Plant Archives Vol. 25, No. 2, 2025 pp. 167-175 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org

DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2025.v25.no.2.027

IMPORTANCE OF HYMENOPTERAN POLLINATORS IN AGRICULTURE ECOSYSTEM : A REVIEW

Tania Roy[1]*, Deepika Sorahia[1], Subhojit Chatterjee[2], Mahesh Pathak[1], T. Rajesh[3], Kennedy Ningthoujam[1] and R.K. Patidar[2]

[1]Department of Entomology, School of Crop Protection, College of Post Graduate Studies in Agricultural Sciences, Central Agricultural University (Imphal), Umiam, Meghalaya-793103, India

[2]Department of Nematology, School of Crop Protection, College of Post Graduate Studies in Agricultural Sciences, Central Agricultural University (Imphal), Umiam, Meghalaya-793103, India

[3]Department of Pathology, School of Crop Protection, College of Post Graduate Studies in Agricultural Sciences, Central Agricultural University (Imphal), Umiam, Meghalaya-793103, India

*Corresponding author E-mail: roytania269@gmail.com

(Date of Receiving-24-05-2025; Date of Acceptance-03-08-2025)

ABSTRACT

Hymenopteran pollinators—principally bees (Apidae) but also including wasps (Vespidae) and certain ants (Formicidae)—serve as keystone contributors to both ecosystem integrity and global agricultural productivity. Their effectiveness stems from traits such as pollen-carrying structures (scopa, corbiculae), floral fidelity, and social behaviors that enhance pollen transfer efficiency. Economically, insect pollination supports global food systems with an estimated annual value ranging from USD $235 to $577 billion, with wild and managed bees making the largest contribution. Pollinator-dependent crops—spanning fruits, vegetables, legumes, nuts, and oilseeds—show not only increased yield and seed set but also enhanced quality attributes such as size, flavour, and shelf stability. Importantly, wild pollinators, such as solitary bees and bumblebees, often outperform managed honeybees (*Apis mellifera*) for specific crops due to better adaptation to local conditions and consistent floral visitation. Beyond their agricultural role, hymenopteran pollinators contribute to ecosystem resilience and genetic diversity in plant communities. Despite their critical value, global pollinator populations are in decline due to threats such as habitat fragmentation, pesticide exposure, climate variability, agricultural intensification, and the spread of invasive species and pathogens. This decline is particularly alarming in ecologically sensitive regions like the Hindu Kush Himalayas, where local food production relies heavily on wild pollinators. To mitigate these impacts, there is a growing push to incorporate pollinator conservation into mainstream farming practices. Approaches like agroecology, organic agriculture, floral diversification, and Integrated Pest and Pollinator Management (IPPM) are gaining traction. Additionally, targeted research on pollinator diversity, especially in understudied tropical and subtropical areas, combined with community participation and policy support, is essential for sustaining both agricultural and ecological systems.

***Key words*:** Agroecology, Ecosystem resilience, Floral fidelity, Invasive, Pollination services

Introduction

Pollinators are fundamental to sustaining both natural ecosystems and agricultural productivity. Among them, hymenopteran insects—including bees, wasps, and ants—are the primary agents responsible for effective pollination in both wild and cultivated plant species. It is estimated that approximately 90% of wild flowering vegetation and more than 75% of key food crops worldwide rely on animal-mediated pollination, at least in part, with Hymenoptera recognized as the most crucial contributors (Klein, 2007; Ollerton *et al*., 2011). Beyond boosting crop yields and improving food quality, these pollinators are crucial for maintaining genetic diversity and ecological resilience across diverse landscapes (Potts *et al*., 2016).

Within Hymenoptera, the family Apidae—which includes honeybees (*Apis* spp.), bumblebees (*Bombus* spp.), and solitary bees—stands out due to their high pollination efficiency, consistent floral visitation and specialized structures like corbiculae and scopae for effective pollen transport (Michener, 2007). Their contributions are especially critical in regions where environmental conditions limit the activity of other pollinators, such as high-altitude habitats, marginal farmlands and biodiversity-rich agroecological zones (IPBES, 2016; ICIMOD, 2019) . These pollinators significantly contribute to the production of essential crops, including fruits, vegetables, oilseeds, nuts and spices, which are crucial for nutrition and economic stability (Garibaldi *et al*., 2013; Rader *et al*., 2016).

