Artykuł przeglądowy **Review**

Impact of the bioaccumulation of selected toxic elements on the condition of bees and other organisms

BEATA MADRAS-MAJEWSKA, LUIZA OCHNIO*, MACIEJ OCHNIO

Apiculture Division, Faculty of Animal Sciences, Warsaw University of Life Sciences – SGGW, Nowoursynowska 166, 02-787 Warsaw
*Department of Informatics, Faculty of Applied Mathematics and Informatics

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Madras-Majewska B., Ochnio L., Ochnio M.

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Summary

Toxic elements often occur in the natural environment at doses higher than the maximum allowable concentration. The honey bee (Apis mellifera L.) is inextricably connected with the external environment, from which it obtains air and water and food. Bees are exposed to contaminants while collecting pollen, nectar, honeydew and water. Therefore, they are highly sensitive to all kinds of environmental pollution and water and air contamination. It is proven that there is a close relationship between the level of accumulation of heavy metals in soil and plants and their content in the bodies of bees and in bee products. Bees are good biological indicators of environmental contamination. At the same time, heavy metals accumulate in bee products that are later consumed by humans and animals. Research on the content of these metals in the bodies and brood of bees is extremely important because the increased use of chemicals in agriculture and other environmental factors, such as pollution with toxic elements, affect the health and mortality of bees. This paper provides an overview of studies on the harmfulness and bioaccumulation of lead, mercury and cadmium in the bodies of bees and on the impact of these elements on living organisms.

Keywords: bioaccumulation, bees, toxic elements, condition

Human activity has multiple effects on the natural environment, However, they are not always positive. One of the consequences of detrimental human activity is contamination of the environment caused by physical, chemical and biological factors. Chemical hazards are by far the largest group of dangers. Anthropogenic emissions have an observable negative impact on the natural environment. The safety of humans and animals is at risk due to continuous exposure to harmful substances emitted into the environment. Industrial development, increased road traffic and intensive agriculture contribute to pollution of the natural environment also with toxic elements, which accumulate in the biosphere of the Earth, and, over time, have increasingly adverse effects on biological life (7, 47). A prime example of these effects is the increase of heavy metals accumulation in soil, water, plants and other parts of the environment (11, 45, 59). Mercury, lead, and cadmium are among the most frequently studied toxic elements.

Toxic effects of mercury, lead, cadmium and their compounds on living organisms

Mercury is toxic to living organisms, but Wilde (55) did not observe any negative effects of mercury on the development of honeybee queens. Animals most vulnerable to mercury are those that seek food at the bottom of water reservoirs, e.g. clams, crabs and non-predatory fish. Most fish react quickly to exposure to mercury at concentrations of about 10 µg Hg/l (ppb). The results observed are mainly reproduction disorders. More susceptible species, such as trout, react even to concentrations of 0.2-0.7 µg Hg/l (ppb) (54). The presence of mercury in human and animal bodies has toxicological significance because mercury has no known metabolic function in higher organisms. Studies show that 75-80% of the elemental mercury dose absorbed by inhalation is retained within the body. In contrast, other inorganic mercury compounds are difficult to absorb by inhalation, but easily by ingestion. In this case, they are mainly found in the kidneys, as well as in the liver, spleen, blood and brain (46). Mercury compounds are excreted from the human body primarily in urine and feces, but also in saliva, milk, hair and – through the skin – with sweat. The half-life of mercury in the human body ranges from 20 to 80 days, depending on the form of that element and the tissue or organ (34).

The presence of lead can be found in all animal tissues. Of the total amount of lead absorbed into the blood. Lead may cause acute poisoning (33). Cadmium is particularly hazardous to humans and animals because it is easily absorbed, accumulates and remains in tissues relatively long. Animal organisms absorb 0.5-5.3% of cadmium supplied with food, whereas humans absorb as much as 4.7-7.0%. Animals exposed to high cadmium concentration exhibit atrophy of the testes, ovaries, kidneys and spleen veins, swelling of joints, visual disturbances, hair loss and brittleness, dryness of skin, as well as considerable susceptibility to infections (33).

The impact and bioaccumulation of toxic elements in bees

Toxic elements at high concentrations are harmful to humans and animals, including bees. Bees and bee larvae are exposed to the penetration of pollutants from the environment (10, 15, 21, 22, 27, 30, 32, 35, 51, 53, 60). Contamination with heavy metals is one of the factors contributing to the disappearance of bees in recent years.

The honey bee (*Apis mellifera L.)* is inextricably connected with the external environment, from which it obtains not only air and water, but also food. Contaminants are transferred to bees while they are collecting pollen, nectar, honeydew and water.

