



Eco toxicological impact of particulate matter on *Apis mellifera* (Honey Bees)

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Abstract

Honey bees (*Apis mellifera*) play a crucial role as pollinators, supporting biodiversity and global food security by helping many flowering plants and crops reproduce. Unfortunately, their populations are facing a decline due to various environmental pressures, with one often overlooked factor being air pollution, particularly particulate matter (PM). This PM—especially the fine particles known as PM_{2.5} and PM₁₀—comes from vehicle emissions, industrial activities, and biomass burning, and it carries harmful substances like heavy metals and polycyclic aromatic hydrocarbons (PAHs). Honey bees encounter PM both through the air and by ingesting contaminated pollen, nectar, and water. This exposure can lead to oxidative stress, a weakened immune system, neurological issues, and changes in behavior that interfere with their foraging, navigation, and communication abilities, which can ultimately harm the health of their colonies and increase the chances of colony collapse. The negative effects of PM also affect crop pollination, which in turn threatens food production and the stability of ecosystems. Despite rising concerns, there's still limited research on how PM impacts pollinators. Future studies need to take a comprehensive approach, incorporating long-term field studies and molecular investigations, to grasp the combined effects of PM and other pollutants. It's vital to enhance air quality policies and conservation strategies focused on pollinators to ensure the survival of bee populations and the essential ecological services they deliver.

Keywords: *Apis mellifera*, particulate matter, air pollution and pollination

Introduction

Honey bees (*Apis mellifera*) play a crucial role as pollinators in both natural habitats and agricultural settings. They are key players in the reproductive success of flowering plants and the productivity of many crops. In fact, it's estimated that nearly 75% of the world's food crops rely on pollination by insects, with honey bees being the stars of the show (Potts *et al.*, 2016)^[11]. This vital ecological service helps not only to preserve biodiversity but also to secure food supplies and bolster global economies. Unfortunately, in recent decades, honey bee populations have been facing concerning declines due to a variety of challenges like habitat loss, pesticide use, climate change, parasites, and diseases (Goulson *et al.*, 2015)^[5]. Among these challenges, environmental pollution—especially air pollution—is emerging as a significant and often overlooked threat to the health of bees. One of the most dangerous elements of air pollution is particulate matter (PM). PM is made up of tiny solid and liquid particles that float around in the air, including things like dust, soot, heavy metals, nitrates, sulfates, and organic chemicals. These particles come in different sizes, with PM_{2.5} (particles smaller than 2.5 micrometers) and PM₁₀ (particles smaller than 10 micrometers) being the most closely monitored because of their serious health impacts (Brook *et al.*, 2010)^[1]. While a lot of research has looked at how PM affects human health—like respiratory, cardiovascular, and neurological issues—its impact on insect pollinators has mostly flown under the radar. Recent studies have shown that honey bees can be exposed to particulate matter in both direct and indirect ways. Direct exposure happens when PM clings to their fuzzy bodies while they're out flying or foraging, which can mess with their ability to regulate heat, fly properly, and perceive their surroundings (Eisenmann *et al.*, 2019)^[3]. Indirect exposure might occur when floral resources—such as pollen, nectar, and water—get contaminated with toxins bound to particulate matter, which

the bees then ingest (Ferrari *et al.*, 2020)^[4]. Additionally, bees can carry these contaminated particles back to their hives, putting larvae and other colony members at risk for sublethal or long-term issues (Zhao *et al.*, 2021)^[20]. These kinds of exposures can trigger a variety of eco-toxicological effects. Physiologically, bees might experience oxidative stress, reduced enzyme activity, and weakened immune responses due to the harmful metals and organic compounds found in PM (Di *et al.*, 2022)^[2]. Behaviorally, exposure to PM has been associated with disorientation, changes in foraging behavior, and difficulties with learning and memory—all crucial for successful pollination and colony health (Wang *et al.*, 2021)^[18]. Chronic exposure could ultimately compromise the colony's overall well-being and make them more vulnerable to other stressors, which might play a role in issues like Colony Collapse Disorder (CCD). Despite its importance, we still know very little about how particulate matter (PM) affects honey bees, or *Apis mellifera*, especially in places with heavy pollution, like urban and industrial areas in developing countries. Most of the research so far has zeroed in on pesticides and biological pathogens, while air pollutants like PM haven't gotten as much attention from scientists. With urbanization and industrial activities on the rise, it's crucial to understand the impact of these airborne particles on pollinator populations.