Hymenopteran pollinator is experiencing alarming declines because of their significant threats include habitat loss and fragmentation, extensive use of pesticides—particularly neonicotinoids—the impacts of climate change, and the emergence of new pathogens (Goulson *et al*., 2015; Sanchez-Bayo & Wyckhuys, 2019) . Understanding these challenges is essential to developing strategies that safeguard pollinator populations and the ecosystem services they provide. As these insects continue to face mounting environmental pressures, it is now more crucial than ever to comprehend ecological roles in greater detail, behavioural patterns and conservation requirements of hymenopteran insects. This review synthesizes a broad spectrum of international and regional research to highlight the critical ecological, economic and agricultural roles these pollinators fulfil. It further identifies the primary anthropogenic pressures jeopardizing their survival and evaluates effective sustainable agricultural strategies, such as pollinator-supportive land-use practices and targeted policy interventions, that can aid in safeguarding their populations. Ultimately, this work advocates for the integration of pollinator conservation into comprehensive, long-term strategies for sustainable agriculture and broader environmental stewardship (Potts *et al*., 2016) .

The Pivotal Role of Hymenopteran Pollinators in Agricultural Systems

Hymenopteran pollinators, especially bees, are vital to agricultural success as they facilitate the reproductive processes of a wide range of crop species. Within this group, species belonging to the families Apidae—such as *Apis mellifera*, *Bombus* spp. and *Xylocopa* spp.—and Halictidae, including *Lasioglossum* spp., are particularly important due to their efficient foraging behavior, strong floral fidelity, and adaptability to diverse agroecological zones (Free, 1993). These pollinators significantly influence both crop yield and product quality, impacting factors like fruit size, nutritional value, shelf life, and marketability (Klein *et al*., 2007; Blitzer *et al*., 2016) .

Managed honeybees (*Apis mellifera*) are widely deployed in commercial agriculture owing to their large colony sizes and ease of management. Nevertheless, wild hymenopterans often exceed the efficiency of managed bees under certain environmental conditions. For instance, bumblebees (*Bombus* species) are superior pollinators for crops like tomatoes and blueberries due to their unique buzz pollination behavior. Similarly, solitary bees demonstrate high flower constancy and efficiently transfer pollen over short distances, making them crucial for crops cultivated in fragmented landscapes (Gathmann & Tscharntke, 2002; Campbell *et al*., 2017). The contribution of hymenopteran pollinators extends beyond merely increasing yield quantity; it also promotes yield stability, especially under environmental stress. Research by Hünicken *et al*., (2021) showed that insect-pollinated crops, such as sunflower and almond, exhibited greater yield stability across seasons compared to crops reliant on wind or self-pollination. This stabilizing effect is attributed to the inherent redundancy and complementarity within diverse pollinator communities (Albrecht *et al*., 2012).

Beyond fruits and vegetables, hymenopterans pollinate a wide spectrum of crops, including legumes, oilseeds, forage species and medicinal plants. In India, species such as *Apis cerana*, *A. dorsata*, and *A. florea* contribute significantly to the pollination of crops like mustard, apple, chickpea, and coffee (Latif *et al*., 2019) . In hybrid seed production, pollination becomes even more critical. Male-sterile lines in such systems rely on effective pollen transfer by insects. For example, Fijen *et al*., (2020) identified poor insect pollination as a major limiting factor in hybrid carrot seed production, emphasizing the need for tailored pollination services in commercial breeding programs.

In addition to their role in pollination, hymenopteran species contribute to ecosystem health through services like soil aeration (*via* nesting), pest suppression and maintaining habitat continuity. Wasps, though less studied for pollination, serve dual roles by contributing incidentally to pollination and acting as natural enemies of crop pests (Brock *et al*., 2021) . In summary, the presence of a diverse hymenopteran community ensures resilience in pollination services, significantly enhances agricultural productivity, and maintains ecological balance within agroecosystems. Therefore, their role is not just functional but also strategically important in the face of climate variability and increasing agricultural intensification.

Pollinator Diversity in Agricultural Systems

The diversity of hymenopteran pollinators is vital for maintaining robust and resilient pollination services across agricultural landscapes. Numerous species contribute to pollination in various cropping systems, ranging from eusocial honey bees (*Apis* spp.) to solitary bees (*Megachile*, *Xylocopa*, *Andrena*, *Lasioglossum*) and wasps (*Polistes*, *Vespula*). This diversity extends beyond just the types of species present; it also encompasses functional diversity, meaning these species vary in their foraging behaviors, seasonal activity patterns (phenology), flower preferences, and nesting strategies (Bertrand *et al*., 2019).

Wild vs. Managed Pollinators

Although *Apis mellifera* is extensively used in managed colonies for large-scale agricultural pollination, wild bee species play an essential and often complementary—and sometimes superior—role in enhancing pollination outcomes. According to Blitzer *et al*., (2016) revealed that the richness of wild bee species significantly improved apple pollination effectiveness, even in orchards with high densities of honeybees. Similarly, Albrecht *et al*., (2012) found that plant reproductive success was more closely linked to wild pollinator diversity than to the presence of managed bees alone.

