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Use of honey as a bioindicator: an integrative review

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Abstract. This integrative literature review aimed to evaluate the use of honey produced by bees of the genus *Apis* as a bioindicator. From 177 records identified in the PubMed, Scopus, and Web of Science databases, 30 studies published between 2019 and 2025 were selected and analyzed. Only publications addressing the use of honey as an “environmental bioindicator” were found. The studies covered different groups of pollutants, including potentially toxic elements (PTEs), agrochemicals, polycyclic aromatic hydrocarbons (PAHs), radionuclides, microplastics, flame retardants, plasticizers, and bisphenol A. The results show that honey is a suitable matrix capable of reflecting the environmental presence of various contaminants, although it exhibits low sensitivity to some of them due to its physicochemical characteristics and the natural barriers imposed by bee physiology. Studies indicate that other hive matrices, such as pollen, wax, propolis, and adult bees, often demonstrate greater efficiency in detecting certain pollutants, reinforcing the need for multi-matrix approaches. Despite the observed limitations, the literature indicates that honey is a promising tool for environmental biomonitoring, especially when integrated with robust analytical methods and complemented by the use of other apicultural matrices.

Keywords: biomonitoring, environment, pollutants, *Apis mellifera*.

Introduction

The use of living organisms and their products as quality indicators and health indicators for ecosystems, habitats or biological communities can be denominated biomonitoring. This approach has been developing as a promising and economically advantageous environmental monitoring methodology, it manages to integrate multiple environmental variables (contaminants, pollutants, climate changes and modifications in land use) over time, something that physical or chemical measurements often fail to capture (Silva *et al.*, 2024; Zaghloul *et al.*, 2020).

The concept of bioindicator refers to an organism, species, community or biological process that, due to its presence, absence, state or response, whether in its abiotic (physical and chemical) or biotic (biological) aspects, can indicate the impacts of environmental changes on habitats, communities or ecosystems, or even represent the biological diversity of a specific group of organisms

or the total biodiversity of an area (Demaku *et al.*, 2023; McGeogh, 1998; Paçarizi; Berisha; Halili, 2019; Zhelyazkova, 2012).

According to Mc Geogh (1998), bioindicators can be divided into three categories, being: (i) environmental indicators, (ii) ecological indicators and (iii) biodiversity indicators. Environmental indicators are species that respond predictably to changes in the environment. Ecological indicators, on the other hand, evaluate the effects of environmental changes on ecosystems, also considering the condition of the species for conservation purposes. And, finally, biodiversity indicators are groups of taxa whose diversity reflects the diversity of other groups in the same habitat, allowing the estimation of the total biodiversity of an area.

Among different groups of organisms used as bioindicators, insects stand out for their wide geographical distribution, high diversity, fast response to environmental changes and action at

multiple trophic levels of the ecosystems (Schowalter, Noriega, Tscharnke, 2018; Zaghoul *et al.*, 2020). With this context, bees (Hymenoptera: Apoidea), especially social species such as *Apis mellifera*, constitute excellent bioindicators due to their sensitivity to ecological changes and the presence of residues and pollutants in plants (Silva *et al.*, 2024), demonstrating high flexibility and effectiveness as indicative organisms (Zaghoul *et al.*, 2020).

During the foraging, bees collect nectar, pollen and plant exudates, incorporating pollutants and contaminants present in the visited plants, as well as atmospheric substances absorbed by respiration (Bargańska; Ślebioda; Namieśnik, 2016), which makes them an effective tool in environmental monitoring of the studied ecosystem, allowing the detection of pollutants and contaminants in an integrated and representative way (Catalano *et al.*, 2024; Davodpour *et al.*, 2019; Di Fiore *et al.*, 2023, Oliveira *et al.*, 2025).

Another factor that contributes to the use of *A. mellifera* as a bioindicator is its domestication (Fuente-Ballesteros *et al.*, 2025), being commercially managed for pollination of various crops and honey production, among other products. They also have biological characteristics that enable standardized and economically viable monitoring strategies, in addition to being present in almost all parts of the world (Quigley; Amdam; Harwood, 2019).

Contextualization and analysis

The use of honey as a biomonitoring tool can be advantageous since it is a natural product, easy to collect and store, in addition to representing an ethical and economically viable alternative for environmental diagnosis. Thus, the present work aims to carry out an integrative review of the literature on the use of honey from bees of the *Apis* genus as bioindicators, highlighting in which areas it is promising and its limitations for environmental monitoring.