Global facts about diseases due to air pollution

Outdoor air contamination from the incineration of fossil fuels is responsible for 8.7 million fatalities annually around the world (Vohra *et al.* (2022).

According to the global burden of illness report, air pollution is the tenth leading cause of disease worldwide and the sixth leading cause of death in South Asia. Particulate matter in the air is an important factor contributing to the third-greatest cause of death in India, behind only interior air pollution and vehicular exhaust.

The report found that severe air pollution is not limited to

Asia “87% of random sample of global cities are in breach of WHO air pollution guidelines, meaning billions of people worldwide are exposed to unsafe levels of fine particulate matter (PM_{2.5})”.

Norms and standards for PM 2.5 Air Pollution

	International standard (By WHO)	USEPA standard	National standard
Annual Mean	10 µg/m ³	12 µg/m ³	40 µg/m ³
24-hours mean	20 µg/m ³	35 µg/m ³	60 µg/m ³

Overview of Particulate Matter (PM)

1. Sources and Composition of Particulate Matter

Particulate matter (PM) is made up of tiny solid and liquid particles that float in the air. It's usually categorized by size, with PM10 being particles that are 10 micrometers or smaller and PM2.5 being even tinier, at 2.5 micrometers or less. The main culprits behind PM are vehicle exhaust, industrial processes, construction dust, burning biomass, and even natural sources like pollen and sea spray (Brook *et al.*, 2010) [1]. These particles are a mixed bag, including heavy metals like lead and cadmium, black carbon, organic compounds, nitrates, and sulfates, all of which can change based on where they come from (Kim *et al.*, 2015) [8]. Unfortunately, these particles can be harmful to both our health and the environment since they can easily enter biological systems.

2. Known Toxicological Effects in Organisms

Exposure to particulate matter can lead to respiratory issues, oxidative stress, inflammation, and even cellular damage in a variety of organisms. It throws a wrench in normal physiological functions, hampers reproduction, and raises mortality rates across different species, including humans, insects, and aquatic life (Brook *et al.*, 2010; Schraufnagel, 2020) [1, 14].

Biology and Ecology of *Apis Mellifera*

1. Life Cycle and Behavior

The Western honey bee, or *Apis mellifera*, goes through a fascinating life cycle with four distinct stages: egg, larva, pupa, and adult. Depending on whether they come from fertilized or unfertilized eggs, queens, workers, and drones develop through different feeding patterns (Winston, 1987) [19]. Workers take on various tasks that change with age, including nursing the young, keeping the hive clean, guarding against threats, and foraging for food (Seeley, 1995) [15]. These bees show remarkable behavior, like communicating through the waggle dance, navigating their environment, and working together socially. Their ability to adapt to changes in their surroundings is impressive, but it also makes them susceptible to stressors like pollution, which can hurt their memory, foraging skills, and overall survival.

2. Sensitivity to Environmental Stressors-

Apis mellifera, commonly known as the honeybee, is particularly susceptible to various environmental stressors like pesticides, air pollution, pathogens, and even the impacts of climate change. These challenges can interfere with their neural functions, weaken their immune systems,

and alter their behavior. As a result, we see a decline in foraging abilities, learning capacity, and even the risk of colony collapse (Goulson *et al.*, 2015; Sánchez-Bayo & Wyckhuys, 2019) [5, 13].

Exposure Pathways for *Apis mellifera*

1. Inhalation and Airborne Contact

Honey bees (*Apis mellifera*) encounter airborne pollutants mainly through direct contact while they're out flying and foraging. Those tiny particles, known as PM2.5, can cling to their bodies, mess with their respiratory spiracles, and even be inhaled, which can cause some serious respiratory and physiological stress (Eisenmann *et al.*, 2019) [3]. On top of that, pollutants like heavy metals and hydrocarbons found in particulate matter can throw off their sense of smell, navigation skills, and immune responses (Di *et al.*, 2022) [2]. If these airborne toxins build up on the bees' bodies, they might also bring those contaminants back to the hive, which can really impact brood development and the overall health of the colony.

2. Contamination of Nectar, Pollen, and Water

Particulate matter (PM) and airborne pollutants can settle on flower surfaces and in water, leading to contamination of nectar, pollen, and water that honeybees, specifically *Apis mellifera*, gather. These foraged resources might end up containing harmful substances like heavy metals, polycyclic aromatic hydrocarbons (PAHs), and pesticides (Ferrari *et al.*, 2020) [4]. When bees and their larvae consume or store these tainted materials, they face oxidative stress, weakened immune systems, and various developmental problems, which could gradually weaken the entire colony (Zhao *et al.*, 2021). This type of contamination poses a danger not only to individual bees but also impacts the overall productivity of the colony and their ability to pollinate effectively.