The efficiency of managed honeybees can be compromised under certain environmental stressors such as extreme weather conditions or disease outbreaks. In contrast, wild pollinator communities contribute to the resilience of pollination systems under such conditions (Brittain *et al*., 2013). Certain wild species, including Xylocopa and Bombus, have demonstrated activity during cooler temperatures and overcast weather, offering more stable pollination services across variable climates (Keasar, 2010). These results highlight how crucial it is to preserve the diversity of wild pollinators in addition to managed populations. Integrating both into agricultural systems can enhance pollination reliability, improve crop quality, and build resilience against environmental and biological uncertainties.

Spatial and Temporal Variability in Pollinator Communities

Pollinator communities are profoundly shaped by land-use patterns, the availability of floral resources, seasonal changes, and the overall heterogeneity of the landscape. For instance, research by Aleixo *et al*., (2014) showed that urban green spaces with staggered blooming periods were able to support pollinator presence throughout the year. Conversely, in agricultural settings, monocultures frequently fall short in providing continuous floral resources, resulting in temporal mismatches that can disrupt pollinator activity (Marja *et al*., 2018) . Implementing diverse plantings, cover crops, and floral strips can help alleviate these mismatches and attract a broader spectrum of hymenopterans.

Regional studies further emphasize the importance of varied landscapes. In areas like Jambi, Sumatra, Siregar *et al*., (2016) observed that forest edges and traditional agroforestry systems supported substantially higher insect pollinator diversity compared to large-scale oil palm plantations. This finding underscores the critical role of mixed land-use systems in preserving vital pollinator habitats.

Specialization and Floral Fidelity

Numerous solitary bee species demonstrate pollen specialization, termed oligolecty, wherein they forage on a limited set of plant taxa. This targeted foraging behavior enhances the accuracy of pollen transfer and supports pollination efficiency in certain crop species (Celep *et al*., 2020) . For example, *Megachile* species are known to favour legumes and cucurbits, while *Chelostoma* bees show a strong preference for bellflowers. Floral constancy—the tendency of a pollinator to repeatedly visit flowers of the same species during a foraging bout—significantly improves cross-pollination and reproductive success (Free, 1993).

Conversely, generalist pollinators such as *Apis mellifera* and *Bombus terrestris* visit a wide variety of floral species within a single foraging trip. This behavioural flexibility is particularly advantageous in diversified farming systems, such as polycultures, where multiple crops bloom simultaneously (Hung *et al*., 2018). Their broad foraging spectrum ensures continued pollination services even during fluctuations in preferred floral resource availability, thereby supporting overall ecosystem function and crop diversity.

Role of Lesser-Known Hymenopterans

Beyond bees, other hymenopterans such as wasps and ants also contribute to pollination, though they are often under represented in pollination studies. While wasps are primarily predatory, many consume nectar and actively pollinate specialized plant taxa, including Ficus (figs) and certain orchid species (Cook & Segar, 2010). Ants, despite being fewer effective pollinators due to their ground-based foraging and antimicrobial secretions, can serve pollination roles under specific ecological conditions

(Dutton & Frederickson, 2012). For instance, research by Delnevo *et al*., (2020) has documented plant adaptations that facilitate ant-mediated pollination in challenging environments, illustrating the evolutionary significance and niche roles of these lesser-known pollinators in certain ecosystems.

Pollination Services and Crop Yield

The link between hymenopteran pollination and enhanced agricultural outcomes is well-established. These insects contribute directly to increased fruit and seed set, improved crop quality, and yield stability across a broad range of cultivated plants. Although abiotic methods like wind and self-pollination are sufficient for some crops, a substantial proportion of horticultural and oilseed species rely heavily on insect-mediated pollination for optimal productivity. Owing to their morphological adaptations and foraging behavior, hymenopteran insects remain the most effective and reliable pollinators across agricultural systems (Gallai *et al*., 2009).

Contributions of Hymenopteran Pollinators to Crop Production and Economic Stability

Hymenopteran pollinators deliver multifaceted benefits to agriculture, influencing crop yield, quality, stability, and contributing significant economic value.

Yield Quantity and Quality

The quantitative impact of pollinators on crop output is well-established. For instance, loquat (*Eriobotrya japonica*) trees that were open-pollinated by native insects displayed notably higher fruit set, alongside superior physiological and chemical characteristics such as sugar content and fruit size (Ahmad *et al*., 2021). Similarly, studies in European and U.S. apple and almond orchards have indicated that wild bees enhance both the quantity and uniformity of fruits, often surpassing the pollination efficiency of managed *Apis mellifera* (Isaacs *et al*., 2017).

Furthermore, pollination services critically influence yield quality. Crops like cucumber, mustard, and strawberry, which depend on complete pollination, tend to produce misshapen or smaller fruits when pollination is insufficient or uneven (Williams, 2002; Bennett *et al*., 2018). Hymenopteran pollinators, particularly those demonstrating flower constancy, improve quality by ensuring consistent and precise pollen transfer.