Material and methods

The present study is characterized by exploratory research using qualitative methods, with technical procedure being an integrative literature review, following the PRISMA 2020 guidelines (*Preferred Reporting Items for Systematic Reviews and Meta-Analyses*) (Page *et al.*, 2021), in the *Web of Science*, *Scopus* and *PubMed* databases, accessed through the CAPES Journal Portal, restricted to articles published in the period from January 1, 2019 to November 1, 2025.

To structure this integrative review, the following steps were used: (i) delimitation of the research objective; (ii) choice of data sources; (iii) choice of keywords for the search; (iv) search and storage of results; (v) selection of articles according to inclusion and exclusion criteria; (vi) data extraction and evaluation of the quality of the evidence in the selected articles (Sampaio *et al.*, 2022).

The review was organized in three stages: (i) identification of records in the *Web of Science*, *Scopus* and *PubMed*; (ii) removal of duplicates, removal of articles published prior to January 2019 and screening of articles published in indexed journals available for download; (iii) inclusion of full and eligible articles that were available online for download.

In the search phase, the following *boolean* expression was used: "honey" AND "bioindicator", filtering by the presence of the two descriptors in the title or abstract of the publication. Table 1 presents the search string used, with the necessary adaptations, for each of the databases mentioned above. The searches were carried out on November 1, 2025.

Table 1. Databases and search strings used in this integrative review.

Database	Search string
<i>Scopus</i>	(TITLE-ABS (honey) AND TITLE-ABS (bioindicator))
<i>Web of Science</i>	(TI=(honey) OR AB=(honey)) AND (TI=(bioindicator) OR AB=(bioindicator))
<i>PubMed</i>	((honey[Title/Abstract]) AND (bioindicator[Title/Abstract]))

Source: Authors.

The following inclusion criteria were used: (i) must include studies on the use of honey from bees of the genus *Apis* to evaluate environmental quality indicators; (ii) all articles must be available for download in full in PDF format and without restrictions; (iii) only studies published between January 1 of 2019 and November 1 of 2025 will be included in this review.

The following exclusion criteria were used: (i) articles that use honey from other bee species, other than the genus *Apis*, will be excluded; (ii) articles that do not use honey as a bioindicator will be excluded; (iii) abstracts, expanded abstracts, dissertations, theses, and literature reviews will be excluded.

As a quality criterion, it was defined that only articles published in peer-reviewed and indexed journals, classified at Q4 or above in the *SCImago Journal & Country Rank* (SJR, 2025), would be selected.

Results and discussion

In total, 177 publications were identified during the search in the databases, being *PubMed* (45), *Scopus* (68) and *Web of Science* (64), on November 1 of 2025. Because there were duplicates, 87 publications were excluded. In addition, 30 publications were excluded because they were outside the stipulated publication period (January 1 of 2019 to November 1 of 2025). The remaining 60 publications were then analyzed, which were screened by reading the title and

abstract regarding adherence to the theme of this study and, if there were any uncertainty, the entire article was read.

Publications were excluded because they were reviews (5), because they were conference articles (1); and those which were outside the scope of the present study (22). After screening, 32 publications remained that were researched. Of the 32 records, only 1 (one) publication was unavailable for download. A total of 31 publications remained that were read in full and analyzed for eligibility and quality criteria. Among the publications read, there was 1 (one) publication in Spanish and 1 (one) in Portuguese, with the rest in English. One (1) publication was excluded because its main focus was not the evaluation of honey as a bioindicator, leaving 30 publications that were included in this integrative review (Figure 1).

It is worth noting that this research did not have as its objective the state of the art on the theme of the use of honey as a bioindicator, and there are other publications that deal with the theme, but which were not found using the methodology used in this review.

The 30 publications included in this integrative review after screening were classified according to the type of pollutant researched in

honey, as follows: agrochemicals (AC), polycyclic aromatic hydrocarbons (PAH), heavy metals, metalloids and other potentially toxic elements (PTE), microplastics (MC), radionuclides (RR), flame retardant (FR), phthalic acid ester (PAE) and bisphenol-A (BPA). The publications were also classified by the SJR indicator and country of origin of the study (Table 2).

Only publications that dealt with the use of honey as a bioindicator of the "environmental bioindicator" type were found. Most of the studies were conducted by researchers from Italy (6), followed by researchers from Poland (3), Brazil (2), Pakistan (2), Romania (2) and the other countries with one (1) publication each (Table 2).

