cs in wax by 21.2% ($P< 0.001$), ^{90}Sr by 40.0% ($P< 0.001$). Multiple replacement during the same time period reduced these indicators by 34.2% ($P< 0.001$) and 48.6% ($P< 0.001$), respectively. Wax obtained from wax raw materials with continued water replacement after the cessation of the transition of non-wax components into the solvent had the lowest amount of ^{137}Cs and ^{90}Sr. The obtained data were lower by 35.9% ($P< 0.001$) and 2.0 times ($P< 0.001$) compared to similar indicators with a single water replacement.

The results obtained indicate that multiple soaking of wax raw materials significantly improves the radiological quality of wax. The optimal regime can be considered multiple water changes until the transition of soluble components stops, since further continuation of the process does not provide significant improvement, but requires additional resources.

As noted by Zafeiraki et al. (2022), beeswax actively accumulates Pb, Cd and other heavy metals. Data analysis (table 1) regarding the content of heavy metals in wax shows that the intensity of soaking and washing of wax raw materials significantly affects its purification from Pb and cadmium Cd. After a single water change within 48 hours, a significant decrease in the concentration of metals occurred, in particular, the Pb content decreased by 4.1 times, Cd by 5.1 times. The most effective purification is achieved with multiple water changes until the transition of non-wax components into the solvent stops. In this case, the Pb content decreases by 9.9 times, and Cd by 30.4 times. The presence of heavy metals in wax obtained from raw materials soaked in water for 48 hours with repeated replacement until the transition of non-wax components ceased was lower. In particular, the concentrations of Pb and Cd were 2.4 ($P < 0.001$) and 6.0 ($P < 0.001$) times lower, respectively, compared to a single water replacement.

It is recommended to use cold or warm water when washing non-wax components from wax raw materials. Due to the effect of temperature on the dissolution of substances, the water temperature significantly impacts the intensity with which non-wax components are removed, as well as the intensity with which radionuclides and heavy metals transition into wax. Relevant studies were conducted based on this, and the results are presented in table 3.

When soaking wax raw materials with a single change of water at a temperature of +20ºC, the specific activity of ^{137}Cs in wax was 23.1 bq/kg, ^{90}Sr – up to 0.35 Bq/kg, with an increase in temperature to +40ºC. These the indicators decreased by 6.9% (P<0.001) and by 17.1% (P<0.001), respectively. Increasing the water temperature for soaking wax raw materials to +60º C contributed to a further reduction in wax contamination by ^{137}Cs by 18.6% (P<0.001), and ^{90}Sr by 31.4% (P<0.001).

These tables show a tendency to decrease the content of heavy metals in wax with increasing water temperature used during a single soaking of wax raw materials. Increasing the temperature to +40 ºC contributed to a significant decrease heavy metals, while the content Pb decreased by 25.4% (P<0.001), Cd by 33.3% (P<0.001). Further increase in temperature to +60 ºC ensured more efficient removal of heavy metals from wax raw materials: in wax, Pb level decreased by 44.6% (P<0.001), Cd by 46.7% (P<0.001).

The process of wax settling at different air temperatures contributes to an additional reduction in the content of heavy metals (Pb, Cd) and the specific activity of the radionuclide ^{137}Cs (table 4).

It is known that the air temperature during the settling of wax has a positive effect on its purification from mechanical impurities (Polishchuk, Skrypnyk, 2006). An increase in the air temperature during the settling of wax significantly enhances the process of desorption of pollutants in the current study. After settling at a temperature of +20 °C, a moderate decrease in Pb content (8.9%, P<0.001), Cd content (15.5%), and ^{137}Cs content

Table 1

Specific activity of radionuclides in wax depending on the number of water soakings and washing of wax raw material (x ± SD, n = 3)

Research material	Radionuclides, bq/kg	
	^{137}Cs	^{90}Sr
Wax obtained from wax raw materials: with a single water change within 48 hours	23.1±0.45	0.35±0.01
with three water changes within 48 hours	18.2±0.23***	0.21±0.012***
with multiple water changes until the transition of non-wax components into the solvent stops within 48 hours	15.2±0.52***	0.18±0.001***
when continuing to replace water after the transition of non-wax components into the solvent has stopped	14.8±0.34***	0.172±0.014***

Note: *** – p < 0.001 differences between control and experimental samples

Table 2

Content of heavy metals in wax depending on the number of water soakings and washing of wax raw material (x ± SD, n = 3)

Research material	Heavy metals, mg/kg	
	Pb	Cd
Wax raw materials	0.728±0.007	0.152±0.003
Wax obtained from wax raw materials: with a single water change within 48 hours	0.177±0.012	0.030±0.0009
with multiple water changes until the transition of non-wax components into the solvent stops within 48 hours	0.073±0.001***	0.005±0***

Note: *** – p < 0.001 differences between control and experimental samples

Table 3

Effect of water temperature during single water replacement soaking of wax raw material on the specific activity of radionuclides and the content of heavy metals in wax (x ± SD, n = 3)

Water temperature, ºC	Radionuclides, Bq/kg		Heavy metals, mg/kg	
	^{137}Cs	^{90}Sr	Pb	Cd
+20	23.1±0.45	0.35±0.01	0.177±0.012	0.030±0.0009
+40	21.5±0.43***	0.29±0.005***	0.132±0.006***	0.020±0***
+60	18.8±0.35***	0.24±0.005***	0.098±0.008**	0.016±0.001***

Note: **– p < 0.01; *** – p < 0.001 differences between the control and experimental samples

(9.8%, P<0.01) was observed. Increase in the air temperature to +45 °C provided a significantly more intensive purification of wax. The Pb content decreased by 20.5% (P< 0.001), Cd by 24.5% (P< 0.05), and the specific activity of ^{137}Cs by 19.5% (P< 0.001). The degree of purification at +45 °C is 12.6% lower for Pb, 10.7% lower for Cd, and 10.8% lower for ^{137}Cs than at +20 °C.