Yield Stability Across Time and Space

Beyond simply increasing yield, hymenopteran pollinators also contribute to its stability. Hünicken *et al*., (2021) showed that the presence of pollinators reduced year-to-year variability in the yields of sunflower and almond crops. This stabilizing role becomes even more critical amid changing climatic conditions, as consistent pollination helps mitigate the negative effects of extreme heat and rainfall. At a landscape scale, Brittain *et al*., (2010) demonstrated that pesticide use negatively impacted pollinator species richness, subsequently affecting pollination services at both local and regional levels. Therefore, pollination success is not solely dependent on species presence but also on landscape connectivity, habitat quality, and sustainable management practices.

Economic Implications of Pollination Services

Pollination services are highly valuable economically. The global monetary worth of pollinator-dependent food output was calculated by Gallai *et al*., (2009), to be between USD 235 billion and USD 577 billion annually. This figure encompasses direct revenue from pollinator-dependent yields and indirect benefits such as improved market quality and extended shelf life for fruits and vegetables. In India, crops like mustard, apple and sunflower show yield increases of up to 30–40% with adequate pollination (Bhagyasree *et al*., 2020). Hybrid seed production systems, especially those utilizing male-sterile lines, are highly reliant on insect pollination. Fijen *et al*., (2020) reported that inadequate pollination was the limiting factor in hybrid carrot seed production, highlighting the necessity for targeted pollinator services in the seed industry.

Case Studies from Developing Regions

In South and Southeast Asia, smallholder farmers often rely on wild pollinators due to the high cost and limited accessibility of managed colonies. Siregar *et al*., (2016) found that insect pollinator abundance and diversity varied significantly with land use in Jambi, Sumatra, with agroforestry systems supporting superior pollination services compared to monocultures. Similarly, Latif *et al*., (2019) reported a positive correlation between chickpea (*Cicer arietinum*) yields and pollinator diversity in Pakistan. These results underscore the crucial significance of landscape-level planning and ecological intensification for enhancing pollination services in smallholder agriculture.

Threats to Hymenopteran Pollinators

Despite their indispensable role in agriculture and ecosystem maintenance, hymenopteran pollinators face mounting pressures from a range of human-induced threats. These include chemical contamination, habitat degradation, climate shifts, invasive species introductions and policy shortcomings—all contributing to notable declines in both wild and managed populations worldwide

(Breeze *et al*., 2014; Sponsler *et al*., 2019).

Pesticide Exposure

One of the most critical threats stems from pesticide use, particularly neonicotinoids, fungicides and insect growth regulators (Johansen, 1977). These compounds negatively impact hymenopteran pollinators by impairing essential behaviors such as foraging, learning, navigation, and reproduction (Mommaerts & Smagghe, 2011). Chronic, low-dose exposure can weaken colony health and increase vulnerability to pathogens and parasites. Sponsler *et al*., (2019) emphasized that the pervasive use of agrochemicals alters entire pollination networks, especially in intensively farmed regions. Furthermore, research by Gradish *et al*., (2019) revealed that *Bombus* species are often more susceptible than *Apis mellifera* due to smaller colony sizes and differing nesting habits.

Habitat Loss and Fragmentation

Widespread land-use change—such as conversion of natural ecosystems into agricultural or urban areas—has severely diminished pollinator habitats. The resulting fragmentation disrupts nesting availability, reduces floral resources and isolates pollinator communities. Intensive farming practices, urban development and the removal of hedgerows further degrade ecological continuity. Studies have shown that pollinator richness decreases with increasing distance from natural or semi-natural habitats (Gathmann & Tscharntke, 2002). While urban green spaces may offer some refuge, limited native vegetation and pollution often compromise their suitability (MacIvor *et al*., 2014).

Climate Change

Climate variability poses another major threat by altering species phenology, ranges, and ecological interactions. Fluctuations in temperature and rainfall influence pollinator activity, floral availability and nectar production (Hung *et al*., 2018). The disturbance of phenological synchrony—the misalignment of pollinators and flowering plants—is one effect that is especially worrisome. For both plants and insects, these mismatches may result in decreased pollination effectiveness and reproductive success (Bennett *et al*., 2020).

Invasive Species and Pathogens

Introduced species can directly and indirectly threaten native hymenopteran populations by outcompeting them, introducing new predators, or transmitting novel pathogens. Although *Apis mellifera* is widely valued for crop pollination, its introduction into non-native ecosystems has, in some cases, displaced indigenous bees and altered local plant-pollinator dynamics (Hung *et al*., 2018). Additionally, invasive plant species may degrade nectar quality or dominate pollinator interactions, thereby reducing native plant pollination. Pollinators are also highly susceptible to diseases such as *Nosema spp.*, deformed wing virus and parasitic mites like *Varroa destructor*, with transmission risks elevated in dense, commercial beekeeping operations (Berenbaum, 2007).