Most of the publications found were related to the use of honey as an environmental bioindicator for PAE (20), followed by publications referring to pollution by AC (6), PAH (4), RR (2) and residues of FR substances (1). Some publications dealt with more than one pollutant, and 2 (two) of the publications that dealt with heavy metals also analyzed bisphenol-A and plasticizer residues (1) and the presence of microplastics in honey (1) (Table 2). The distribution of publications by year of publication can be seen in Figure 2.

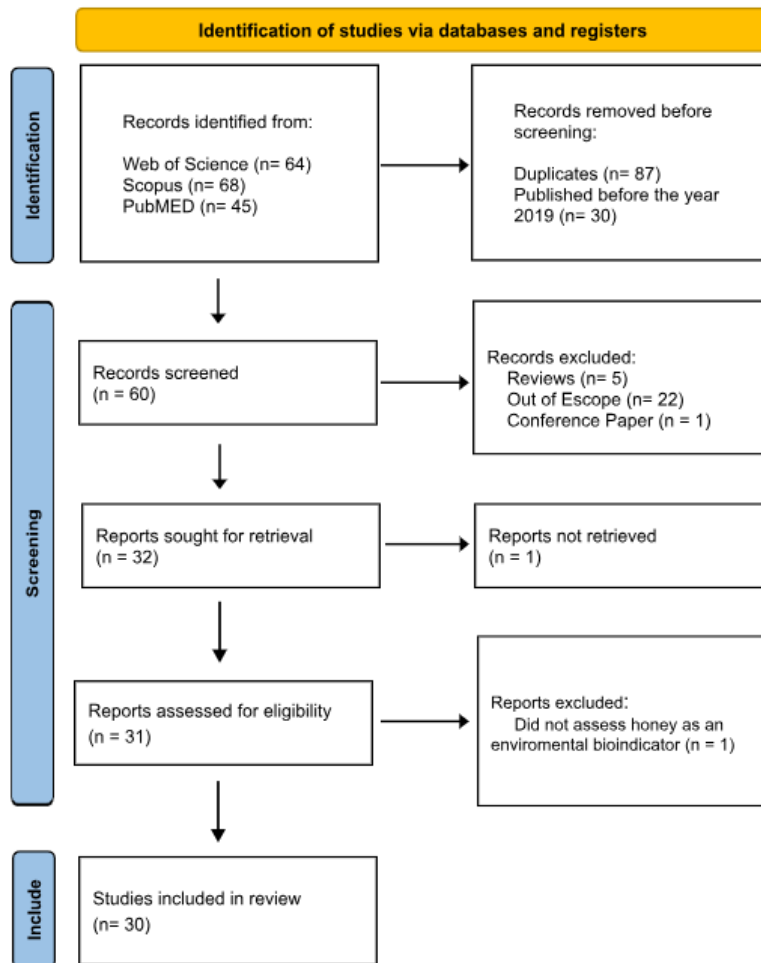


Figure 1. Flow diagram of this integrative review based on the PRISMA 2020 protocol.

Table 2. Reference, publication title, type of pollutant, country of origin, SJR indicator and name of the journal of the publications included in this integrative review, grouped by type of pollutant and organized by year of publication.

