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Climate change, air pollution, and risks to honeybees – a review of biomonitoring data

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Abstract. Environmental pollution and climate change are among the biggest concerns of the World population and represent an increased risk for the survival of very sensitive animals and insects, including honeybees. Environmental health monitoring can be performed through the biomonitorization of sentinel species. Honeybees are essential pollinators for global sustainale terrestrial productivity. This work presents a global overview of the available information on biomonitoring of honeybees and identifies the most characterized environmental pollutants. Available data clearly demonstrate the presence of different metals (arsenic, nickel, cadmium, lead, *etc.*), PAHs (naphthalene, acenapthylene, acenaphthene, fluorene, phenanthrene, anthracene, pyrene, chrysene, benzo(a)pyrene, benz(a)anthracene, isomers of benzofluoranthene, indeno(1,2,3-c,d)pyrene, and dibenz(a,h)anthracene), polychlorinated biphenyls, plasticizers residues, and microplastics on bees. The contamination of bees was increased near urban areas and/or locals with increased anthropization. Biomonitoring of bees allows the identification of local sources of pollution in the surroundings of beehives (*e.g.*, urban traffic emissions, forest fires, and agriculture). Additional studies are needed to better characterize the impact of environmental pollutants on bees.

Keywords: Environmental biomonitoring; Sentinel species; Bees; Metals; Polycyclic aromatic hydrocarbons

1. Introduction

Climate change has been causing an increase in the frequency and intensity of extreme weather events, *e.g.*, wildfires and prolonged droughts. Recently, The Lancet Commission on Pollution and Health highlighted that pollution causes 9 million premature deaths per year (one in six deaths worldwide), which represents the largest environmental risk factor for the development of disease and promotes premature death (Fuller et al., 2022). Over the last decades, the occurrence and severity of wildfires, with hotter and longer fire seasons, have increased due to global warming and climatic changes (Fernandez-Anez et al., 2021). Large wildfires strongly impact the quality of the air, water, and soil of burned areas and cause a strong negative impact on the fauna and flora of the affected areas, being responsible for the (partial/total) destruction of the habitat of many species and the available food resources (Certini et al., 2021; Oliveira et al., 2020). Pollution, climate change, and biodiversity loss are directly interconnected.

Environmental pollution is a planetary threat and its dispersion through large distances away from the sources affects not only local areas but also transcends local boundaries. Air pollution is the most characterized and widespread type of pollution that severely affects the environment and human health (EEA, 2020; Yu et al., 2023). The International Agency for Research on Cancer classified air pollution as a whole and particulate matter as carcinogens to humans (IARC 2013).

Environmental monitoring is frequently done with different monitoring systems to verify the presence and determine the levels of ambient pollutants (*e.g.*, carbon monoxide, particulate matter, ozone, metals, nitrogen oxides, volatile organic compounds, *etc.*) in different matrices (air, water, and soils) (Kariyawasam et al., 2021; Mearns et al., 2019; Wright et al., 2018). However, these environmental monitoring tools are expensive, require regular management, and cannot be applied to all areas. Therefore, innovative and alternative devices are required to better monitor the environment, preferably with non-invasive and more realistic approaches. Environmental biomonitoring comprises the use of organisms (known as biomonitors/sentinels) from local fauna and flora to collect qualitative/quantitative information related to their habitat including the presence and impact of pollutants in different media (Huang et al., 2018; Jesus et al., 2022; Oliveira et al., 2018, 2020).

Honeybees have been identified as the local "ideal bioindicator" for environmental biomonitoring due to its biological characteristics and their direct contact with bioavailable contaminants from environmental media, such as vegetation, water, soil, and air, in the surrounding area of hives during beekeeping practices (Al-Alam et al., 2019). Pollutants can accumulate on bees´ tissues, be carried to their hives, and be incorporated into bees' products. Honeybees are very sensitive to environmental changes and their mortality rates are also a good indicator of local pollution. Moreover, honeybees' products (*e.g.*, honey, wax, pollen, *etc*.) can also be used to identify environmental sites more affected by ambient pollution. The information related to the use of honeybees as environmental biomonitor/sentinel is slowly emerging from the literature. This work aims to collect and revise the available information on the biomonitoring of honeybees and highlight the principal pollutants found in this very sensitive specie.