Knowledge Gaps and Policy Integration

A frequently overlooked yet significant issue is the lack of scientific understanding and policy integration related to pollinator conservation. Many regions still lack systematic monitoring of pollinator populations, while agricultural policies often emphasize short-term yield over long-term biodiversity (Breeze *et al*., 2014; Cho, 2018). In hybrid seed production systems, insufficient coordination between crop flowering periods and pollinator availability further limits pollination success (Fijen *et al*., 2020). Addressing these challenges requires cross-sectoral collaboration among scientists, farmers, and policymakers to align conservation goals with agricultural sustainability.

Conservation and Management Strategies for Hymenopteran Pollinators

Given the escalating threats to pollinator populations, implementing effective conservation and management strategies is crucial for sustaining hymenopteran diversity and the vital pollination services they provide. These strategies demand an integration of ecological understanding with practical land-use practices and supportive policy frameworks (Isaacs *et al*., 2017).

Pollinator-Friendly Farming Practices

Pollinator conservation fundamentally relies on promoting habitat heterogeneity and floral diversity within agricultural landscapes. Practices such as intercropping, agroforestry, crop rotation, and planting flowering cover crops are effective in enhancing the availability of floral resources throughout the growing season (Campbell *et al*., 2017). Establishing flower strips and hedgerows serves a dual purpose: providing valuable foraging areas and acting as corridors and nesting sites, thereby supporting wild bee populations and other beneficial insects. Integrated Crop Pollination (ICP), as proposed by Isaacs *et al*., (2017), exemplifies a comprehensive approach that combines managed honey bees, wild pollinators and habitat enhancement to stabilize pollination services, proving particularly effective in high-value fruit and seed crops.

Reducing Pesticide Risks

- Mitigating exposure to pesticides is paramount for pollinator conservation. Key strategies include:

- Adopting Integrated Pest Management (IPM) to reduce reliance on chemical interventions.
- Applying pesticides during non-bloom periods or when pollinators are least active (e.g., early morning or late evening).
- Utilizing selective and less toxic compounds, such as biopesticides.
- Providing farmers with training in pollinator-safe pesticide use.
- Legislative measures, such as the European Union's partial ban on neonicotinoids, demonstrate that policy interventions can effectively reduce pesticide-related risks (Sponsler *et al.*, 2019). However, successful implementation requires robust enforcement and ongoing education.

Enhancing Nesting and Foraging Sites

The conservation of nesting resources is often an overlooked aspect of pollinator management. Solitary bees, for example, require specific nesting substrates like bare ground, wood cavities, or hollow plant stems. Providing artificial nests, "bee hotels," or simply leaving patches of undisturbed soil can significantly boost native bee populations (Keasar, 2010; MacIvor *et al.*, 2014). In tropical ecosystems, maintaining forest fragments and hedgerows is crucial for supporting large-bodied pollinators such as *Xylocopa* spp. and *Apis dorsata*, which depend on tall trees or shaded canopies for nesting (Bradbear, 2009).

Landscape-Level Planning

Effective pollinator conservation must extend beyond individual field boundaries. Landscape-scale approaches integrate natural habitats, semi-natural patches, and diversified cropping systems to enhance ecological connectivity and ensure the year-round availability of floral resources (Aleixo *et al.*, 2014; Bertrand *et al.*, 2019). Studies confirm that pollinator richness increases in landscapes with a higher proportion of wild vegetation within a 1–2 km radius (Gathmann & Tscharntke, 2002). Payment for Ecosystem Services (PES) schemes can further incentivize landowners to adopt pollinator-friendly practices, offering financial support for maintaining wildflower corridors or conserving native vegetation.

Public Awareness and Farmer Education

Engaging local knowledge, cultural practices, and farmer participation are vital for successful pollinator management. Training programs and awareness campaigns can equip farmers with the ability to identify pollinator species, understand their ecological roles and implement appropriate conservation measures. Community-based initiatives, such as those promoting beekeeping for livelihood improvement, have demonstrated success in many parts of India and Africa. These programs not only contribute to income diversification but also foster a sense of stewardship for pollinator resources (Bradbear, 2009).

Research and Policy Integration

A deeper scientific understanding of pollinator ecology is essential for developing evidence-based conservation strategies. Key areas requiring further research include:

- Comprehensive pollinator population monitoring.
- Detailed studies on floral preferences and foraging ranges.
- Specific responses of pollinators to changes in climate and land use.
- The ecological role of lesser-known taxa such as wasps and ants (Brock *et al.*, 2021; Dodd *et al.*, 1999).