References	Publication Title	Type of Pollutant	Country	SJR Indicator	Journal
(Davodpour et al., 2019)	Honeybees (<i>Apis mellifera</i> L.) as a Potential Bioindicator for Detection of Toxic and Essential Elements in the Environment (Case Study: Markazi Province, Iran).	PTE	Iran	Q1	Archives of environmental contamination and toxicology
(Kazazic et al., 2020)	Monitoring of honey contamination with polycyclic aromatic hydrocarbons in Herzegovina region	PAH	Bosnia and Herzegovina	Q2	Chemistry and Ecology
(Konopka; Świsłowski; Rajfur, 2020)	Biomonitoring of Atmospheric Aerosol with the use of <i>Apis mellifera</i> and <i>Pleurozium schreberi</i>	PTE	Poland	Q3	Chemistry, Didactics, Ecology, Metrology
(Attaullah et al., 2021)	Honey as a bioindicator of environmental organochlorine insecticides contamination.	AC	Pakistan	Q2	Revista brasileira de biologia
(Ben Mukibi et al., 2021)	Organochlorine pesticide residues in Uganda's honey as a bioindicator of environmental contamination and reproductive health implications to consumers.	AC	Uganda	Q1	Ecotoxicology and environmental safety
(Mihaljev et al., 2021)	Radioactive Residue in honey	RR	Serbia	Q3	Archives of Veterinary Medicine
(Leal et al., 2022)	Perfil de elementos inorgânicos em amostras de mel do Estado do Maranhão como um potencial bioindicador de origem geográfica	PTE	Brazil	Q4	Química Nova
(Passarella et al., 2022)	PAHs presence and source apportionment in honey samples: Fingerprint identification of rural and urban contamination by means of chemometric approach.	PAH	Italy	Q1	Food chemistry
(Ponce-Vejar et al., 2022)	Detection and Concentration of Neonicotinoids and Other Pesticides in Honey from Honey Bee Colonies Located in Regions That Differ in Agricultural Practices: Implications for Human and Bee Health.	AC	Mexico	Q2	International journal of environmental research and public health
(Šerevičienė; Zigmontienė; Paliulis, 2022)	Heavy Metals in Honey Collected from Contaminated Locations: A Case of Lithuania	PTE	Lithuania	Q1	Sustainability (Switzerland)
(Yayinie; Atlabachew, 2022)	Multi-element Analysis of Honey from Amhara Region-Ethiopia for Quality, Bioindicator of Environmental Pollution, and Geographical Origin Discrimination.	PTE	Ethiopia	Q1	Biological trace element research
(Zafeiraki et al., 2022)	Adult Honeybees and Beeswax as Indicators of Trace Elements Pollution in a Vulnerable Environment: Distribution among Different Apicultural Compartments.	PTE	Slovakia	Q1	Molecules (Basel, Switzerland)
(Cordero et al., 2023)	El Bioindicador Idóneo para la Detección de Plomo Atmosférico a Partir de una Experiencia en Cuenca, Ecuador	PTE	Ecuador	Q4	Revista Politecnica
(Demaku et al., 2023)	Determination of Heavy Metals in Bee Honey as a Bioindicator in the Istog, Drenas and Kastriot Regions	PTE	Kosovo	Q2	Inzynieria Ekologiczna
(Di Fiore et al., 2023)	Biomonitoring of polycyclic aromatic hydrocarbons, heavy metals, and plasticizers residues: role of bees and honey as bioindicators of environmental contamination.	PTE, PAH, PAE, BPA	Italy	Q1	Environmental science and pollution research international

(Girolametti et al., 2023)	Mercury in honey from the Marche region (central Italy). Risk assessment from human consumption and its use as bioindicator of environmental pollution.	PTE ¹	Italy	Q1	Heliyon
(Leung et al., 2023)	Targeted and non-targeted screening of flame retardants in rural and urban honey.	FR	Canada	Q1	Chemosphere
(Singh et al., 2023)	Cosmopolitan honey bee, <i>Apis mellifera</i> , as quick and efficient marker of pesticide pollution in environment through RP-HPLC.	AC	India	Q1	Environmental science and pollution research international
(Casula et al., 2024)	Multiresidue Methods Analysis to Detect Contamination of Selected Metals in Honey and Pesticides in Honey and Pollen.	PTE, AC	Italy	Q1	Foods
(Catalano et al., 2024)	Use of Honey Bees and Hive Products as Bioindicators to Assess Environmental Contamination in Targeted Areas of the Campania Region (Italy)	PTE, PAH	Italy	Q1	Animals
(Hung et al., 2024)	Availability of Using Honeybees and Hive Products as Bioindicators of Ambient Pesticide Exposure in Taiwan.	AC	Taiwan	Q1	Toxics
(Jakkielska; Frankowski; Ziola-Frankowska, 2024)	Speciation analysis of arsenic in honey using HPLC-ICP-MS and health risk assessment of water-soluble arsenic.	PTE ²	Poland and Ukraine	Q1	Journal of hazardous materials
(Solera et al., 2024)	Honey production in the south by the Legal Amazon: a study on the potential contamination of mercury in apiaries.	PTE ¹	Brazil	Q1	Environmental science and pollution research international
(Glevitzky et al., 2025)	Honey as a Bioindicator: Pollution's Effects on Its Quality in Mining vs. Protected Sites	PTE	Romania	Q2	Applied Sciences (Switzerland)
(Godebo et al., 2025)	Metals in honey from bees as a proxy for environmental contamination in the United States.	PTE	USA	Q1	Environmental pollution
(Inaudi et al., 2025)	Pollution profiling in Italian honeys: Elements and microplastics as comprehensive indicators of environmental contamination and food safety.	PTE, MC	Italy	Q1	The Science of the total environment
(Mushtaq et al., 2025)	Honey Bee Products as Bio Indicator of Heavy Metals Pollution and Health Risk Assessment Through the Consumption of Multifloral Honey Collected in Azad Kashmir, Pakistan.	PTE	Pakistan	Q1	Biological trace element research
(Naccari et al., 2025)	Study of Toxic Metals and Microelements in Honey as a Tool to Support Beekeeping Production and Consumer Safety.	PTE	Italy	Q1	Foods (Basel, Switzerland)
(Szarlowicz; Jędrzejek; Najman, 2025)	Bee Products as a Bioindicator of Radionuclide Contamination: Environmental Approach and Health Risk Evaluation	RR	Poland	Q1	Sustainability (Switzerland)
(Vlad et al., 2025)	Comprehensive Assessment of Potentially Toxic Element (PTE) Contamination in Honey from a Historically Polluted Agro-Industrial Landscape: Implications for Agricultural Sustainability and Food Safety	PTE	Romania	Q1	Agriculture (Switzerland)