Being closely connected with the environment, bees are directly threatened by adverse changes occurring in their habitats, such as increasing contamination (6). The enormous adaptability of bee colonies to different climatic conditions enabled those insects to colonize almost all regions in the world except the Arctic and Antarctic. It is significant that bees are able to make relatively long flights in search of food. In a hive of one colony it is possible to find collection from an area of approximately 25 km^2 (35). The fact that bees from one colony can fly over such a large area means that each day worker bees visit many species of plants and thousands of flowers.

Bees collect nectar and pollen from pollen-providing plants that are currently blooming in the given area (43). This means that bees visit plants growing in various soils, in different climates and at different heights above sea level. It should be pointed out that even when the area is dominated by a single species of plants, bees look for pollen from other plant species, as they prefer food of non-homogeneous composition (42-44). Moreover, bees may be easily moved along with their hives to another location.

If a colony of bees operates in a contaminated environment, plant material used by the bees and the air they breathe are contaminated as well, and, as a result, some pollutants will accumulate in their bodies (38). The accumulation of heavy metals in bees may result from their drinking contaminated water (14, 28).

Thus, contaminants present in a given area accumulate in bees, in their brood and in bee products (35-37). Many scientific publications provide information on the content of heavy metals in bees, bee products (1, 12, 31) and, less frequently, in the brood (21, 60). There is a close relationship between the accumulation level of heavy metals in soil and plants and their content in the organisms of bees and in bee products (38, 41).

Bioaccumulation of toxic elements in bees depends on their age, function in the colony, individual traits, as well as the part of the body. Höffel (15) found higher levels of lead and cadmium concentrations in flying bees (foragers) compared with bees staying in the hive (workers). In addition, drones were characterized by a lower content of those elements than worker bees (35). It should be emphasized that both forms of insects were of the same age. Szymanowska-Bielawska (49) experimentally demonstrated that the content of minerals in bees significantly depends on the body part used for testing. The concentrations of elements in the head, thorax and abdomen are significantly different. Generally, the concentrations of lead in those body parts are the highest, e.g. in the head – Pb 0.00091 ppm, in the thorax – 0.0025 ppm, in the abdomen – 0.003 ppm. Another cause of the increased concentration of toxic elements in the body is the purification of the raw material of honey from mechanical impurities and their chemical components, which takes place in the honey sac (17). This process, combined with the imperfection of the excretory system in insects, causes the accumulation of these impurities in large quantities in the bodies of bees, especially of worker bees (35).

The impact of environmental pollution (industrial and automotive) on the bioaccumulation of toxic elements and on the bee's organism

The adverse impact of rapidly growing industry on bees has long been observed in industrialized areas. Numerous cases of high concentrations of lead and cadmium in the bodies of bees have been described (3, 8, 9, 20, 22, 28). Bacilek (2) reports a case in which contaminated bees contained 12-185 mg Pb/kg of body weight (ppm), while the lead concentration in the control group was 0.9-1.5 mg Pb/kg of body weight (ppm). In Poland, concentrations of lead, cadmium and fluoride were determined in samples of live bees from apiaries located near the electrochemical plant „Ema Brzezie" in Raciborz (47). The samples contained, on average, 6.92 μg Pb/kg of body weight (ppb), 1.63 μg Cd/kg of body weight (ppb) and 14.00 μg F/bee. In control insects, these concentrations were, respectively, 0.54 μg, 0.06 μg, and 0.30 μg. In southern Poland, near plants extracting and processing lead and zinc, the concentrations of these elements were studied in dead bees and in the surrounding environment (flowering plants) (4). Each sample was found to contain more lead, zinc and cadmium than control samples from non-industrialized regions, e.g. the bodies of bees contained Pb – 271-607 ppm, Zn – 145-590 ppm, and Cd – 6-20 ppm. Gonnet (13) observed increased levels of Pb, As and Cu in dead bees in the vicinity of a zinc smelter in Miasteczko Śląskie, as well as other industrial plants in the former county of Tarnowskie Góry. A joint publication edited by Migula (24) provides interesting data on the contamination of bees and bee products with heavy metals in southern Poland. According to these studies, lead concentration in honey ranged from 0 to 0.155 mg/kg, in many cases exceeding the allowable levels, whereas the cadmium content ranged from 0 to 0.043 mg/kg. Roman (38), in an experiment conducted in the vicinity of copper plants (Legnica-Głogów Mining District) and cement-lime plants (Opole), showed that bees were contaminated with toxic metals (As, Cd, Cr, Cu, Hg, Pb and Zn). The results prove that the higher the environmental pollution with heavy metals, the greater the accumulation of these metals in worker bees.

One of the most dangerous and toxic elements is arsenic. Svoboda (50) cites cases of arsenic poisoning of bees in Slovakia in 1938 and 1954. Kresak (19) reports that bees poisoned in Slovakia in 1938 contained not only arsenic, but also other elements and compounds: fluoride magnesium, lead, zinc, copper, beryllium, SO_2, sulfuric acid and hydrochloric acid. Thus, bees are an extremely sensitive indicator of the presence of toxic elements in the environment.