Equally crucial is the integration of research into policy. National Pollinator Strategies, exemplified by frameworks developed in the UK and the US, provide structured approaches for stakeholder engagement, habitat protection, and research funding. While India's National Beekeeping and Honey Mission is a positive step, it needs to expand its scope to explicitly include wild pollinator protection.

Future Directions and Research Needs

With increasing reliance on pollination services due to agricultural expansion, climate change, and population growth, advancing knowledge and protection strategies for hymenopteran pollinators is becoming critical. Although progress has been made in recognizing their value, significant gaps remain.

Enhanced Pollinator Monitoring

Long-term and standardized monitoring programs are essential to track pollinator trends and guide conservation. Many countries, including India, lack comprehensive data on wild pollinators (Hung *et al.*, 2018; Gallai *et al.*, 2009). Citizen science initiatives involving local communities can supplement formal research by documenting pollinator activity and habitats (Pannure, 2016).

Broadening Taxonomic Focus

Research remains biased toward *Apis mellifera*, overlooking the contributions of solitary bees, bumblebees, wasps and ants. Future studies should examine their pollination roles, foraging patterns, species-specific floral preferences, and resilience under marginal conditions (Brock *et al*., 2021).

Climate Resilience

Pollinators' responses to climatic shifts—like altered flowering times or range shifts—are poorly understood. Research should explore thermal limits, phenological mismatches and strategies such as microhabitats and climate-adapted flora to sustain pollination under stress (Bennett *et al*., 2020).

Genomics and Disease Management

Modern tools like genomics and remote sensing can reveal population dynamics and adaptive traits in wild bees (Gradish *et al*., 2019). Surveillance of diseases, including those transmitted from managed bees, is crucial for pollinator health and requires coordinated biosecurity frameworks.

Policy and Economic Integration

Localized economic assessments can help quantify pollinators' value to specific crops and guide policies. Incentive-based schemes, including payment for ecosystem services and pollinator stewardship programs, can support conservation efforts (Gallai *et al*., 2009; Cho, 2018).

Education and Capacity Building

Incorporating pollinator studies into educational curricula fosters awareness and ecological literacy. Specialized training in entomology, agroecology, and conservation is essential for building research and outreach capacity. Cross-disciplinary collaboration will drive scalable solutions.

Conclusion and Recommendations

Hymenopteran pollinators play an indispensable role in sustaining agriculture and biodiversity. Their contribution to yield improvement, crop quality, and ecological stability underscores their importance. However, pressures from pesticides, habitat loss, climate change and pathogens continue to drive population declines.

Current management heavily depends on honey bees, often neglecting more efficient wild pollinators. Yet, on-farm practices like integrated crop pollination, habitat enhancement, pesticide reduction and diversified farming have demonstrated effectiveness in sustaining pollinator diversity. Increasing awareness and training among farmers and stakeholders is essential.

Key recommendations include

1. Establishing regional monitoring programs (Pannure, 2016).
2. Incentivizing pollinator-friendly agricultural practices (Breeze *et al*., 2014).
3. Integrating pollinator health into food security and climate strategies.
4. Promoting research on underrepresented taxa like solitary bees and parasitic wasps (Cook & Segar, 2010).
5. Strengthening outreach, education, and training initiatives.

In summary, safeguarding hymenopteran pollinators is essential not only for ecological balance but also for agricultural resilience and food security. Their protection must be mainstreamed into policy, research, and land-use practices to ensure sustainable agroecosystems in a changing world.

References

Ahmad, S., Khalofah A., Khan S.A., Khan K.A., Jilani M.J., Hussain T., Skalicky M., Ghramh H.A. and Ahmad Z. (2021). Effects of native pollinator communities on the physiological and chemical parameters of loquat tree (*Eriobotrya japonica*) under open field condition. *Saudi Journal of Biological Sciences*. **28(6)**, 3235-41.

Albrecht, M., Schmid B., Hautier Y. and Müller C.B. (2012). Diverse pollinator communities enhance plant reproductive success. *Proceedings of the Royal Society B, Biological Sciences*. **279(1748)**, 4845-52.

Aleixo, K.P., de Faria L.B., Groppo M., do Nascimento Castro M.M. and da Silva C.I. (2014). Spatiotemporal distribution of floral resources in a Brazilian city, Implications for the maintenance of pollinators, especially bees. *Urban Forestry & Urban Greening*. **13(4)**, 689-96.

Bennett, J.M., Steets J.A., Burns J.H., Burkle L.A., Vamosi J.C., Wolowski M., Arceo-Gómez G., Burd M., Durka W., Ellis A.G. and Freitas L. (2020). Land use and pollinator dependency drives global patterns of pollen limitation in the Anthropocene. Nature Communications. **11(1)**, 3999.

