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Sustaining Pollinator Diversity through Eco-friendly Management Strategies

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This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Pollinators, encompassing a diverse array of insects and vertebrates, play a pivotal role in maintaining biodiversity and ecosystem health. This paper explores the significance of pollinators in global ecosystems, emphasizing their indispensable contribution to crop production, nutritional diversity, and the overall quality of human diets. However, current rates of species extinction, primarily driven by human impacts such as pesticide use, habitat loss, and climate change, pose grave threats to pollinator populations worldwide. Pesticides, particularly neonicotinoids, have been identified as a significant cause of bee colony losses, leading to issues like Colony Collapse

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Disorder and substantial declines in bee species. Additionally, factors such as habitat degradation, pathogens, and heavy metal pollution further exacerbate the decline of pollinators. Various conservation strategies are proposed to address these challenges, including habitat restoration, sustainable farming practices, and minimizing pesticide use through integrated pest management. Furthermore, the importance of genetically modified crops in mitigating adverse effects on pollinators is discussed, highlighting the need for evidence-based approaches to ensure the safety of these technologies. Raising awareness about the importance of pollinators and promoting sustainable agricultural practices are essential for safeguarding pollinator populations and ensuring global food security. Integrated Pest and Pollinator Management (IPPM) emerges as a promising approach to harmonize pest control with preserving beneficial species, offering a holistic strategy for sustainable crop production. Overall, concerted efforts at the individual, community, and policy levels are imperative to address the multifaceted challenges facing pollinators and to secure the resilience of ecosystems worldwide.

Keywords: Colony collapse disorder; conservation; integrated pest and pollinator management; pesticide impact; pollinator diversity; Varroa mite.

1. INTRODUCTION

Biodiversity in pollinators and pollination systems is remarkably diverse, encompassing over 25,000 to 30,000 bee species along with various other insects, such as beetles, moths, wasps, butterflies and flies [1]. Additionally, vertebrate pollinators including birds, bats, rodents and monkeys contribute significantly to pollination, particularly in tropical and sub-tropical regions (Table 1). About 80 % of flowering plant species rely on animal pollination, predominantly by insects [2] (Table 2). In tropical forests, for instance, insects may account for up to 95 % of the pollination of canopy trees, while vertebrates, including bats and various taxa, contribute to the pollination of 20 to 25 % of understory and subcanopy plants [3]. Pollination is vital for human livelihoods, especially in agro-ecosystems where pollinators are indispensable for orchard, horticultural, and forage production. Birds, bats and bees impact 35 % of global crop production, enhancing yields for 87 major food crops and various plant-derived medicines [4]. Beyond abundance, pollination significantly contributes to the nutritional diversity, vitamin sufficiency, and overall quality of human diets [5]. To adapt to changing climates, optimal crop production requires a diverse set of pollinators, potentially extending beyond managed honeybees. Current rates of species extinction, driven by human impacts, are estimated to be 100 to 1,000 times higher than the natural norm [6]. In the foreseeable future, the majority of biodiversity loss is anticipated to be among insects, with approximately 40% of invertebrate pollinator species, particularly butterflies and bees, followed by vertebrate pollinators, with approximately 16.5% facing the risk of extinction [7]. Of these, human-induced pesticide use, changes in land use, widespread adoption of intensive agricultural practices, monocultures, and have resulted in extensive loss of pollinators.

