International Journal of Enhanced Research in Science, Technology & Engineering
ISSN: 2319-7463, Vol. 12 Issue 1, January-2023, Impact Factor: 7.957

Impact of Environmental Conditions on the Apiculture Industry in India:

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ABSTRACT

India's apiculture industry has witnessed remarkable growth between 2015 and 2021, with honey production rising from approximately 61,000 metric tonnes in 2015–16 to over 125,000 metric tonnes in 2021–21. This expansion has been accompanied by diversification of bee-based products—including beeswax, pollen, propolis, royal jelly, and bee venom—and increasing exports to key international markets such as the United States, Saudi Arabia, and the European Union (Agricultural and Processed Food Products Export Development Authority [APEDA], 2021; National Bee Board [NBB], 2021). Government initiatives, particularly the National Beekeeping and Honey Mission (NBHM), along with the expansion of commercial apiaries, have facilitated scientific beekeeping and supported rural livelihoods (Ministry of Agriculture & Farmers Welfare, 2021). Despite these gains, environmental stressors increasingly challenge colony health and productivity. Climate variability, including erratic rainfall, droughts, and unseasonal temperature fluctuations, disrupts nectar flow, foraging activity, and brood development (Singh, Gupta, & Kumar, 2020; Sharma, Chauhan, & Thakur, 2021). Pesticide exposure—particularly neonicotinoids—impairs navigation, immunity, and survival (Chhuneja & Gill, 2019; Ahsan et al., 2021; Hisamoto et al., 2024). Habitat loss and monoculture expansion reduce floral diversity, causing nutritional stress, while pathogen and parasite pressures, including *Varroa destructor*, *Nosema* spp., and emerging viral threats, further compromise colony performance (Kaushik, Meena, & Singh, 2021; Panziera et al., 2021; FAO, 2020; Noël et al., 2020; Glinski, 2021). To sustain growth, a multi-pronged approach is essential: stricter regulation of pesticides, conservation of floral resources through agroforestry and crop diversification, enhanced surveillance of diseases and parasites, and adoption of climate-smart beekeeping technologies. Strengthening research–extension linkages and fostering farmer–beekeeper collaborations will enhance colony resilience, stabilize honey production, and preserve the ecological and economic benefits of apiculture in India.

Keywords: Apiculture in India**,** Honey bee colony, health variability, Pesticide exposure, Habitat degradation, Pathogens and parasites

INTRODUCTION

Apiculture, the scientific management and rearing of honey bees (*Apis* spp.), has emerged as a vital agri-allied activity in India, contributing significantly to rural livelihoods, agricultural sustainability, and ecosystem services. Honey bees provide a range of valuable products including honey, beeswax, pollen, propolis, royal jelly, and bee venom, while also serving as key pollinators for diverse agricultural and horticultural crops (Chhuneja & Gill, 2019; FAO, 2020; Noël et al., 2020). By enhancing crop productivity through pollination, bees play an essential role in food security and biodiversity conservation, making apiculture both an economically and ecologically important sector.

Over the last decade, India's apiculture industry has witnessed remarkable growth. National honey production nearly doubled from approximately 61,000 metric tonnes in 2015–16 to over 125,000 metric tonnes in 2021–21, driven by rising domestic demand, export potential, and government support under initiatives such as the National Beekeeping and Honey Mission (NBHM) (Agricultural and Processed Food Products Export Development Authority [APEDA], 2021; National Bee Board [NBB], 2021; Ministry of Agriculture & Farmers Welfare, 2021). This growth has been complemented by diversification into other bee products, and a strengthening of commercial apiaries and scientific beekeeping practices, positioning India among the top global producers and exporters of honey.

Despite these gains, the sustainability of India's apiculture sector faces mounting environmental pressures. Climate variability, characterized by erratic rainfall, unseasonal temperature fluctuations, and prolonged droughts, directly impacts nectar secretion, floral availability, foraging behavior, and brood development, often resulting in reduced colony strength and increased overwintering mortality (Singh, Gupta, & Kumar, 2020; Sharma, Chauhan, & Thakur, 2021). Concurrently, extensive use of systemic insecticides, particularly neonicotinoids, impairs bee navigation, communication, and immunity, thereby increasing mortality and compounding colony vulnerability (Chhuneja & Gill, 2019; Ahsan et al., 2021; Hisamoto et al., 2021). Habitat degradation due to deforestation, urbanization, and large-scale monocultures reduces floral diversity, leading to nutritional stress and compromised colony health (Kaushik, Meena, & Singh, 2021; Panziera et al., 2021). Pathogens and parasites, including *Varroa destructor*, *Nosema* spp., and emerging viral diseases, further exacerbate colony decline, often interacting synergistically with abiotic stressors (FAO, 2020; Noël et al., 2020; Glinski, 2021).

Recognizing these challenges, the Government of India has implemented multiple policy measures under NBHM, including capacity-building programs, establishment of bee breeders' centers, promotion of modern hive technologies, and support for colony multiplication (Ministry of Agriculture & Farmers Welfare, 2021). However, adoption gaps remain in climate-smart beekeeping practices, integrated pest management, and habitat conservation. Addressing these gaps through strengthened research–extension linkages, farmer–beekeeper collaborations, and landscape-level floral conservation is crucial for ensuring long-term resilience and sustainable growth.