2. Methods

Data related to biomonitoring assays performed with honeybees were searched in the scientific databases Scopus and ISI Web of Science up to February 2023. The search was made with the combination of at least two of the following keywords: environmental biomonitoring, honeybees, and air pollution; the Boolean symbol "and" was always used. The following inclusion criteria were applied: i) to be written in English, and ii) to use honeybees as biomonitors. Only the most representative studies that allow presenting a broad and complete overview of available data are chronologically presented.

3. Results and Discussion

Honeybees are bioindicators as individuals and/or as population in their environment and are crucial pollinators for the well-functioning of almost all terrestrial ecosystems. Available literature clearly demonstrated the susceptibility of honeybees to environmental contamination, particularly air pollution. The Chernobyl disaster caused the accumulation of radioisotopes in honeybees from the West Coast of the United States of America (Ford et al., 1988). To the best knowledge of these authors, the great potential of using honeybees to monitor the environment was for the first time demonstrated by Perugini et al. (2009) with the detection of very low concentrations of some PAHs in Italian beehives located far away from possible sources of pollution. These authors reported the prevalence of low molecular weight PAHs in honeybees and described increased levels of some compounds (fluorene, phenanthrene, anthracene, fluoranthene, benz(a)anthracene, and benzofluorene isomers) in bees than in the honey they produced. Also, predominantly increased levels of bee contamination with PAHs were found in sampling sites near an airport with intense air traffic and motor vehicle circulation as well as in a moderately polluted area close to small roads and a local incinerator (Perugini et al., 2009). Lambert et al. (2012) also characterized the levels of 4 PAHs, namely benzo(a)pyrene, benz(a)anthracene, benzo(b)fluoranthene and chrysene, in beehive matrices, *i.e*., honey, trap pollen, and foraging bees, from different apiaries from a Western French region. These authors found increased concentrations of those compounds in bees than in beehive products and the great dispersion of values observed was attributed to local events of increased environmental contamination. Badiou-Bénéteau et al. (2013) evaluated the potential of honeybees to be used as a biomarker of environmental quality through the determination of (neural/metabolic) biochemical biomarkers (*e.g*., glutathione-S-transferase, acetylcholinesterase, alkaline phosphatase and metallothioneins) in bees living in urban and semi-natural areas from the La Reunion Island (France). Significant differences in the activity of some biomarkers (glutathione-S-transferase, acetylcholinesterase, alkaline phosphatase) were reported between both locations, suggesting that honeybees from urban areas are subjected to environmental stress that promoted oxidative stress on sensitive insects due to exposure to environmental pollutants (*e.g*., metals). Some authors gathered the potential of honeybees, pine tree leaf, and propolis to be used as environmental bioindicators of airborne PAHs in a Turkish industrial area characterized by a petrochemical industry, iron/steel factories, gas turbines, and natural gas-coal combined power plants (Aliaga, Izmir, Turkey) (Kargar et al., 2017). A total of eight PAHs (naphthalene, acenapthylene, acenaphthene, fluorene, phenanthrene, anthracene, pyrene, and benz(a)anthracene) were found in honeybees and this sentinel specie was pointed as a better indicator because it can provide a broader range of environmental data related with airborne pollutants present in both the gas and the particulate phase and over longer periods of time (the lifetime of the honeybee). Also, statistical analysis including diagnostic ratios allowed the identification of coal and biomass burning as the predominant sources of PAHs in the sampled area (Kargar et al., 2017). Gomez-Ramos et al. (2019) developed a methodology based on a combined chromatographic analytical approach to screen non-targeted environmental contaminants from different chemical groups (*e.g*., PAHs, phthalates, synthetic musks, residues of veterinary treatments, among others). The methodology was successfully applied to honeybees from apiaries located in different Spanish regions. A biomonitorization assay performed with honeybees from a Northern American city, Québec (Canada), demonstrated the sensitivity of honeybees to differentiate the environmental contamination with heavy metals (Pb, Ni, As, and Cd) and some PAHs (benzo(a)pyerene, ben(a)anthracene, dibenz(a,h)anthracene, and