Pesticides emerged as main cause behind the demise of bee colonies, responsible for annual losses ranging from 23% to over 50% of colonies. The indiscriminate use of pesticides, particularly neonicotinoids which is a systemic, poses a significant threat to insect pollinators, beneficial insects, and overall insect populations, leading to issues like Colony Collapse Disorder, habitat destruction, and substantial declines in bee species, with additional concerns arising from harmful effects induced by fertilizers and other chemical substances in various ecosystems [8,9] (Fig. 2) Most farmers are aware of the harmful effects of pesticides on the environment and other species, but the issue lies in a lack of proper care. In Gimbo District, a beekeeper lost ten bee colonies due to improper application of pesticides by farmer. It is a major challenge for beekeepers [10]. Beekeepers observed more colony loss particularly in the early 2000s, with some losses attributed to Colony Collapse Disorder (CCD) which is a phenomenon marked by the sudden disappearance of numerous worker bees, leaving their queen behind [11]. The assessment of pesticide residues in honeybees, nectar, and pollen indicates that some residues may currently be harmful to bees. Honeybees are exposed to significant doses, reaching up to 50–100% of the lethal dose for fipronil and imidacloprid (96.66% and 59.77%, respectively), 10–50% of the lethal dose for permethrin (10.87%) through oral exposure. Moderate risk of sublethal effects (1-10%) for specific organophosphate, pyrethroid and carbamate pesticides may lead to impaired navigation, foraging efficiency or reduced colony health in pollinators. For other pesticides, the risk of harm through oral exposure is below 1%, indicating a lower potential for negative impacts on pollinator populations [12].

Monoculture practices contribute to the overuse of pesticides, loss of foraging resources for native pollinators, increased stress and nutritional deficiencies in honey bees, and the potential for mass colony losses during long-distance transportation for crop pollination [13]. Varroa mite damage bees by feeding on their body fluids, transmitting viruses, and weakening the bees immune system [14]. These parasitic mites primarily target honey bee larvae and pupae, causing deformities and often leading to the premature death of affected individuals. Additionally, these mites can reduce the overall lifespan of adult bees and weaken entire colonies [15]. The Varroa mites also contribute to the spread of various bee viruses like Deformed Wing Virus (DWV), Acute Bee Paralysis Virus (ABPV) which further effecting the health and survival of bee populations [16]. Pathogens, particularly viral diseases like Deformed Wing virus, Black Queen Cell Virus and Acute Bee Paralysis Virus contribute to the decline of pollinator populations, especially in honey bees and bumble bees, as they interact with factors such as poor nutrition and pesticide exposure, with evidence suggesting spillover from managed bees to wild populations [17]. The presence of transgenic crops has the potential to directly impact lepidopteran pollinators with transgenic proteins expressed in pollen and nectar potentially causing toxicity and neural disturbances [18]. Although some observations suggest that certain Bt-toxins may be safe to Hymenopterans and their colonies [19,20].

The decline in pollinators is linked to metal pollution, particularly heavy metals like cadmium, copper, iron, manganese, and zinc, along with adverse effects from industrial discharge, sewage, and agricultural runoff, while light pollution from urbanization negatively affects nocturnal pollinators, impacting their physiology, behaviour, and communication [21]. Climate change, marked by rising temperatures, altered rainfall patterns, and increased frequency of extreme events, has multifaceted impacts on organisms, affecting the metabolism and life cycles of plants and pollinators, leading to shifts in flowering times, disruptions in pollinator services, and potential declines in biodiversity, with consequential threats to global food security and nutritional balance, as well as the need for the development and implementation of bioindicators, such as dragonflies, to monitor and assess ecological changes in aquatic ecosystems [22]. Bees, when exposure to electromagnetic radiation from cordless telephones resulted in heightened agility, increased swarming drive, and a lack of winter clustering, while colonies exposed to DECT cordless telephone base station fields exhibited slower weight and area development, along with significant differences in the homing ability of bees exposed to the field compared to those that were not [23]. To address this issue, initiatives must focus on habitat restoration, advocating for sustainable farming practices, and minimizing pesticide use through integrated pest management. By integrating research, community engagement, and policy advocacy, comprehensive conservation actions can safeguard the future of pollinators and the ecosystems they support.

2. DIVERSITY OF POLLINATORS

Diversity of pollinators includes Bumble bee, Wasp, Stingless bee, Pierid butterfly, Honey bee, Eye gnats, Hawk moth, House fly and Blow fly (Fig. 1). It plays a crucial role in maintaining biodiversity and ecosystem health and they exhibit a remarkable diversity in terms of their characteristics, behavior, and interaction with plants. The co-evolutionary relationship between flowering plants and their pollinators commenced approximately 225 million years ago [24].