Many authors report harmful effects of fluoride emitted by steel mills, the glass and the plastics industries, and insecticide factories on bees (5, 16, 54, 55). Peterson (30) found a fluoride content exceeding 182 ppm in the bodies of bees living near lead and copper smelters and in the vicinity of power plants.

There are a number of reports showing that the content of pollutants in bees depends on the distance between the source of contamination and the apiary (10, 32, 51, 52). Terzic et al (51) found arsenic in dead bees near a copper smelter, at concentrations ranging from 0.45 to 1.62 mg/kg of body weight (ppm). At a distance of 170 km from the source of arsenic emission, its content amounted to 0.048 mg/kg of bee body weight (ppm). At a distance of 25 km from the smelter, the average concentration of arsenic in clinically healthy bees was 0.109 mg/kg of body weight (ppm). A similar relationship between the distance from the facility emitting harmful substances and their concentration in bees was observed by Devey (10). In his studies conducted in the western part of Montana, United States, he found that the fluoride content in bees amounted to 221 ppm at a distance of 0.8 km from the aluminum smelter and 3.5-16.5 ppm in control bees from areas located 80 km from the smelter.

Lead concentrations have been measured in bee samples from various regions of Poland (21, 22). It was found that the lead content in the bodies of bees ranged from 0.114 mg/kg to 4.76 mg/kg. The average concentration for the entire area of Poland was 0.823 mg Pb/kg. The results of this study are difficult to compare with those obtained by different authors. In an industrial area, lead concentration was 29.59 mg/kg, whereas in a non-industrial region it amounted to 15.12 mg/kg (26). Roman (38) demonstrated a large discrepancy in the lead content in various samples of bees (0.01-20.13 mg/kg). The average concentration of lead in forager bees in subsequent years amounted to 1.06 mg/kg and 3.116 mg/kg in the region of Opole, 0.932 mg/kg and 7.160 mg/kg in the area of Głogów, and 1.9 mg/kg and 3.8 mg/kg in Ruda. High concentrations of lead in bees were reported by Bornus (4) in samples originating from the areas where lead and zinc were processed. This author found lead concentrations at levels of 271-607 mg/kg.

Madras-Majewska (21) found that the mercury concentration in bees ranged from 0.00009 mg/kg to 0.0232 mg/kg, and the average for Poland was 0.0013 mg/kg. The values of mercury concentration in bees, similar to those obtained in this paper, were obtained by May et al. (23) and amounted to 0.0017-0.0112 mg/kg. However, in their studies Żarski et al. (60) found a significantly higher average concentration of mercury in bees, i.e. 0.00867 mg/kg. A similarly high content of mercury in bees was found by Roman (38), who conducted research in a highly contaminated industrial area.

On the basis of her own research, Madras-Majewska (21, 22) determined that the lead content in brood ranged from 0.01 mg/kg to 0.0697 mg/kg. The average for the entire Poland was 0.0219 mg/kg. Her study on lead in brood was innovative, as no other research on the subject had been reported in the available literature. The comparison of Madras-Majewska's results on the accumulation of mercury in brood samples (originating from different regions of Poland) (21) with those obtained by other authors was very difficult, since this issue had been mostly ignored by other researchers. Żarski et al (60) found that the average concentration of mercury in brood amounted to 0.009 mg/kg. These results compared with the results obtained by Madras-Majewska show that the average concentration of mercury in the brood (0.00053 mg/kg) is lower than that reported by Madras-Majewska. Mercury concentration in brood observed by Madras-Majewska (21) ranged from 0.00001 to 0.00682 mg/kg. Thus, the contamination of brood is not likely to reduce the value of this bee product.

In areas with increased road traffic, much attention has been paid to examining bees and their products for pollution with heavy metals (18, 25, 40, 58). Pratt and Sikorski (32) found that the bodies of bees collecting nectar from plants near busy roads contained lead in an amount of 28.1 ppm (in control bees – the average was 1.4 ppm). Lead concentration in plants growing in the immediate proximity of the road amounted on average to 13.6 ppm, and in plants growing within 850 m of the road it decreased to 0.2 ppm.

The development of industry and the rapid increase of road traffic exposes bees and their products to contamination with heavy metals. At high concentrations, heavy metals become harmful to both bees and humans, as they have no positive (physiological) function. Substances that do not degrade, or that actually transform into even more toxic substances, are often introduced into the natural biogeochemical cycle. These substances, present in various chemical compounds and physical forms, penetrate into food and organisms, causing short or long-term damage. They weaken the immunity barrier, which is conducive to diseases. Contamination with heavy metals contributes to the weakening of colonies and the widespread disappearance of bees. This threat to bees should be eliminated.

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Corresponding author: dr hab. Beata Madras-Majewska prof. nadzw. SGGW, ul. Nowoursynowska 166, 02-787 Warszawa; e-mail: beata_madras_majewska@sggw.pl