Therefore, this review synthesizes current knowledge on the impacts of climate variability, pesticide exposure, habitat degradation, and pathogen/parasite pressures on India's apiculture industry. By highlighting the environmental challenges and potential adaptive strategies, it underscores the need for an integrated approach to promote sustainable apiculture that supports rural livelihoods, enhances pollination services, and contributes to national food security.

METHODOLOGY

This review was conducted using a structured literature survey to evaluate the impact of environmental conditions on India's apiculture industry. A systematic search was performed across Scopus, Web of Science, PubMed, Google Scholar, and Research Gate using keywords such as "Apiculture in India", "Honey bee colony health", "Climate change and honey bees", "Pesticide impact on *Apis* spp.", "Varroa destructor", "Nosema spp.", and "NBHM". Publications from 2010 to 2021 were included.

Inclusion criteria comprised studies focusing on *Apis* species, environmental stressors affecting colony health, Indian apiculture practices, and policy interventions. Exclusion criteria included non-Indian studies, anecdotal reports, and research unrelated to honey bee health.

Key data extracted included honey production trends, colony health metrics, impacts of climate variability, pesticide exposure, habitat degradation, and pathogen/parasite prevalence. Government interventions and technological solutions under NBHM were also analyzed.

Data were synthesized qualitatively to identify patterns, interconnections, and research gaps. Findings were organized thematically to address economic significance, environmental stressors, interactions between biotic and abiotic factors, and policy measures.

This approach ensured a comprehensive understanding of the multifactorial impacts on India's apiculture sector while highlighting adaptive strategies and future research directions.

DISCUSSION

Growth and Economic Significance

India's apiculture sector has experienced remarkable growth over the last decade, with honey production nearly doubling from approximately 61,000 metric tonnes in 2015–16 to over 125,000 metric tonnes in 2021–21 (APEDA, 2023; NBB, 2021). This growth has been accompanied by rising exports to international markets, including the United States, Saudi Arabia, and the European Union, and the diversification of bee products such as beeswax, pollen, propolis, royal jelly, and bee venom. These products not only provide additional economic value but also support rural livelihoods, offering income stability for farming communities (Ministry of Agriculture & Farmers Welfare, 2021; Chhuneja & Gill, 2019). Beyond economic benefits, beekeeping contributes significantly to agricultural productivity by enhancing pollination services, thereby strengthening food security and conserving biodiversity across farming landscapes (FAO, 2020; Panziera et al., 2021).

Climate Variability

Climate variability poses a major challenge to honey bee colony performance and productivity. Erratic rainfall patterns, unseasonal temperature fluctuations, and prolonged droughts disrupt nectar secretion, reduce floral availability, and limit foraging efficiency (Singh, Gupta, & Kumar, 2020; Sharma, Chauhan, & Thakur, 2021; Vincze et al., 2021). Extreme climatic events also adversely affect brood development, reduce colony strength, and increase overwintering mortality. Consequently, pollination activity diminishes during adverse weather, which can negatively impact yields of fruits, vegetables, and oilseeds. These impacts underscore the need for climate-adaptive management practices such as strategic apiary placement, seasonal colony management, and water supplementation to maintain colony resilience (Vincze et al., 2021).

Pesticide and Agrochemical Stress

The widespread use of systemic insecticides, particularly neonicotinoids, constitutes another critical threat to colony health. Exposure impairs navigation, disrupts communication, suppresses immunity, and increases mortality among honey bees (Chhuneja & Gill, 2019; Ahsan et al., 2021; Hisamoto et al., 2020). Monoculture-dominated landscapes exacerbate nutritional stress by limiting floral diversity, reducing the quality and availability of pollen and nectar essential for healthy colonies (Kaushik, Meena, & Singh, 2021; Panziera et al., 2021). Addressing these risks requires integrated pest management strategies, stricter regulation of agrochemical use, and increased awareness among farmers to adopt bee-friendly practices (FAO, 2020; Ahsan et al., 2021).

Habitat Degradation and Floral Scarcity

Habitat degradation, deforestation, and monoculture expansion significantly reduce floral diversity, leading to nutritional stress that negatively affects brood development, adult longevity, and honey production (Kaushik, Meena, & Singh, 2021; Panziera et al., 2021). To mitigate these impacts, agroforestry systems, intercropping, and the establishment of flowering hedgerows are recommended as strategies to restore floral resources and enhance colony resilience. Promoting flower-rich landscapes is crucial not only for maintaining colony health but also for sustaining pollination services across agricultural ecosystems (Ministry of Agriculture & Farmers Welfare, 2021; Vikaspedia, 2021).