2.1 Hymenoptera (Melittophily)

Hymenopterans are a diverse order of insects that includes important pollinators, primarily bees. Among these, bees are especially critical as pollinators, ensuring the fertilization of numerous crops, including fruits, vegetables, and oilseeds. For instance, honey bees play a crucial role in California almond production due to almonds are entirely dependent on insect pollination [38]. Their presence during the almond bloom ensures the successful transfer of pollen between flowers, directly influencing the size and quality of the crop which fuels a multibillion-dollar industry that significantly contributes to both California's and the U.S. economy [39]. *Apis mellifera,* owing to its highly social nature, has become a dominant species in global commercial pollination. However, the importance of non-*Apis* bees, both wild and domesticated, in pollinating various crops is being increasingly recognized. Non-Apis species, such as solitary bees used in orchard crop pollination, bumble bees used primarily for greenhouse tomato pollination, Megachile used in alfalfa pollination, and stingless bees used in coffee and other crop pollination. Hymenopterans also act as parasitoids, particularly from the Braconidae family, which play a crucial role in natural pest control in various crop ecosystems that reduce the need for chemical pesticides [40]. Additionally, ants particularly leafcutter ants, play a vital role in nutrient cycling by breaking down organic matter and returning nutrients to the soil, thus maintaining soil fertility and ecosystem health [41].

Fig. 1. Diversity of pollinators

(A) Bumble bee (B) Wasp (C) Stingless bee (D) Pierid butterfly (E) Honey bee (F) Eye gnats (G) Hawk moth (H) House fly (I) Blow fly

Table 1. Insect Pollinators and Their Pollination Rates [25]

Order	Common name	Mode of pollination	% of pollination
Hymenoptera	Honeybees	Melittophily	56.5%
	Wasps	Sphecophily	5%
Coleoptera	Beetles	Cantharophily	5%
Diptera	Flies	Myophily	19%
Lepidoptera	Butterflies and moths	Phalaenophily	4%
Passerformes	Birds	Ornithophily	4%
Chiroptera	Bats	Chiropterophily	6.5 %

Table 2. Percent increase in the yield of crops due to pollinators

Crop	Yield attributes	% increase in the yield due to pollinators	Reference
Tomato	Fruit set	8.3-27.40	[26]
Chilli	Fruit set	73-84	[27]
Onion	Seed set	90.47	[28]
Okra	Fruit set	73-84	[29]
Brinjal	Seed yield	35-67	[26]
Cabbage	Seed yield	100-300	
Cucurbits	Fruit weight and fruit set	32.50-4800	
Apple	Fruit set and fruit weight	15-20	[30]
Peach		22-44	[31]
Plum		13-39	[31]
Citrus		24-35	[31]
Strawberry		112-48	[31]
Mango	Fruit productivity	3-5	[32]
Papaya		5-10	
Litchi		20-25	
Grapes		10-20	
Pear		10-15	
Guava		5-10	
Almond	Fruit productivity	50-75	[33]
Cumin	Seed yield and quality	40.03	[33]
Coriander	Germination	70.25-72.50	[34]
	Seed set	64.76-65.94	
Fennel	Seed set	70.04	[35]
Bell pepper	Fruit yield	82.35	[36]
Cardamom	Fruit set	21-37	
Gingelly	Seed set	Upto 25	
Sunflower	Seed yield	43	[37]

Bees are covered in branched and feathery hairs called setae, which create a dense covering known as pubescence. These hairs are excellent at trapping pollen grains. As bees move from flower to flower, pollen grains adhere to their body hairs, allowing for efficient pollen transfer [42]. Certain species of bees, such as honey bees and bumblebees have a specialized structure pollen basket or corbicula on their hind legs which is used to carry and transport pollen back to the hive. Some bees have specialized hairs on their legs or body, often referred to as pollen brushes or scopal hairs, which help in collecting and transporting pollen. In addition to the pollen basket, honey bees have a specialized structure called a pollen comb located on their hind legs. This structure aids in grooming and collecting pollen [43]. It has specialized mouthparts adapted for collecting nectar and pollen from flowers. They have a long proboscis that allows them to reach deep into flowers to access nectar. Some bees also have specialized structures on their mouthparts, such as labial palps, which aid in grooming and manipulating pollen [44].