Eco-Toxicological Effects of PM on *Apis mellifera*

Several researchers, including Azhar Abbas Khan, found. et al., 2023 shown that exposure to particulate matter (PM) (2.5 m and 10 m) in an agro-industrial ecosystem had negative effects on the foraging performances, Behavioural impairments, foraging behavior, and brood development of *Apis mellifera* in the treated area. A decreased number of bees were found in simulated hives made of particulate matter, which likely reflects fewer broods and less honey production.

According to Yoori Cho et al. honeybees rely on the polarization of the skylight to guide them on their foraging journeys, however an increase in airborne particulate matter (PM) in the atmosphere changes this polarization. Honeybees extend their foraging flights as air quality drops. Exposure to particulate matter (PM), especially the harmful PM2.5 and PM10, presents serious threats to our honeybee friends, *Apis mellifera*. These tiny particles can cling to the bees' bodies and find their way into their breathing holes, causing oxidative stress, inflammation, and even damage at the cellular level (Di *et al.*, 2022) [2]. Moreover, PM can negatively impact their central nervous system, messing with their sense of smell, learning capabilities, and memory,

which in turn hampers their foraging and navigation skills (Eisenmann *et al.*, 2019)^[3]. When bees collect contaminated pollen, nectar, and water, they unwittingly bring back toxic substances like heavy metals and polycyclic aromatic hydrocarbons (PAHs) to their hives. This can lead to a weakened immune system, stunted brood development, and higher mortality rates (Zhao *et al.*, 2021). Over time, such exposure undermines the resilience of bee colonies and makes them more susceptible to additional stressors like diseases and pesticides. All of these factors together pose a serious threat not only to pollination services but also to the stability of our ecosystems and food security. That's why PM pollution is a pressing environmental issue for honey bee health and their vital ecological role.

Mechanisms OF Toxicity

1. Cellular and Molecular Mechanisms

Particulate matter (PM), particularly the finer particles known as PM_{2.5}, causes a range of cellular and molecular issues in honeybees (*Apis mellifera*). When bees come into contact with PM, it may infiltrate their respiratory system and cuticle, leading to oxidative stress due to an overproduction of reactive oxygen species (ROS). This oxidative imbalance can harm crucial biomolecules like lipids, proteins, and nucleic acids, resulting in cellular dysfunction (Di *et al.*, 2022)^[2]. The damage inflicted by ROS can impair mitochondria, reducing ATP production and negatively impacting energy-dependent activities such as flight, thermoregulation, and immune responses. On a molecular level, exposure to PM can change the expression of genes involved in detoxification, particularly those connected to cytochrome P450 enzymes, glutathione S-transferase, and antioxidants like superoxide dismutase (Guseva *et al.*, 2020)^[7]. Moreover, genes related to stress and immune responses are often downregulated, which diminishes the bees' ability to fight off pathogens and deal with environmental toxins. Even their neurological genes that impact olfactory perception and learning seem to be affected, shedding light on the behavioral changes observed in bees that have been exposed. These cellular disturbances don't just affect individual bee health; they can also jeopardize the survival of entire colonies and their ability to pollinate effectively. This emphasizes the pressing need for regulations to cut down on airborne pollutants.

2. Synergistic Effects with Other Pollutants

When bees, specifically *Apis mellifera*, are simultaneously exposed to both particulate matter (PM) and pesticides, the

toxic effects can really ramp up. PM has the ability to cling to pesticide residues, making them more available and helping them get into the bees' tissues (Sanchez-Bayo & Goka, 2014)^[12]. This combination weakens their antioxidant defenses, detoxification enzymes, and immune systems, which in turn heightens behavior problems and the risk of dying (Goulson *et al.*, 2015)^[5]. Plus, the interaction can negatively impact reproduction and brood development, leading to a greater chance of colony collapse. These findings underline how crucial it is to consider multiple stressors when conducting ecological risk assessments for our pollinators.