benzofluoranthene isomers) in different urban and rural locations (Grenier et al., 2021). Cochard et al. (2021) also performed a biomonitoring study with honeybees to examine the impact of airborne PAHs present in different French industrial sites and used the bees´ contamination with some PAHs (*e.g*., benzo(a)pyrene, benz(a)anthracene, isomers of benzofluoranthene, indeno(1,2,3-c,d)pyrene, and dibenz(a,h)anthracene) to differentiate the sampled sites into semi-natural, agricultural, and urban areas. The highest levels of PAHs were found in bees living in urban sites (Cochard et al., 2021). Sari et al. (2021) described an innovative passive sampling approach to monitor the presence of airborne polychlorinated biphenyls (PCBs) in the environment where honeybees are inserted through the collection of polyurethane foam discs in both urban and semi-urban regions in Ankara, Turkey. Simultaneously, the study also collected honeybees and pollen samples. As previously described by some authors, honeybees presented the highest concentrations of environmental pollutants, *i.e*., PCBs (Sari et al., 2021). The presence of PCBs in honeybees was suspected caused by the absorption of these contaminants from local surface waters in the surrounding area of beehives. However, no relationship was observed between the age of honeybees and the levels of PCBs (Sari et al., 2021). Edo et al. (2021) demonstrated the presence of microplastics (13 types of synthetic polymers) on honeybees from Denmark. Andrade de Santana et al. (2022) presented the chemical profile via scanning electron microscopy and energy dispersive X-ray spectroscopy of some metals (Mg, Al, Ca, Mn, Fe, Ni, Cu, Zn, As, Mo, Cd, Ba, and Pb) in the body of bees from Caatinga (Brazil) areas to identify local sources of environmental contamination. Some authors evaluated the impact of covid-19 pandemic lockdown on local environmental contamination with heavy metals through honeybees biomonitorization in the Campania region (Italy) (Scivicco et al., 2022). It was reported statistically lower levels of heavy metals (As, Ba, Cr, Cu, Mn, Ni, Pb, Sb, and V) at the end pandemic lockdown than in some months after with partial and total resumption activities. Moreover, Smith and Weis (2022) also found increased amounts of some metals (*e.g.*, Pb, Zn, Sb) associated with anthropogenic activities in bee samples collected throughout Metro Vancouver (Canada) during foraging hours than in those living in more suburban/urban areas. Similar findings were reported by Conti et al. (2022) for Italian bees. However, some authors highlighted for the inter- and in-hive variability in the elemental composition of honeybees which should be taken in consideration in future studies (Zarić et al. 2022). More recently, Di Fiore et al. (2023) also used honeybees as biomonitors to assess environmental contamination with PAHs, metals (*e.g.*, Cd, Co, Pb, Be, Cr, and Ni), and some plasticizers residues (*e.g.*, dimethyl phthalate, diethyl phthalate, diisobutyl phthalate, dibutyl phthalate, bis(2-ethylhexyl)phthalate, di-n-octylphthalate, and bisphenol A) in different sites of the Molise Region (Italy). These authors highlighted a greater accumulation of some heavy metals in bees than in the honey produced (except for Cu). Moreover, different PAHs such as pyrene, benzo(a)pyrene, benz(a)anthracene, chrysene, and benzofluoranthene isomers were found in bees. These findings were attributed to environmental pollution phenomena over the lifetime of bees in their habitat (Di Fiori et al., 2023). Sebastiani et al. (2023) reported a comparative study related to the environmental contamination with different classes of polycyclic aromatic compounds (including aliphatic hydrocarbons, PAHs, and polycyclic aromatic sulfur heterocycles) in honeybees living in two areas affected by cement plant emissions with background reference areas at the Apennine Mountains (Umbria, Italy). This study was able to positively identify 177 compounds on foraging bees. Additional studies including honeybees are needed to better characterize the potential of these very sensitive pollinators to serve as environmental sentinels. Also, available information could be used to estimate further environmental risks.

4. Conclusion

Despite limited, available literature clearly identifies honeybees as good environmental biomonitors and suggests its use as sentinels in future environmental biomonitoring assays. Honeybees are good sentinels for environmental contamination with metals, PAHs, PCBs, plasticizers residues, and microplastics. However, more studies are necessary to better characterize the contamination of honeybees with other relevant pollutants and to explore the impact of environmental contamination on bees' health.