2.2 Diptera (Myophily)

Diptera commonly known as flies that serve as lesser-known but nonetheless significant pollinators. These are the second most common group visiting flowers, being seen around 72 per cent of crops. Among the flies, the hoverflies (Syrphidae family) were the most frequent non-bee visitors, visit more than half of the different crop plants including many fruits, vegetables, and oilseed crops Their hairy bodies inadvertently collect and transfer pollen between flowers as they seek nourishment. Another group of flies, the blow flies in the Calliphoridae family, also made significant visit to flowers [45]. Additionally, families such as Empididae (dance flies), Bombyliidae (bee flies), Tachinidae and Anthomyiidae also contribute to pollination by visiting flowers for sustenance. While flies may not possess the same level of specialization as bees in pollination, their diverse interactions with flowering plants add to the overall complexity of ecological systems. Apart from pollinators, fruit flies are major pests in fruit and vegetable crops, causing significant economic losses worldwide. Leaf miner flies are important pests in various crops, such as tomatoes, beans, and citrus [46].

Dipteran pollinators have compact bodies, which allow them to move easily among flowers. Most of them are relatively small to medium-sized, facilitating their entry into flowers [47]. These pollinators have legs adapted for perching on flowers, allowing them to feed efficiently. Some species have specialized hairs on their legs that aid in pollen collection and transportation. They often have short, clubbed antennae, which help to navigate and locate flowers. In general, irrespective of the different size of the pollinators, pollen is loaded on the posterior part of the head or behind the eyes and anterior part of the thorax [48].

2.3 Lepidoptera (Phalaenophily)

Lepidopteran which includes butterflies and moths, play a notable role in pollination, around 54 per cent of crops, contributing to the reproductive success of various flowering plants. They pollinate numerous food crops such as tomatoes, strawberries, and apples, enhancing genetic diversity and resilience in plants. The presence of diverse lepidopteran species in an ecosystem is an indicator of environmental health. They are sensitive to changes in habitat quality, making them valuable bioindicators for monitoring ecosystem changes and guiding conservation efforts [49].

Unlike bees, lepidopterans do not actively collect pollen for food instead, pollen transfer occurs incidentally as they feed on nectar [50]. They are attracted to flowers primarily for nectar, which serves as their main energy source. As they feed, their bodies encountered the reproductive structures of the flowers, leading to unintentional pollen transfer. The structure of lepidopteran mouthparts, possess a proboscis, a long, straw-like structure adapted for sipping nectar, allows them to pick up and carry pollen from one flower to another. This contributes to the fertilization of plants and the production of seeds. The nectar-feeding butterflies had higher pollination efficiency than the nectar- and pollen-feeding honey bees. Butterflies usually have straight antennae with clubbed ends, while moth antennae can vary from feathery to thread-like, aiding in the detection of floral scents [51]. Certain butterflies may preferentially visit specific flower types, leading to co-evolutionary adaptation between the insects and the plants and these are diurnal or daytime pollinators while moths depending on the species may be active during the day or night. This temporal variation can influence the types of plants they pollinate. Minimize artificial light at night, as excessive lighting can disrupt the behaviour of nocturnal pollinators and affect their populations [52].

2.4 Coleoptera (Cantharophily)

Beetles are one of the most abundant groups of insects, and many species actively participate in pollination around 51 per cent of crops. They are primary pollinators for many ancient plant lineages including magnolias, water lilies, and some cycads [53]. These plants have evolved to attract beetles specifically through their floral structures and scents. Many beetles are adapting at burrowing into flowers or climbing onto them, which encountered reproductive structures. With strong mouthparts and diverse body shapes, beetles often access flowers in search of nectar, pollen and transfer pollen. Certain beetles are active at night and pollinate nocturnal flowers, which are often large and fragrant to attract these insects. Unlike some other beetles, *Chrysolina aurata*, have specialized surfaces for pollen adherence, these beetles rely on a fluid on their mouthparts to help the pollen stick to the bristles. Staphylinidae beetles have been identified as potential or conclusive pollinators for 56 plant species, primarily in monocots and magnoliids [54].