Bennett, J.M., Steets J.A., Burns J.H., Durka W., Vamosi J.C., Arceo-Gómez G., Burd M., Burkle L.A., Ellis A.G., Freitas L. and Li J. (2018). GloPL, a global data base on pollen limitation of plant reproduction. Scientific Data. **5(1)**, 1-9.

Berenbaum, M.R. (2007). Colony collapse disorder and pollinator decline. In Statement to Congress of USA; **29 (Vol. 29)**.

Bertrand, C., Eckerter P.W., Ammann L., Entling M.H., Gobet E., Herzog F., Mestre L., Tinner W. and Albrecht M. (2019). Seasonal shifts and complementary use of pollen sources by two bees, a lacewing and a ladybeetle species in European agricultural landscapes. *Journal of Applied Ecology*. **56(11)**, 2431-42.

Blitzer, E.J., Gibbs J., Park M.G. and Danforth B.N. (2016). Pollination services for apple are dependent on diverse wild bee communities. *Agriculture, Ecosystems &*

Environment. **221**, 1-7.

Bradbear, N. (2009). Bees and their role in forest livelihoods, a guide to the services provided by bees and the sustainable harvesting, processing and marketing of their products.

Breeze, T.D., Vaissière B.E., Bommarco R., Petanidou T., Seraphides N., Kozák L., Scheper J., Biesmeijer J.C., Kleijn D., Gyldenkærne S. and Moretti M. (2014). Agricultural policies exacerbate honeybee pollination service supply-demand mismatches across Europe. *PloS one*. **9(1)**, e82996.

Brittain, C., Kremen C. and Klein A.M. (2013). Biodiversity buffers pollination from changes in environmental conditions. *Global change biology*. **19(2)**, 540-7.

Brittain, C.A., Vighi M., Bommarco R., Settele J. and Potts S.G. (2010). Impacts of a pesticide on pollinator species richness at different spatial scales. *Basic and Applied Ecology*. **11(2)**, 106-15.

Brock, R.E., Cini A. and Sumner S. (2021). Ecosystem services provided by aculeate wasps. *Biological Reviews*. **96(4)**, 1645-75.

Campbell A.J., Wilby A., Sutton P. and Wäckers F. (2017). Getting more power from your flowers, multi-functional flower strips enhance pollinators and pest control agents in apple orchards. *Insects*. **8(3)**, 101.

Celep, F., Atalay Z., Dikmen F., Doçan M., Sytsma K.J. and Claßen-Bockhoff R. (2020). Pollination ecology, specialization, and genetic isolation in sympatric bee-pollinated Salvia (*Lamiaceae*). *International Journal of Plant Sciences*. **181(8)**, 800-11.

Cho, S. (2018). Transforming gender and emotion, The butterfly lovers story in China and Korea. University of Michigan Press.

Cook, J.M. and Segar S.T. (2020 Jan). Speciation in fig wasps. *Ecological Entomology*. **35**, 54-66.

Delnevo, N., van Etten E.J., Clemente N., Fogu L., Pavarani E., Byrne M. and Stock W.D. (2020). Pollen adaptation to ant pollination, a case study from the Proteaceae. *Annals of Botany*. **126(3)**, 377-86.

Dodd, M.E., Silvertown J. and Chase M.W. (1999). Phylogenetic analysis of trait evolution and species diversity variation among angiosperm families. *Evolution*. **53(3)**, 732-44.

Dutton, E.M. and Frederickson M.E. (2012). Why ant pollination is rare, new evidence and implications of the antibiotic hypothesis. *Arthropod-Plant Interactions*. **6(4)**, 561-9.

Fijen, T.P., Scheper J.A., Vogel C., van Ruijven J. and Kleijn D. (2020). Insect pollination is the weakest link in the production of a hybrid seed crop. *Agriculture, Ecosystems & Environment*. **290**, 106743.

Free, J.B. (1970). *Insect pollination of crops*.

Gallai, N., Salles J.M., Settele J. and Vaissière B.E. (2009). Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. *Ecological economics*. **68(3)**, 810-21.

Garibaldi, L.A., Steffan-Dewenter I., Winfree R., Aizen M.A., Bommarco R., Cunningham S.A., Kremen C., Carvalheiro L.G., Harder L.D., Afik O. and Bartomeus I. (2013). Wild pollinators enhance fruit set of crops regardless of honeybee abundance. *Science*. **339(6127)**, 1608-11.

Gathmann, A. and Tscharntke T. (2002). Foraging ranges of solitary bees. *Journal of animal ecology*. **71(5)**, 757-64.

Goulson, D., Nicholls E., Botías C. and Rotheray E.L. (2015). Bee declines driven by combined stress from parasites, pesticides, and lack of flowers. *Science*. **347(6229)**, 1255957.