Source: Authors. AC – agrochemicals; PAH – Polycyclic aromatic hydrocarbons; PTE – heavy metals, metalloids and other potentially toxic elements; RR – radionuclides; MC – microplastics; FR – flame retardant; PAE – phthalic acid ester e BPA – bisfenol-A. 1 Only Mercury (Hg) analyses were performed in the honey. 2 Only Arsenic (As) analyses were performed in honey.

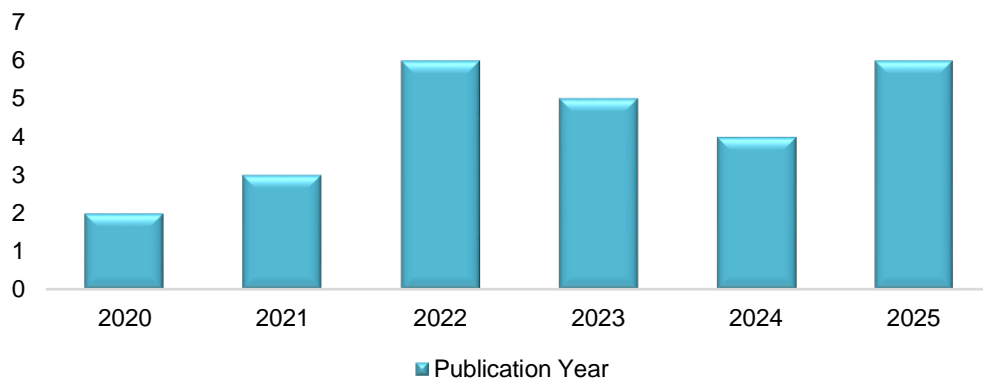


Figure 2. Graph representing the distribution of publications by year of publication.

Agrochemicals

Agrochemicals are any substance or mixture of substances used to prevent, control, or eliminate organisms considered pests in agricultural activities, including insects, weeds, fungi, and other biological agents that may compromise productivity (Phiri; Mavinkere Rangappa; Siengchin, 2024).

Although there is a control of the dose of agrochemicals applied in the environment by agricultural managers, the level of persistence of these compounds in the environment is not evident (Quigley; Amdam; Harwood, 2019). The use of bees and of different products from the hive has been shown to be effective as a matrix for monitoring environmental contamination by agrochemicals (Attaullah *et al.*, 2021; Hung *et al.*, 2024), allowing the detection of several classes of pesticides, such as neonicotinoid insecticides and organochlorines, as well as some herbicides and fungicides (Ponce-Vejar *et al.*, 2022).

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Bees, especially *A. mellifera*, due to their wide foraging radius and intense interaction with different environmental compartments (air, water, soil and vegetation), act as fast and efficient markers of the pollution present in the surroundings of the hives (Singh *et al.*, 2023). The detection of the presence of pesticides banned in some countries or regions (such as paraquat, banned for use in Taiwan since 2020) in honey samples highlights the potential of this matrix as a qualitative bioindicator of

the use of these substances, although it has lower sensitivity when compared to other matrices, such as pollen, wax and adult bees (Casula *et al.*, 2024; Hung *et al.*, 2024).