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References

Al-Alam J., Chbani A., Faljoun Z., and Millet M. (2019), The use of vegetation, bees, and snails as important tools for the biomonitoring of atmospheric pollution-a review. *Environmental Science and Pollution Research*, **26**(10), 9391 - 9408.

Andrade de Santana S.E., Silva A.P., Serrão J.E., de Mello Afonso P.R.E., Nunes L.A., and Waldschmidt A.M. (2022), Chemical Profle of Elements in the Stingless Bee Melipona. *Biological Trace Element Research*, **200**, 3885-3889.

Badiou-Bénéteau A., Benneveau A., Géret F., Delatte H., Becker N., Brunet J.L., et al. (2013), Honeybee biomarkers as promising tools to monitor environmental quality, *Environment International*, **60**, 31-41.

Certini G., Moya D., Lucas-Borja M.E., and Mastrolonardo G. (2021), The impact of fire on soil-dwelling biota: A review. *Forest Ecology and Management*, **488**, 118989 – 119010.

Cochard P., Laurie M., Veyrand B., Le Bizec B., Poirot B., and Marchand P. (2021), PAH7 concentration reflects anthropization: A study using environmental biomonitoring with honeybees, *Science of the Total Environment*, **751**, 141831.

Conti M.E., Astolf M.L., Finoia M.G., Massimi L., and Canepari S. (2022), Biomonitoring of element contamination in bees and beehive products in the Rome province (Italy). *Environmental Science and Pollution Research*, **29**, 36057–36074.

Di Fiore C., De Cristofaro A., Nuzzo A., Notardonato I., Ganassi S., Iafigliola L. et al. (2023), Biomonitoring of polycyclic aromatic hydrocarbons, heavy metals, and plasticizers residues: role of bees and honey as bioindicators of environmental contamination, *Environmental Science and Pollution Research*, https://doi.org/10.1007/s11356-023-25339-4.

EEA (2020), Air Quality in Europe – 2020 Report, European Environment Agency, Luxembourg.

Edo C., Fernández-Alba A.R., Vejsnæs F., van der Steen J.J.M., Fernández-Piñas F., and Rosal R. (2021), Honeybees as active samplers for microplastics. *Science of the Total Environment*, **767**, 144481.

Fernandez-Anez N., Krasovskiy A., Müller M., Vacik H., Baetens J., Hukić E., et al. (2021), Current Wildland Fire Patterns and Challenges in Europe: A Synthesis of National Perspectives. *Air, Soil and Water Research* **14** (3), 1 - 19.

Fuller R., Landrigan F.J., Balakrishnan K., Bathan G., Bose-O'Reilly S., Brauer M., et al. (2022), Pollution and health: a progress update, *Lancet Planet Health*, **6**, e535–47.

Gómez-Ramos M.M., Ucles U., Ferrer C., Fernández-Alba A.R., and Hernando M.D. (2019), Exploration of environmental contaminants in honeybees using GC-TOF-MS and GC-Orbitrap-MS, *Science of the Total Environment*, **647**, 232-244.

Grenier E., Giovenazzo P., Julien C., and Goupil-Sormany I. (2021), Honeybees as a biomonitoring species to assess environmental airborne pollution in different socioeconomic city districts, *Environmental Monitoring and Assessment*, **193**, 740.

Huang S., Dai C., Zhou Y., Peng H., Yi K., Qin P., et al. (2018), Comparisons of three plant species in accumulating polycyclic aromatic hydrocarbons (PAHs) from the atmosphere: a review. *Environmental Science and Pollution Research,* **25**(17), 16548 - 16566.

IARC (2013), Air Pollution and Cancer, Vol. 161, International Agency for Research on Cancer, France.

Jesus F., Pereira J.L., Campos I., Santos M., Ré A., Keizer J., et al. (2022), A review on polycyclic aromatic hydrocarbons distribution in freshwater ecosystems and their toxicity to benthic fauna. *Science of the Total Environment,* **820**, 153282 - 153296.