Gradish, A.E., Van Der Steen J., Scott-Dupree C.D., Cabrera A.R., Cutler G.C., Goulson D., Klein O., Lehmann D.M., Lückmann J., O'Neill B. and Raine N.E. (2019). Comparison of pesticide exposure in honeybees (*Hymenoptera, Apidae*) and bumble bees (*Hymenoptera, Apidae*), implications for risk assessments. *Environmental Entomology*. **48(1)**, 12-21.

Hung, K.L., Kingston J.M., Albrecht M., Holway D.A. and Kohn J.R. (2018). The worldwide importance of honeybees as pollinators in natural habitats. *Proceedings of the Royal Society B, Biological Sciences*. **285(1870)**, 2017-2140.

Hünicken, P.L., Morales C.L., Aizen M.A., Anderson G.K., García N. and Garibaldi L.A. (2021). Insect pollination enhances yield stability in two pollinator-dependent crops. *Agriculture, Ecosystems & Environment*. **320**, 107573.

ICIMOD (2019). Himalayan pollinators, Importance and conservation. International Centre for Integrated Mountain Development.

IPBES (2016). The assessment report on pollinators, pollination and food production. Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.

Isaacs, R., Williams N., Ellis J., Pitts-Singer T.L., Bommarco R. and Vaughan M. (2017). Integrated crop pollination, combining strategies to ensure stable and sustainable yields of pollination-dependent crops. *Basic and Applied Ecology*. **22**, 44-60.

Johansen, C.A. (1977). Pesticides and pollinators. *Annual review of entomology*. **22(1)**, 177-92.

Keasar, T. (2010). Large carpenter bees as agricultural pollinators. *Psyche, A Journal of Entomology*. **2010(1)**, 927463.

Klein, AM. (2007). Importance of pollinators in changing landscapes for world crops. *Proc. R. Soc. B. Biol. Sci*. **274**, 303-13.

Latif, A., Malik S.A., Saeed S., Iqbal N., Saeed Q., Khan K.A., Ting C. and Ghramh H.A. (2019). Diversity of pollinators and their role in the pollination biology of chickpea, *Cicer arietinum* L. (Fabaceae). *Journal of Asia-Pacific Entomology*. **22(2)**, 597-601.

MacIvor, J.S., Cabral J.M. and Packer L. (2014). Pollen specialization by solitary bees in an urban landscape. *Urban Ecosystems*. **17(1)**, 139-47.

Marja, R., Viik E., Mänd M., Phillips J., Klein A.M. and Batáry P. (2018). Crop rotation and agri environment schemes determine bumblebee communities via flower resources. *Journal of Applied Ecology*. **55(4)**, 1714-24.

Michener, C.D. (2007) The Bees of the World Johns Hopkins University Press. Baltimore, Md, USA.

Mommaerts, V. and Smagghe G. (2011). Side-effects of pesticides on the pollinator Bombus, an overview. In-Tech.

Ollerton, J., Winfree R. and Tarrant S. (2011). How many flowering plants are pollinated by animals? *Oikos*. **120(3)**, 321-6.

Pannure, A. (2016). Bee pollinators decline, Perspectives from India. *International Research Journal of Natural and Applied Sciences*. **3(5)**, 2349-4077.

Potts, S.G., Imperatriz-Fonseca V., Ngo H.T., Aizen M.A., Biesmeijer J.C., Breeze T.D., Dicks L.V., Garibaldi 2L.A., Hill R., Settele J. and Vanbergen A.J. (2016). Safeguarding pollinators and their values to human well-being. *Nature*. **540(7632)**, 220-9.

Rader, R., Bartomeus I., Garibaldi L.A., Garratt M.P., Howlett B.G., Winfree R., Cunningham S.A., Mayfield M.M., Arthur A.D., Andersson G.K. and Bommarco R. (2016). Non-bee insects are important contributors to global crop pollination. *Proceedings of the National Academy of Sciences*. **113(1)**, 146-51.

Sánchez-Bayo, F. and Wyckhuys K.A. (2019). Worldwide decline of the entomofauna, A review of its drivers. *Biological conservation*. **232**, 8-27.

Siregar, E.H., Atmowidi T. and Kahono S. (2016). Diversity and abundance of insect pollinators in different agricultural lands in Jambi, Sumatera. *HAYATI Journal of Biosciences*. **23(1)**, 13-7.

Sponsler, D.B., Grozinger C.M., Hitaj C., Rundlöf M., Botías C., Code A., Lonsdorf E.V., Melathopoulos A.P., Smith D.J., Suryanarayanan S. and Thogmartin W.E. (2019). Pesticides and pollinators, A socioecological synthesis. *Science of the Total Environment*. **662**, 1012-27.

Williamsm, I.H. (2002). Insect pollination and crop production, a European perspective. Pollinating Bees-The Conservation Link Between Agriculture and Nature. *Ministry of Environment, Brasilia*. **2002**, 59-65.