The method of processing wax raw materials significantly impacts the reduction of the specific activity of radionuclides and the concentration of heavy metals in the finished wax. In the two study areas, Northern Polissia and Central Forest-Steppe, both wet and dry methods significantly purify the product, although the dry method is more effective (table 5).

Tlak et al. (2016) found that processing and settling methods produce wax with lower heavy metal content, whereas significant concentrations of these metals are found in waste or sediment. In the current study, processing heavily contaminated wax raw materials harvested in the Polissia region using a wet method decreased the level of the radionuclide ^{137}Cs in the wax by 111.1 times. The dry method provided even greater purification, decreasing the level of ^{137}Cs by 154.9 times. The concentration of Pb in wax decreased by 7.3 and 9.6 times, respectively, when processing wax raw materials using the wet and dry methods. The Cd content decreased by 7.1 and 9.3 times, respectively; thus, the dry method produced better results. Comparing the indicators of radionuclides and heavy metals in wax obtained by different processing methods, the dry method resulted in 28.2% less ^{137}Cs (P < 0.001), 21.1% less Pb (P < 0.01), and 23.1% less Cd (P < 0.05).

A similar trend was observed for raw materials from the Central Forest-Steppe region, where the initial level of contamination was significantly lower and within acceptable limits. After wet processing, the specific activity of ^{137}Cs in wax decreased 24.8 times; after dry processing, it decreased 33.5 times. The Pb concentration decreased 4.9-fold with the wet method and 7.9-fold with the dry method. The Cd content in wax remained unchanged, suggesting the limited ability of cadmium to be removed under conditions of minimal contamination. The specific activity of ^{137}Cs in wax obtained by dry processing was 26.0% lower (P < 0.001), and the Pb content was 37.5% lower (P < 0.001) than with the wet method.

Thus, the results of the studies indicate the high efficiency of preliminarily removing soluble, non-wax components from wax raw materials through soaking and washing, as well as the significant influence of temperature regimes, settling conditions, and processing method on reducing the level of radionuclide and toxic contamination of wax.

Conclusions.

It was found that among the studied technological operations of processing wax raw materials (multiplicity of soaking, water and air temperature, wet

Table 4

Influence of air temperature during wax settling on the specific activity of ^{137}Cs (Bq/kg) and the Concentration of Pb and Cd (mg/kg) (x ± SD, n = 3)

Temperature during wax settling, ºC	Before settling			After settling		
	Pb	Cd	^{137}Cs	Pb	Cd	^{137}Cs
+20	0.078±0.0008	0.011±0.0008	0.82±0.01	0.071±0.0002***	0.009±0.0003	0.74±0.01**
+45	0.078±0.0008	0.011±0.0008	0.82±0.01	0.062±0.001***	0.0083±0.0003*	0.66±0.01***

Note: * – p < 0.05; ** – p < 0.01; *** – p < 0.001 differences between the control and experimental samples

Table 5

Effect of different processing methods of wax raw material on the specific activity of ^{137}Cs and the concentration of heavy metals in wax (x ± SD, n = 3)

Research material, sampling location	^{137}Cs, Bq/kg	Heavy metals, mg/kg	
		Pb	Cd
Raw wax materials from the Northern Polissia region	2867.0±13.7	1.390±0.026	0.093±0.0017
Wax obtained: by wet processing of raw wax materials	25.80±0.69	0.190±0.005	0.013±0.0005
dry processing of wax raw materials	18.50±0.32***	0.145±0.003**	0.010±0.0005*
Wax raw materials from the Central Forest-Steppe	18.10±0.37	0.590±0.02	0.050±0.005
Wax obtained: by wet processing of raw wax materials	0.73±0.011	0.12±0.001	0.05±0
dry processing of wax raw materials	0.54±0.015***	0.075±0.0029***	0.05±0

Note: * – p < 0.05; ** – p < 0.01; *** – p < 0.001 differences between the control and experimental samples

and dry processing method), the highest efficiency of reducing the specific activity of radionuclides and the content of heavy metals in wax was observed with repeated leaching of non-wax components from wax raw materials until their transition to water was stopped. The reduction in the specific activity of ^{137}Cs and the concentration of Pb and Cd in beeswax obtained under conditions of repeated soaking of wax raw materials until the transition of non-wax components to water was higher compared to a single soaking in water at a temperature of 60 ºC by 1.24, 1.34 and 3.2 times, respectively; with settling of wax at an elevated air temperature (45 ^{0}C) by 1.35, 2.1 and 5.5 times; and also with the dry method of processing wax raw materials – 1.09, 1.8 and 4.6 times, respectively.

Prospects for further research include optimizing soaking and processing modes for wax raw materials to ensure maximum purification from radionuclides and heavy metals. It is also advisable to investigate the impact of various technological parameters on the stability and quality of purified wax.

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