Kargar N., Matin G., Matin A.A., and Buyukisik H.B. (2017), Biomonitoring status and source risk assessment of polycyclic aromatic hydrocarbons (PAHs) using honeybees, pine tree leaves, and propolis, *Chemosphere*, **186**, 140-150.

Kariyawasam T., Doran G.S., Howitt J.A., and Prenzler P.D. (2021), Polycyclic aromatic hydrocarbon contamination in soils and sediments: Sustainable approaches for extraction and remediation. *Chemosphere* **291**(3), 132981 - 132998.

Lambert O., Veyrand B., Durand S., Marchand P., Le Bizec B., Piroux M., et al. (2012), Polycyclic aromatic hydrocarbons: Bees, honey and pollen as sentinels for environmental chemical contaminants. *Chemosphere*, **86**, 98-104.

Mearns A.J., Bissell M., Morrison A.M., Rempel-Hester M.A., Arthur C., and Rutherford N. (2019), Effects of pollution on marine organisms. *Water Environment Research*, **91**(10), 1229 - 1252.

Oliveira M., De Gasperi Portella C., Ramalhosa M.J., Delerue-Matos C., Sant'Ana L.S., and Morais S. (2020), Polycyclic aromatic hydrocarbons in wild and farmed whitemouth croaker and meagre from different Atlantic Ocean fishing areas: Concentrations and human health risk assessment. *Food and Chemical Toxicology*, **146**, 111797 - 111807.

Oliveira M., Delerue-Matos C., Pereira M.C., and Morais S., (2020), Environmental Particulate Matter Levels during 2017 Large Forest Fires and Megafires in the Center Region of Portugal: A Public Health Concern? *International Journal of Environmental Research and Public Health*, **17**(3), 1032 – 1052.

Oliveira M., Gomes F., Torrinha Á., Ramalhosa M.J., Delerue-Matos C., and Morais S. (2018), Commercial octopus species from different geographical origins: Levels of polycyclic aromatic hydrocarbons and potential health risks for consumers. *Food and Chemical Toxicology,* **121**, 272 - 282.

Perugini M., Di Serafino G., Giacomelli A., Medrzycki P., Sabatini A.G., Persano Osso L., et al. (2009), Monitoring of Polycyclic Aromatic Hydrocarbons in Bees (Apis mellifera) and Honey in Urban Areas and Wildlife Reserves. *Journal Agricultural and Food Chemistry*, **57**, 7440-7444.

Sari M.F., Esen F., and Tasdemir Y. (2021), Levels of polychlorinated biphenyls (PCBs) in honeybees and bee products and their evaluation with ambient air concentrations. *Atmospheric Environment,* **244**, 117903.

Scivicco M., Nolasco A., Esposito L., Ariano A., Squillante J., Esposito F. et al. (2022), Effects of Covid-19 pandemic lockdown and environmental pollution assessment in Campania region (Italy) through the analysis of heavy metals in honeybees. *Environmental Pollution*, **307**, 119504.

Sebastiani B., Mariucci S., and Palmieri N. (2023), Foraging Honeybees (Apis mellifera ligustica) as Biocenosis Monitors of Pollution in Areas Affected by Cement Industry Emissions, *Environments*, **10**, 34.

Smith K.E., and Weis, D. (2022), Metal and Pb isotope characterization of particulates encountered by foraging honeybees in Metro Vancouver. *Science of The Total Environment*, **826**, 154181.

Yu W., Ye T., Zhang Y., Xu R., Lei Y., Chen Z., et al. (2023), Global estimates of daily ambient fine particulate matter concentrations and unequal spatiotemporal distribution of population exposure: a machine learning modelling study, *Lancet Planet Health*, **7**, e209–18.

Wright L.P, Zhang L, Cheng I, Aherne J, and Wentworth G.R. 2018), Impacts and Effects Indicators of Atmospheric Deposition of Major Pollutants to Various Ecosystems - A Review. *Aerosol and Air Quality Research*, **18**(8), 1953 – 1992.

Zarić N.M., Brodschneider R., and Goessler W. (2022), Honey bees as biomonitors – Variability in the elemental composition of individual bees, *Environmental Research*, **204**, 112237.