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THE SILENT CRISIS: UNDERSTANDING THE IMPACT OF AIR POLLUTION ON INSECT POLLINATORS

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Abstract

Air pollution is a major global issue, well known for its harmful effects on human health, but it also poses a serious threat to pollinators, which is often overlooked. Air pollutants are present worldwide and encompass any substance that disrupts the natural composition of the atmosphere, causing environmental contamination. Rapid urbanization, intensive agriculture, and outdated vehicles have significantly increased pollution in developing regions. Burning fuels release pollutants like nitrogen oxides, sulfur oxides, ozone, and particulates, which can react in the atmosphere to form harmful compounds. With pollinators supporting 75% of global crop species and 8% of agricultural food production, pollution-induced declines could have severe ecological and economic consequences. Air pollution is a growing threat to insect populations, disrupting their ability to communicate, find food, and reproduce. Air pollution disrupts pollinators by impairing their sensory perception, altering floral scents, and breaking down pheromones, making it harder to find food, mates, and defend colonies. These disruptions threaten insect pollinator populations, which are essential for maintaining ecosystem balance and food production.

Key words: air pollutants, insect pollinators

Introduction

Air pollution is an escalating global concern with severe consequences for both human and ecological health. It results from industrial emissions, vehicular exhaust, and agricultural activities, releasing harmful pollutants such as nitrogen oxides (NO_x), ozone (O_3), particulate matter (PM), and heavy metals into the atmosphere (Ryalls et al., 2022). Among these, fine particulate matter (PM2.5) and ground-level ozone are particularly hazardous due to their ability to penetrate deep into the respiratory system, leading to respiratory diseases, cardiovascular disorders, and reduced life expectancy (WHO, 2021; Kim et al., 2015). Additionally, heavy metals such as lead (Pb) and cadmium (Cd) accumulate in biological systems, causing long-term toxic effects (Dżugan et al., 2018).

Beyond its direct effects on human health, air pollution disrupts ecosystems, particularly affecting insect pollinators, which are crucial for maintaining biodiversity and ensuring global food security. Pollutants interfere with pollinators' olfactory perception, impairing their ability to detect floral scent cues and efficiently transfer pollen (McFrederick et al., 2008; Fuentes et al., 2016). Recent studies indicate that exposure to high levels of PM reduces foraging efficiency and can even alter reproductive success in pollinators such as honeybees (Apis mellifera) (Khan et al., 2024; Jiang et al., 2023). This decline in pollinator efficiency leads to reduced plant reproduction rates, ultimately resulting in lower crop yields and threatening global food production (Ryalls et al., 2022). Given that approximately 75% of global food crops depend on insect pollination, these disruptions pose a significant threat to agricultural sustainability (Klein et al., 2007; IPBES, 2016).

Furthermore, pollinators serve as essential bioindicators of environmental health. Studies have shown that honeybees accumulate heavy metals and other airborne pollutants, providing valuable insights into atmospheric contamination levels (Celli & Maccagnani, 2003; Negri et al., 2015; Costa et al., 2019). The decline in pollinator populations due to pollution is not just an ecological crisis but an urgent agricultural and economic issue. Addressing air pollution is critical for preserving these vital species, ensuring ecosystem resilience, and maintaining agricultural productivity for future generations.

The Impact and Consequences of Air Pollution on Insect Pollinators

The Impact of Air Pollution on Pollinators

Air pollution, caused by industrial emissions, vehicle exhaust, and agricultural activities, poses a serious threat to insect pollinators. Pollutants such as nitrogen oxides (NOx), ozone (O_3), fine particulate matter (PM), and heavy metals interfere with pollinators' ability to find food, navigate, and reproduce (Ryalls et al., 2022; Leonard et al., 2019). Given that pollinators play a vital role in maintaining ecosystems and supporting agriculture, the negative effects of pollution on these species go beyond biodiversity loss and could disrupt global food production.

Disruption of Sensory Perception and Foraging Behavior

Pollinators depend on floral scent signals to locate flowers. However, pollutants like ozone and nitrogen oxides react with and degrade these scents, reducing the range over which pollinators can detect them (McFrederick et al., 2008; Fuentes et al., 2016). This forces insects to spend more time and energy searching for food, making foraging less efficient. Research has shown that in polluted environments, pollinators struggle to locate floral scent plumes, leading to longer search times and reduced pollen transfer between flowers (Fuentes et al., 2016; Ryalls et al., 2022).

Effects on Cognitive Function and Physical Health

Air pollution affects the cognitive abilities of pollinators, impairing their learning and memory. Honeybees exposed to diesel exhaust showed a decline in their ability to recognize and remember floral odors (Reitmayer et al., 2019; Leonard et al., 2019). Similarly, houseflies exposed to high levels of particulate matter exhibited weakened olfactory perception, which could hinder their ability to locate food and mates (Wang et al., 2023).

Pollutants also harm pollinators physically. Heavy metals like arsenic and cadmium accumulate in bees, reducing colony health and survival rates (Bromenshenk et al., 1991). Studies on Giant Asian honeybees (Apis dorsata) found that exposure to particulate matter led to weakened immune responses, heart function disruptions, and higher mortality rates (Thimmegowda et al., 2020).

Consequences for Pollination and Ecosystems

The decline in pollinator populations due to air pollution has direct consequences for plant reproduction. Many crops and wild plants rely on insect pollination, and a decrease in pollinator numbers leads to reduced pollen transfer. Experiments with controlled pollution exposure showed that increased pollution levels reduced pollinator numbers by 62–70% and flower visits by 83–90% (Ryalls et al., 2022). This decline not only threatens biodiversity but also affects food security and agricultural economies.