Beetles commonly visit large, bowl-shaped flowers, where they may feed on nectar or consume pollen. While less responsive to flower colours, beetles are often attracted to strong scents emitted by certain flowers [55]. Some beetles are generalist feeders, while others exhibit specialization in feeding on specific plants, fostering plant-beetle co-evolution. Beetles may crawl or walk on flowers, facilitating pollen transfer between floral structures. Certain beetle species are active at night, contributing to nocturnal pollination processes [56]. Beetles, known for their longevity, may spend extended periods on flowers, increasing the chances of successful pollination. Beetles as pollinators are widespread, adapting to diverse ecosystems, including tropical rainforests, deserts, and temperate regions. Understanding the role of beetles as pollinators is crucial for conservation efforts, as their presence contributes to the overall biodiversity and health of ecosystems.

2.5 Birds (Ornithophily)

Hummingbirds, primarily inhabiting the Americas, are renowned for their exceptional hovering capabilities and slender bills adapted for sipping nectar. With their rapid wing beats and unique ability to sustain mid-air positions, hummingbirds play a crucial role in pollination [57]. These avian pollinators are particularly drawn to tubular, brightly coloured flowers, and as they feed on nectar, they inadvertently transfer pollen from one bloom to another, facilitating cross-pollination and contributing to the reproductive success of various flowering plants. In regions where hummingbirds are absent, the ecological role of pollination is often fulfilled by sunbirds, found in Africa, Asia, and Australia. Sunbirds, characterized by iridescent plumage and long, slender bills, mirror the hovering feeding behavior of hummingbirds and serve as vital pollinators in tropical and subtropical ecosystems [58].

2.6 Bats (Chiropterophily)

Bats particularly in tropical regions, emerge as a crucial nocturnal pollinator with adaptations such as echolocation and keen olfactory senses, bats navigate in the dark and efficiently pollinate night-blooming flowers, enhancing the genetic diversity and survival of numerous plant species [59]. Bats have a better memory in search of food compared to bees. Nectar-feeding bats can remember up to 40 different locations where they find food, making it easier for them to navigate and forage in the dark tropical environments during the night. These diverse avian and mammalian pollinators collectively highlight the intricate web of ecological interactions that sustains plant biodiversity across different geographical regions.