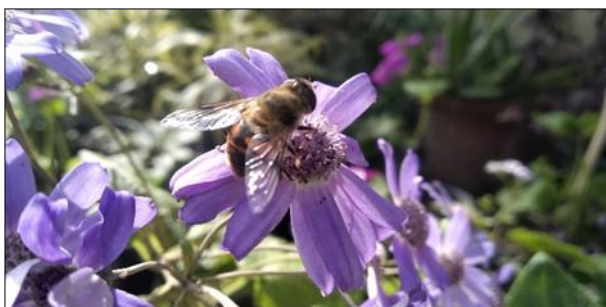
Ecological and Agricultural Implications

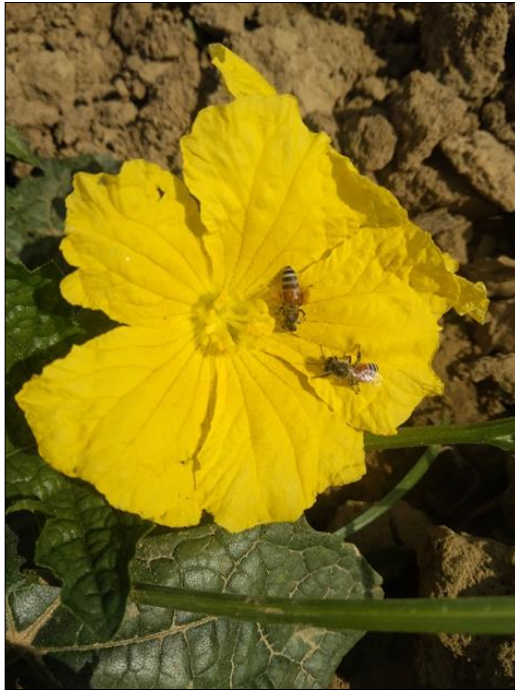
a. Impact on Crop Yield and Food Security

The exposure of honeybees, or *Apis mellifera*, to particulate matter (PM) and other pollutants has a significant negative impact on pollination—a crucial service that underpins global agriculture. When bees encounter airborne contaminants, it disrupts their health, navigation, and foraging behavior, which ultimately hampers their pollination effectiveness (Di *et al.*, 2022)^[2]. This drop-in bee activity can lead to lower yields in crops that depend on pollinators, including fruits, vegetables, nuts, and oilseeds (Klein *et al.*, 2007)^[9]. Furthermore, chronic stress from particulate matter, especially when combined with pesticides or pathogens, can cause colony collapse disorder, posing a serious threat to food security and economic stability (Potts *et al.*, 2010)^[11]. Considering that over 75% of the world's top crops depend on animal pollinators, the decline of bee populations poses a significant risk to sustainable agriculture and the vital ecosystem services we rely on.

b. Biodiversity and Ecosystem Service Decline

Bees, particularly *Apis mellifera*, are crucial players in our ecosystem, but they're facing serious challenges that impact their populations and, in turn, the wider environment. These little pollinators are essential for preserving biodiversity, as they help pollinate both wild plants and crops (Potts *et al.*, 2010)^[10]. When exposed to pollutants, bee populations can weaken, resulting in fewer seeds and fruits, which jeopardizes plant reproduction and species diversity (Goulson *et al.*, 2015)^[5]. The decline in pollination services can ripple through food webs, putting the stability and resilience of ecosystems at risk. Therefore, the deteriorating health of our bees presents a grave risk to ecological balance and sustainable development.





Future Directions

To tackle the rising worries about the harmful effects of particulate matter (PM) on honeybees, especially *Apis mellifera*, we really need to focus on some key research and policy directions moving forward.

First off, it's essential to conduct long-term, field-based monitoring of PM exposure across different environments—be it urban, peri-urban, or rural. This will help us understand the cumulative impact on honey bee health, behavior, and how entire colonies function. Additionally, these studies

should look into how PM composition and concentration change with the seasons and across various regions.

Second, to truly grasp the combined impact of different stressors like pesticides, heavy metals, climate stress, and pathogens, we need to create research frameworks that look at how they all work together. By understanding the interplay between these factors, we can enhance our risk assessments and develop better strategies for mitigation.

Third, diving into the world of molecular and cellular studies through omics technologies—like genomics, transcriptomics, and proteomics—can reveal early signs of PM toxicity. This can even help us spot sub-lethal impacts before a colony's demise. Plus, looking into how PM exposure affects genes over generations is definitely promising.

we really need to weave pollinator health into our air quality regulations. It's crucial for governments and local agencies to encourage green buffers, implement emission controls, and create habitats that support pollinators right next to industrial areas and farms.

Additionally, we can't overlook the importance of bringing together experts from various fields—toxicologists, entomologists, environmental scientists, and policymakers—so we can craft well-rounded conservation strategies. Protecting honeybees from particulate matter pollution isn't just an environmental duty; it's absolutely vital for maintaining biodiversity, ensuring food security, and keeping our ecosystems in balance.

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