However, the exclusive use of honey has limitations that may compromise its efficacy as a bioindicator of agrochemicals. Hung *et al.* (2024) cite that the detection capacity in honey varies according to the type of pesticide, and certain chemicals, such as methoxychlor, are often not detected in this matrix (Attaullah *et al.*, 2021; Singh *et al.*, 2023). Hung *et al.* (2024) also observed that the association between herbicides and environmental dust tends to occur in a very restricted radius, of about 150 m, which reinforces that the range of honey as a bioindicator of these compounds is limited.

For Konopka, Świśłowski and Rajfur (2020), "the number of dead bees in front of a hive (in the case of pesticide pollution) is the most important variable and indicator of the environmental condition", as it directly reflects the acute exposure of colonies to toxic compounds and allows a rapid and sensitive assessment of the chemical pressure exerted on the habitat, often culminating in the loss of multiple hives by beekeepers.

Heavy Metals, Metalloids and Other Potentially Toxic Elements (PTE)

Potentially Toxic Elements (PTE) correspond to a set of chemical elements (including metals, metalloids and some non-metals) that can cause adverse effects to living organisms when present in the environment in high concentrations (Davodpour *et al.*, 2019; Inaudi *et al.*, 2025; Vlad *et al.*, 2025).

PTE monitoring is a central concern for environmental and food security, since these elements can accumulate in ecosystems, enter production chains, and pose significant risks to human health and biodiversity (Davodpour *et al.*, 2019). Although many of these elements have a natural origin (Naccari *et al.*, 2025), resulting from geochemical processes, its presence at high levels

in the environment is often associated with the intensification of anthropogenic activities, such as mining, industry, improper disposal of electronic waste, use of machinery and equipment, and the incorporation of these metals into various materials (Cordero *et al.*, 2023).

Honey is considered as a promising environmental bioindicator for monitoring PTE, given the ability of bees to forage over a substantial area, incorporating contaminants from diverse environmental compartments such as water, air, soil, and nectar (Cordero *et al.*, 2023; Davodpour *et al.*, 2019; Leal *et al.*, 2022). The analysis of honey makes it possible to evaluate environmental contamination at the regional level (Demaku *et al.*, 2023; Leal *et al.*, 2022) and helps detect spatial patterns (Godebo *et al.*, 2025), with significantly higher concentrations of PTE such as lead (Pb), cadmium (Cd), copper (Cu) and iron (Fe) in honey from areas affected by mining and industrial activities, as well as the proximity of the apiary to roads and motor vehicle routes, compared to protected areas (Glevitzky *et al.*, 2025; Konopka; Świsłowski; Rajfur, 2020; Vlad *et al.*, 2025).

For example, although the levels of metals in samples coming from the USA are markedly lower than global averages (Godebo *et al.*, 2025), Pb substantially exceeds international limits in samples from possibly contaminated regions, confirming honey as a possible bioindicator of environmental degradation (Mushtaq *et al.*, 2025; Šerevičienė; Zigmontienė; Paliulis, 2022; Vlad *et al.*, 2025).

Despite its potential, honey has important limitations that suggest it is not the most sensitive matrix for all pollutants. In several studies, the concentrations of toxic metals in honey are often low, often close to or below the limits of quantification or detection of the analytical method applied (Casula *et al.*, 2024; Di Fiore *et al.*, 2023; Girolametti *et al.*, 2023; Inaudi *et al.*, 2025; Konopka; Świsłowski; Rajfur, 2020), which makes monitoring using honey alone an ineffective tool for assessing the level of pollution in some cases (Konopka; Świsłowski; Rajfur, 2020).

The low accumulation of pollutants in honey is often attributed to the role of bees as a natural biological barrier, capable of partially restricting the transfer of certain contaminants to the final product (Di Fiore *et al.*, 2023; Džugan *et al.*, 2018; Konopka; Świsłowski; Rajfur, 2020; Vlad *et al.*, 2025). Analyses conducted by Cordero *et al.* (2023) demonstrate that pollen stands out as a more sensitive bioindicator than honey for the detection of Pb. In addition, other studies show that both wax and adult bees tend to accumulate higher concentrations of toxic elements, reinforcing the importance of considering multiple hive matrices in environmental monitoring (Cordero *et al.*, 2023; Zafeiraki *et al.*, 2022).