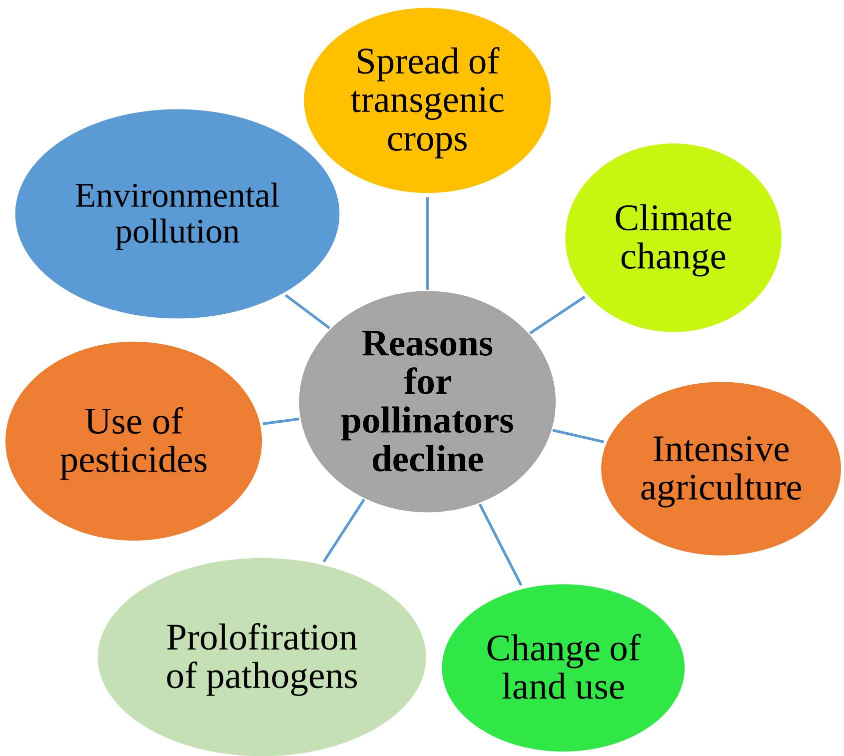

Fig. 2. Reasons for declining of pollinators

3. MAINTENANCE IN ECOSYSTEM

3.1 Planting Bee-Friendly plants

By measuring the different aspects of bee activity, such as honey stores, brood area, egg laying, pollen stores, there was plenty of food available for the bees, known as Bee flora in the month of April and the bees were active and thriving. As the months progressed, especially by June, these values decreased to zero which is called Dearth period. This decline was due to shortage of food source for the bees [60]. Orchards surrounded by diverse landscapes with various habitats like croplands, grasslands and woodlands which support more and unique resources for wild bees. These varied habitats had different types of flowers that bloom at different times, ensuring a continuous supply of food for bees throughout their foraging periods [61]. Plants with different colours, shapes, and sizes to attract a diverse range of bee species. Avoid using pesticides and herbicides, as they can harm bees.

3.2 Provide Nesting Site

Providing nesting sites for bees involves creating suitable environments where bees can build their nests and lay eggs. This is particularly important for solitary bees, which do not live in colonies and need individual nesting spaces [62]. One simple way to build nesting sites is to leave patches of bare ground, as some ground-nesting bees prefer this for their nests. Additionally, installing bee hives can be beneficial. These are structures with small cavities that mimic natural nesting sites, providing shelter for solitary bees [63]. By incorporating these elements into gardens or outdoor spaces, individuals can support bee populations by giving them safe and suitable places to nest and reproduce.

3.3 Use of Safe Pesticides

Synthetic pesticides are a key factor in the decline of bee populations. Botanical biopesticides could be a good substitute for synthetic pesticides in protecting plants due to high selectivity and break down quickly in the environment. In some cases, these biopesticides can harm bees, causing both lethal and sublethal effects but these effects are less severe compared to those caused by synthetic pesticides [64]. Anethole and lemongrass oil showed promising control of Varroa mite which is a parasite on bees and appeared relatively safe for both honey bee larvae and adults. It found that the gene related to detoxification in bees was not affected by the treatments [65]. Continuous release of oregano oil was highly effective, achieved a 97.4% control rate for varroa mites with minimal impact on bee mortality. Bees are more active during the day, especially when temperatures are warmer. Spraying pyrethroids on flowering crops during when honeybees are less active as in the early morning or late evening, may lead to unreported bumblebee deaths. But this is a big concern, when spraying pesticides in March or April, as it can harm bumblebee colonies during the time when queens are starting new colonies. It is important to take steps to protect bumblebees during these times and be careful with the choice and timing of pesticides. Insecticides with more selective mode of action, which are engineered to target specific pests and limit harmful effects to beneficial arthropods have recently become available for control of many potato pests. When using pesticides, checking the guidelines of label Environmental Hazard section for safeguarding bees is important [66].

3.4 Use of Genetically Modified Crops

By examining data from 1994 to 2017, proteins and traits from these transgenic crops, including protease inhibitors, Cry or VIP toxins, RNAi, and herbicide tolerance neither negatively affected honey bee survival nor exhibited sublethal effects in controlled conditions. There is no evidence that consuming transgenic pollen from these crops contributes to CCD [67]. When honeybees were exposed to pollen from genetically modified cabbage containing insecticidal proteins (Cry1Ba3), there were no significant differences in pollen consumption, survival, weight, midgut enzyme activity and detoxification enzyme which shows that the Cry1Ba3 cabbage pollen is unlikely to have harmful side effects on honeybees [68]. Similarly, exposure of bumble bees to two *Bt* formulations (*kurstaki* and *aizawai*) at recommended field rates did not reduce survival when applied dermally or via treated pollen [69].

