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Effect of Rising Temperatures on Pollination and Crop Productivity

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Abstract

Rising global temperatures associated with climate change pose a significant threat to crop productivity by disrupting pollination processes. Heat stress affects pollination through two major pathways: direct impairment of crop reproductive biology and indirect impacts on pollinator behaviour, health, and abundance. Elevated temperatures during flowering reduce pollen viability, germination, and pollen tube growth in many crops, leading to poor fertilization, reduced seed and fruit set, and yield losses. Heat stress also alters floral traits such as nectar volume and sugar concentration, decreasing floral attractiveness to pollinators. Simultaneously, pollinators particularly bees experience physiological stress, reduced foraging activity, impaired reproduction, and increased mortality during heatwaves, resulting in diminished pollination services. The combined effects of pollen sterility and pollinator decline substantially lower productivity in pollination-dependent crops including cereals, legumes, fruits, and oilseeds. Evidence from experimental and modelling studies suggests that continued warming could cause significant global yield reductions in major crops if adaptive measures are not implemented. Integrating heat-tolerant crop breeding, climate-smart agronomic practices, and pollinator conservation strategies is therefore essential to sustain pollination services and ensure agricultural productivity under a warming climate.

Keywords: High temperature, pollination, climate smart agriculture, crops.

Introduction

Climate change–induced global warming has emerged as one of the most critical threats to agricultural sustainability. Rising mean temperatures, increased frequency of heatwaves, and prolonged warm spells directly affect crop growth and yield. Among the most vulnerable stages of crop development is reproduction, particularly pollination and fertilization, which are highly sensitive to thermal stress.

The impact of elevated temperature on crop productivity occurs through two interconnected pathways:

1. Direct effects on crop reproductive biology, especially pollen development, viability, and fertilization.
2. Indirect effects through pollinators, whose activity, survival, and efficiency decline under heat stress.

As nearly 75% of global food crops depend to some extent on animal pollination, understanding the combined influence of rising temperatures on pollen and pollinators is vital for ensuring future food security. Climate change alters agricultural production and food systems, and climate smart agriculture approach to transforming agricultural systems to support global food security and poverty reduction (Indianraj and Kumar, 2022).

How Heat Stress Affects Pollination

Effects on Pollen and Floral Biology

High temperature stress during reproductive stages disrupts pollen development, particularly microsporogenesis and meiosis. Temperatures exceeding 30 °C have been shown to impair pollen formation in several crops such as chickpea, soybean, mungbean, and common bean. Heat stress results in malformed pollen grains, reduced pollen viability, poor pollen tube growth, and failure of fertilization (Saini & Aspinall, 1982; Kaushal *et al.,* 2013).

Meta-analytical studies confirm that elevated temperatures significantly reduce pollen germination and pollen tube elongation, ultimately lowering seed set and fruit formation. Interestingly, wild relatives of crop plants tend to show greater tolerance to thermal stress, likely due to long-term evolutionary adaptation (Hedhly *et al.,* 2009). Heat stress also alters floral traits such as nectar secretion and sugar concentration. Reduced nectar volume and quality diminish floral rewards, making flowers less attractive to pollinators such as bees, butterflies, and flies, thereby further reducing pollination success.

Crop-Specific Reproductive Failures

Rice (*Oryza sativa*): Rice is highly sensitive to high temperatures during flowering. Exposure to temperatures above 37–39 °C disrupts spikelet fertility by inhibiting anther dehiscence, reducing pollen production, and impairing starch accumulation in pollen grains. This leads to poor pollen viability and reduced fertilization rates (Endo *et al.,* 2009; Wu *et al.,* 2016).

Faba bean (*Vicia faba*): A controlled study in the United Kingdom demonstrated the buffering role of insect pollination under heat stress. When plants were exposed to temperatures near 30°C during flowering, non-pollinated plants suffered yield losses of approximately 15%, whereas insect-pollinated plants lost only 2–3%, indicating that effective pollination can partially mitigate heat-induced reproductive failure (Bishop *et al.,* 2016).

Effects of Rising Temperatures on Pollinators

Behavioural and Physiological Impacts

Pollinators, especially bees, are highly sensitive to thermal extremes. During heatwaves, bees struggle to regulate body temperature and often reduce flight activity, shorten foraging duration, and avoid mating. These behavioural changes substantially reduce pollination services in crops such as almonds, blueberries, and apples. Bumblebees maintain nest temperatures between 28–32 °C for optimal larval development. When nest temperatures exceed 36 °C, brood mortality increases sharply, leading to colony weakening and population decline (Vanderplanck *et al.,* 2019).

Global Trends in Pollinator Decline

Global analyses reveal a steep decline in bee diversity since the 1990s. While habitat loss, pesticide exposure, and diseases are major drivers, climate change is increasingly recognized as a critical stressor affecting pollinator survival, phenology, and distribution (Soroye *et al.,* 2020). The decline of pollinators threatens pollination-dependent crops such as tomato, coffee, avocado, cocoa, and guava, leading to reduced yields and compromised quality.

Combined Consequences for Crop Productivity

The interaction between declining pollen quality and reduced pollinator activity has profound consequences for crop productivity. Heat-induced pollen sterility combined with lower pollination efficiency results in reduced fertilization success, poor seed and fruit set, and ultimately yield losses. Crop modeling studies suggest that, without effective adaptation strategies, global yields of maize, rice, wheat, and soybean could decline by 5–10% by mid-century due to temperature stress alone (Zhao *et al.,* 2017). Empirical evidence from farm-level studies in the United States indicates that each 1 °C increase in growing-season temperature may result in 16–20% yield reductions in major crops, with substantial economic implications for farmers and food systems (Lobell *et al.,* 2011).

Adaptation and Mitigation Strategies

Crop-Based Interventions

- Breeding heat-tolerant and thermoresilient varieties with stable pollen viability.
- Adjusting sowing dates to shift flowering toward cooler periods of the day (early morning or evening flowering).

Agro-Ecological Techniques

- Mulching, shading, and soil moisture conservation to reduce canopy temperature.
- Establishment of wildflower strips and buffer zones to enhance floral resources for pollinators.

Pollinator-Focused Approaches

- Conservation of diverse pollinator habitats and reduction of pesticide exposure.
- Development and deployment of thermotolerant bee strains.
- Use of supplemental or assisted pollination, including robotic pollination, in high-value orchard systems.

Conclusion

Rising temperatures pose a serious threat to global agriculture by disrupting pollination through direct damage to crop reproductive processes and indirect impacts on pollinators. The combined effects significantly reduce crop productivity, especially in pollination-dependent systems. Integrating climate-resilient crop breeding, agro-ecological management, and pollinator conservation is essential to safeguard pollination services and ensure future food security under a warming climate.

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