As a way to optimize environmental monitoring, it is worth noting that the integrated analysis of different hive matrices is essential to improve the sensitivity and accuracy of monitoring

(Di Fiore *et al.*, 2023; Konopka; Świsłowski; Rajfur, 2020; Solera *et al.*, 2024). It is crucial to consider that honey contamination does not always reflect only environmental pollution, but is also influenced by botanical origin (Di Fiore *et al.*, 2023; Girolametti *et al.*, 2023), by inadequate beekeeping practices and by contamination from equipment used during processing (Leal *et al.*, 2022; Naccari *et al.*, 2025).

Polycyclic Aromatic Hydrocarbons (PAH)

Polycyclic Aromatic Hydrocarbons (PAH) are a class of organic compounds of great environmental relevance due to their persistence and high toxicity. They are formed by two or more fused aromatic rings, usually with a planar structure, and are widely used as indicators of anthropogenic activities in atmospheric pollution. Its main origin is associated with the incomplete combustion of organic matter, as occurs in the burning of coal and wood, in vehicle emissions and in industrial processes linked to the petrochemical sector (Di Fiore *et al.*, 2023; Kazazic *et al.*, 2020; Passarella *et al.*, 2022).

Honey is widely recognized as an advantageous biological matrix for monitoring environmental pollution, including PAH, which are genotoxic and carcinogenic compounds (Catalano *et al.*, 2024; Passarella *et al.*, 2022). As with the other types of pollutants mentioned above, the authors emphasize the efficacy of honey as a bioindicator arising from the biological characteristics of bees, which are capable of sampling xenobiotics over a vast foraging radius (Catalano *et al.*, 2024; Kazazic *et al.*, 2020). Chemical analysis of honey thus provides a reliable estimate of the bioavailable fraction of PAH dispersed in the environment, allowing the flow of contaminants released by human activities such as vehicular traffic, domestic heating and industrial emissions to be traced (Catalano *et al.*, 2024; Passarella *et al.*, 2022).

However, the use of honey as a monitoring matrix for PAH has specific limitations related to the nature of the product itself and beekeeping practices. Honey, being a predominantly polar matrix, with about 18% water, has a low bioaccumulation capacity for high molecular weight PAH and hydrophobic molecules (Passarella *et al.*, 2022). Consequently, the concentrations of PAH detected in honey are generally low and at trace levels (Kazazic *et al.*, 2020), often below the limits of quantification (Catalano *et al.*, 2024). Another source of PAH contamination in honey may be linked to the smoke used to calm the bees during procedures in the hive (Passarella *et al.*, 2022).

Passarella *et al.* (2022) found that low molecular weight PAH, such as phenanthrene and naphthalene, tend to be the most abundant in honey samples, but the presence of naphthalene may, in certain cases, reflect a direct and non-environmental contamination, resulting from unregulated beekeeping practices, such as the use of naphthalene inside the hives to protect the combs from the wax moth.

Catalano et al. (2024) draws attention to the proper selection of appropriate substrates for the identification of pollutants, given their physicochemical characteristics of lipophilicity or hydrophilicity. Given honey's low affinity for PAH, other matrices such as pollen and propolis, which have a higher lipid content, may be a more efficient choice in terms of quantifying PAH in the environment (Passarella et al., 2022).

Kazazic et al. (2020) and Passarella et al. (2022) warn of the absence of maximum residual limits (MRLs) for PAH in honey in the European Union, which poses a regulatory challenge, although the levels found in the studies were not of concern for human health according to the authors.

Radionuclides

Radionuclides or radioisotopes are unstable atoms of chemical elements that emit radiation during decay to become more stable. They can be of natural origin (carbon-14; uranium-238) or artificially produced (cesium-137; polonium-210). They represent a risk to human health and other animals, due to their ionizing radiation capable of causing damage to DNA molecules and consequently cancer. Some of the anthropogenic sources are accidents in nuclear power plants, application of artificial phosphate fertilizers, pollution from coal-fired power plants, and the use of ammunition with "depleted uranium" (Mihaljev et al., 2021).

The analysis of radionuclides in honey is important to ensure the safety of consumers, as these elements can be transferred along the food chain and pose risks even at low concentrations. However, for environmental evaluation, other hive matrices are more adequate. Szarłowicz, Jędrzejek and Najman (2025) concluded that honey has very low concentrations of radionuclides when compared to other matrices (such as propolis, which demonstrated a better correlation with soil radioactivity) limiting the potential of honey as an environmental indicator for this type of pollutant. Still, the authors point out that, despite the low levels found, the ingestion of honey in large quantities should not be disregarded in the risk assessment.