Pathogens and Parasites

Honey bee colonies in India are increasingly affected by pathogens and parasites, including *Varroa destructor* mites, *Nosema* spp., and viral diseases (FAO, 2020; Noël et al., 2020; Glinski, 2021). These biotic stressors, when combined with abiotic factors such as climate variability and pesticide exposure, exacerbate colony vulnerability and reduce honey yields. Effective disease management through regular monitoring, early detection, and integrated control strategies—including hygienic practices and biological control—are essential to maintain colony health and productivity (Noël et al., 2020; Glinski, 2021).

Policy Interventions and Adaptive Strategies

Government initiatives under the National Beekeeping and Honey Mission (NBHM) have promoted scientific hive management, capacity building, and colony multiplication programs, strengthening the apiculture sector (Ministry of Agriculture & Farmers Welfare, 2021; PIB, 2021; Vikaspedia, 2021). Adaptive strategies recommended for sustainable apiculture include climate-resilient practices such as seasonal hive management, water supplementation, and colony relocation (Vincze et al., 2021); enhancement of floral diversity through agroforestry, intercropping, and flowering hedgerows (Ministry of Agriculture & Farmers Welfare, 2021; Kaushik, Meena, & Singh, 2021); mitigation of pesticide risks via integrated pest management and bee-safe chemical practices (Chhuneja & Gill, 2019; Ahsan et al., 2021); and disease management through monitoring, hygienic practices, and biological control (FAO, 2020; Noël et al., 2020). Strong research–extension linkages and farmer–beekeeper collaborations are essential for the effective adoption of these strategies.

Research Gaps

Despite progress, several knowledge gaps remain. Quantitative data on climate change impacts across diverse agro-ecological zones are limited (Vincze et al., 2021), and the synergistic effects of pesticides, pathogens, and nutritional stress are underexplored (Chhuneja & Gill, 2019; Ahsan et al., 2025). Technology-driven solutions such as hive sensors, predictive colony models, and landscape-level pollinator management require further development (Glinski, 2021; Kaushik, Meena, & Singh, 2021; Vikaspedia, 2021). Addressing these gaps is critical to enhance the resilience, productivity, and sustainability of India's apiculture sector.

CONCLUSION

India's apiculture industry has experienced remarkable growth in recent years, driven by rising domestic demand, expanding exports, and government initiatives such as the National Beekeeping and Honey Mission (APEDA, 2023; NBB, 2021; Ministry of Agriculture & Farmers Welfare, 2021). Honey and other bee products—including beeswax, pollen, propolis, royal jelly, and bee venom—provide significant economic benefits, contributing to rural livelihoods and income diversification. Beyond economic value, honey bees play a crucial ecological role by supporting pollination services, thereby enhancing crop productivity, food security, and biodiversity conservation (Chhuneja & Gill, 2019; FAO, 2020; Panziera et al., 2021).

Despite this growth, the sector faces mounting challenges from environmental stressors. Climate variability including unseasonal temperature fluctuations, droughts, and erratic rainfall affects nectar flow, foraging behavior, and colony development. Pesticide exposure, particularly to neonicotinoids, compromises navigation, immunity, and survival, while habitat degradation and monoculture expansion reduce floral diversity and cause nutritional stress. In addition, pathogens and parasites such as *Varroa destructor*, *Nosema* spp., and viral infections further threaten colony health and productivity (Singh, Gupta, & Kumar, 2020; Kaushik, Meena, & Singh, 2021; Noël et al., 2020).

To ensure the long-term sustainability of India's apiculture industry, a multi-pronged approach is essential. Recommendations include:

1. **Pesticide Regulation and Awareness**: Implement stricter control on the use of harmful agrochemicals and promote bee-friendly farming practices.
2. **Floral Diversity Conservation**: Encourage agro forestry, intercropping, and establishment of flowering hedgerows to enhance pollen and nectar availability.
3. **Climate-Smart Beekeeping**: Adopt seasonal hive management, relocation of colonies, and water supplementation to mitigate climatic risks.
4. **Disease and Parasite Management**: Strengthen monitoring, early detection, and integrated pest management to reduce pathogen load.
5. **Research and Extension**: Expand research on climate change impacts, pesticide-pathogen interactions, and technology-driven solutions such as hive sensors and predictive colony management.
6. **Farmer–Beekeeper Collaboration**: Foster partnerships and knowledge transfer to facilitate adoption of sustainable practices and increase resilience at the grassroots level.

In conclusion, while India's apiculture sector holds significant growth potential and contributes to rural livelihoods and agricultural ecosystems, its future sustainability depends on proactive environmental management, policy support, and the adoption of adaptive, science-based beekeeping strategies. By implementing these measures, India can ensure healthy bee colonies, stable honey production, and continued provision of vital ecological services.

Disclaimer (Artificial Intelligence)

The author(s) affirm that no generative AI technologies, including Large Language Models (e.g., Chat GPT, Copilot) or text-to-image tools, were used in the preparation, analysis, or editing of this manuscript.

Acknowledgements

The author gratefully acknowledges the support and guidance of laboratory colleagues for their valuable technical assistance and constructive inputs during the preparation of this study. This research was carried out using the author's own resources, and no external funding or financial assistance from any agency was received.

Competing Interests

The author declares that there are no competing interests related to this work.

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