Pollinators as Indicators of Air Pollution

Pollinators, particularly honeybees, can be used as bioindicators to monitor pollution levels. Studies have found that honeybees collect pollutants like heavy metals and pesticides while foraging, allowing researchers to track environmental contamination (Celli & Maccagnani, 2003; Negri et al., 2015). This highlights the urgent need for strategies to reduce air pollution and protect pollinators from its harmful effects.

Addressing air pollution is essential for ensuring the survival of pollinators and maintaining the ecosystems and food systems they support. Given the strong link between air pollution and pollinator health, it is crucial to explore additional biological indicators that can help assess environmental pollution levels. One such approach is the Air Pollution Tolerance Index (APTI), which evaluates the capacity of plants to withstand pollution stress.

Air Pollution Tolerance Index (APTI) and Its Relevance to Pollinators

Understanding APTI and Its Parameters

The Air Pollution Tolerance Index (APTI) is a widely accepted method for assessing a plant's ability to withstand air pollution. Plants exposed to pollutants undergo physiological and biochemical changes, which can be measured using specific parameters: chlorophyll content, leaf extract pH, ascorbic acid content, and relative water content (Singh & Rao, 1983; Sharma et al., 2017). These parameters help determine the extent to which plants can tolerate or mitigate pollution stress (Buchchi Babu et al., 2013; Sharma et al., 2017). Higher APTI values indicate a greater capacity to withstand pollution, making such plants suitable for urban greenery and biofilter applications (Singh & Rao, 1983). The APTI is calculated using the formula:

APTI = [A (T+P) + R]/10

where:

- **A** = Ascorbic acid content (mg/g)
- **T** = Total chlorophyll content (mg/g)
- **P** = Leaf extract pH
- **R** = Relative water content (%)

Chlorophyll Content and Its Estimation

Research indicates that chlorophyll content is a key indicator of a plant's photosynthetic efficiency, which can be adversely affected by air pollution. Pollutants such as sulfur dioxide (SO_2) and nitrogen oxides (NO_x) degrade chlorophyll, leading to reduced plant growth and productivity (Agbaire & Esiefarienrhe, 2009). The total chlorophyll content is calculated using spectrophotometry, with the absorbance measured at 663 nm and 645 nm. The concentrations of chlorophyll a, chlorophyll b, and total chlorophyll are determined using the following formulas:

- **Chlorophyll a (mg/g)** = [{(12.7 × A663) − (2.69 × A645)} × 25] / (1000 × W)
- **Chlorophyll b (mg/g)** = [{(22.9 × A645) − (4.68 × A663)} × 25] / (1000 × W)
- **Total Chlorophyll (mg/g)** = [{(20.2 × A645) + (8.02 × A663)} × 25] / (1000 × W)

where **V** (25 mL) is the final volume of the chlorophyll extract and **W** (1g) is the fresh weight of the leaf tissue.

Leaf Extract pH and Its Role

Leaf pH plays a crucial role in determining a plant's resistance to acidic pollutants. Plants with near-neutral pH values can better tolerate pollution-induced stress, while those with lower pH values are more susceptible to damage (Singh & Rao, 1983). The pH of the leaf extract is measured using a water analyzer kit (Pillai, 2023).

Ascorbic Acid Content and Its Measurement

Research suggests that ascorbic acid is a vital antioxidant that helps plants combat oxidative stress caused by air pollutants such as ozone (O_3) and particulate matter (Shannigrahi et al., 2004). Higher ascorbic acid levels enhance a plant's tolerance to air pollution. The ascorbic acid content is determined using titration and is calculated using the formula:

- **Ascorbic Acid Content (mg/g)** = $(0.5\ gm \times V_2 \times 25 \times 100) / (V_1 \times 5 \times 5)$

where $\mathbf{V_1}$ represents the value of the standard, and $\mathbf{V_2}$ is the volume of the dye solution used.

Relative Water Content and Its Calculation

Studies indicate that relative water content (RWC) is an important physiological parameter reflecting a plant's ability to retain moisture under pollution stress. Plants with higher RWC can better sustain their metabolic processes in polluted environments (Shannigrahi et al., 2004). The RWC is calculated using the formula:

- **RWC (%)** = $[(W_f - W_d) / (W_t - W_d)] \times 100$

where $\mathbf{W_f}$ is the fresh weight, $\mathbf{W_t}$ is the turgid weight, and $\mathbf{W_d}$ is the dry weight of the leaf.

Air Pollution Tolerance Index (APTI) Calculation

Studies show that the **APTI value** integrates these four biochemical parameters to assess a plant's tolerance to air pollution.

- **APTI** = $[(A \times (T + P)) + R] / 10$

where **A** is ascorbic acid content (mg/g), **T** is total chlorophyll content (mg/g), **P** is leaf extract pH, and **R** is relative water content (%).

Importance of APTI in Pollinator Conservation

While APTI is primarily used to evaluate plant tolerance to pollution, its implications extend to insect pollinators as well. Since pollinators depend on plants for nectar, pollen, and habitat, understanding which plant species thrive in polluted environments can aid in selecting species that support pollinator populations despite environmental stress (Bromenshenk et al., 1991).

Conclusion

Air pollution disrupts insect pollinators by impairing their foraging, navigation, and overall health, which in turn affects plant reproduction, biodiversity, and food production. The Air Pollution Tolerance Index (APTI) helps to identify plants that can withstand pollution and continue supporting pollinators. Selecting these pollution-resistant plants can create safer habitats for vital insects and promote a good ecological balance. Understanding which plants thrive in polluted conditions allows us to sustain pollinator populations and maintain agricultural productivity. Protecting such pollinators is crucial for preserving both natural ecosystems and food security.

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