Microplastics

The presence of microplastics in the environment has been studied intensively in recent years, being pointed out as a potential risk for several insects, including bees (Alma; De Groot; Buteler, 2023). In the study by Inaudi et al. (2025), performing joint analysis of inorganic elements and microplastics in Italian honey, revealed the presence of microplastics in 100% of the samples, with concentrations ranging from 29 to 129 fibers and/or particles per kilogram. However, the predominance of colorless fibers, identified by the authors as Nylon 6 and Low-Density Polyethylene (LDPE), indicates a possible contamination associated with equipment used in production, as well as the use of plastic packaging.

The correlation between microplastics and lead, found by the authors, reinforces the hypothesis that these materials can act as vectors of heavy metals, increasing the risks, especially since about 21% of the particles were smaller than 130 µm, a range associated with a greater potential for interaction with biological tissues (Kannan; Vimalkumar, 2021). Thus, honey emerges as a possible bioindicator capable of reflecting environmental and anthropogenic contamination, although it is not the most sensitive matrix for metals as previously discussed.

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Still, the work presents a promising field for integrated pollutant monitoring, encouraging revisions in honey production practices, avoiding contamination by microplastics, and deepening the assessment of the combined risks between microplastics and heavy metals.

Flame Retardant

Flame retardants (FR) are a class of chemicals added to commercial products for the purpose of imparting flammability resistance. However, because they are not chemically bound to materials, they are easily released into the environment during the production and disposal processes (Leung et al., 2023).

The study by Leung et al. (2023) shows promise in the evaluation of FR in the environment using honey, and it was possible to detect the presence of these contaminants in this matrix. However, given the result of the analysis comparing honey samples from different locations, part of which was urbanized areas and the other part of rural areas, and not finding significant differences in the concentration of these substances in the honey samples, when supposedly the samples of urban origin would be more susceptible to greater exposure to CRs, further studies would be needed to prove this matrix as being adequate for its monitoring in the environment.

Phthalic Acid Ester (PAE) and Bisphenol-A

The research carried out by Di Fiore et al. (2023) demonstrates that honey may be suitable for monitoring the presence of BPA and Phthalic Acid Esters (PAE). The results indicated that the most present EAFs, such as Diisobutyl phthalate (DiBP), Di(2-ethylhexyl) phthalate (DEHP) and Di-n-octyl phthalate (DnOP), were in line with the data in the literature describing their wide diffusion in various

environmental compartments, confirming the validity of the honey matrix for the biomonitoring of these pollutants. The proximity of hives to an area close to roads with heavy vehicular traffic recorded the highest levels of PAE, and the presence of these pollutants was attributed to road dust.

However, using honey to monitor PAE and BPA presents some limitations and challenges. The study, which simultaneously evaluated several pollutants, determined BPA and PAE only in honey samples and not in the bees themselves or other matrices from the hive. In addition, the presence of these plasticizers in honey does not always reflect only atmospheric deposition or absorption by vegetation and soil; It can also be related to the production processes or the plastic packaging used. Specifically, the possibility of honey being contaminated due to the increased use of plastic combs in some countries is a relevant consideration. Despite these potential sources of bias, the results obtained corroborate the possibility of evaluating the diffusion of PAE and BPA in the environment using honey as a bioindicator.

Conclusion

The integrated analysis of the 30 publications included in this review shows that honey has significant potential as an environmental bioindicator, especially for PTE, PAH, and certain agrochemicals, consistently reflecting the environmental quality of the sampled areas. However, its sensitivity varies widely among different pollutants, being lower for highly lipophilic compounds, radionuclides, and some classes of pesticides, which limits its use as the only monitoring matrix.

Several factors, such as botanical origin, beekeeping practices, processing conditions and physicochemical characteristics of honey, influence the levels of substances detected, reinforcing the need for cautious interpretations. The literature also highlights that complementary matrices of the hive, such as pollen, wax, propolis and the adult bees themselves, often have greater detection capacity and better correlation with sources of environmental pollution than honey.

Hung *et al.* (2024) mentions that despite the use of different apiary matrices as bioindicators, few studies evaluate their relationship with environmental pollutants. Evaluating the various publications included in this review, we can reach the same conclusion, given the small number of studies that perform comparative analyses between these matrices and other pollutant monitoring methodologies.

Thus, although honey presents itself as an ethical, accessible, and operationally viable matrix, its more robust use as a bioindicator depends on integration with other matrices, comparative studies, and the application of sensitive analytical methods, ensuring more accurate and comprehensive environmental diagnoses.

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