3.5 Raising Awareness Among the Growers and Consumers

Educating and raising awareness about the importance of bees is crucial for fostering a sense of responsibility towards their well-being and the health of ecosystems. Using social media platforms to share interesting facts, info graphics, and articles about bees by highlighting their importance in maintaining biodiversity and supporting food production. Participating in or organizing events and exhibitions focused on how urbanization and changes in land use contribute to the loss of natural habitats for bees [70]. Celebrating May 20th as World Bee Day is dedicated to raising awareness about the importance of bees. Use this occasion to organize events, workshops, and educational activities in your community [71]. In many developing countries, small-scale farmers rely on natural and spontaneous transfer of pollen from male to female flower parts without intentional human intervention, often unaware of its economic value. Through the factor of production method, a form of figuring out how much honey bees contribute to farming by looking at the resources and efforts involved in pollination. It helps us understand the economic value of bees in making crops grow better and was found that bee pollination significantly enhances crop yields and quality with nearly 40% of the annual crop value attributed to this service, predominantly provided by feral bees [72]. Farmers applied pesticides, particularly pyrethroids and organophosphates at an average of 2.9 kg/ha per crop season showed threats to health and the environment where, both farmers and retailers often did not adopt proper safety measures due to lack of incentives. It shows that training programs and awareness initiatives, delivered through media channels like radio, television, and posters, could improve safety practices among farmers and retailers regarding pesticide handling [73].

3.6 IPPM (Integrated Pest and Pollinator Management)

Integrated pest management (IPM) is a well-established decision support system that prioritizes employing various approaches to manage pest populations. Integrated Crop Pollination (ICP) is a relatively new approach cognate to IPM, but tailored for pollinators. It stresses the amalgamation of various tactics to ensure consistent and sustainable crop pollination [74]. The concept of Integrated Pest and Pollinator Management (IPPM) proposes incorporating pollinator management into IPM practice. Alternatively, it involves integrating IPM with crop pollination management through coordinated, ecology-based strategies to mitigate the impacts of both pests and pollinators [75]. The main aim of IPPM is to harmonize the control of pests, including insects, weeds, and diseases, with the preservation and promotion of beneficial species such as pollinators, predators, parasitoids, and entomopathogens [76] (Fig. 3).

Expanding the IPPM concept involves managing agroecosystem functions influenced by pests, natural enemies and pollinators, where arthropods play a central role in each function. The significance of co-management of pest and pollinator is highlighted by the fact that certain species can fulfill multiple roles such as predation, pollinator and herbivory. For instance, hoverflies larva act as predator while adults serve as pollinators, and certain bee species like *Trigona spinipes* can function as either pollinators or pests depending on the specific crop type [77]. The formulation of IPPM strategies involves combining measures that offer complementary or synergistic advantages for crop yield, while simultaneously addressing potential conflicts such as ecosystem 'disservices'.

3.6.1 Benefits of IPPM

- Enhanced focus on sustainable crop pollination and pest control [79]
- Precise targeting of pests leads to broader environmental benefits and sustainable ecology [80]
- Minimized trade-offs with increased co-benefits for both pest and pollinator management [81]
- Reduced exposure of pollinators to harmful pesticides, fostering a more pollinator-friendly environment [82]
- Improved crop productivity through selective pest reduction and enhanced pollination [83]

3.7 Pollination Information Management System (PIMS)

A number of national level organizations focused on the conservation and sustainable use of pollination services for sustainable agriculture have teamed up with Food and Agriculture Organization (FAO) to build the Pollination Information Management System. The purpose is to provide farmers, farm advisers, and land managers with up-to-date, reliable information on managing pollination services of important crops worldwide.

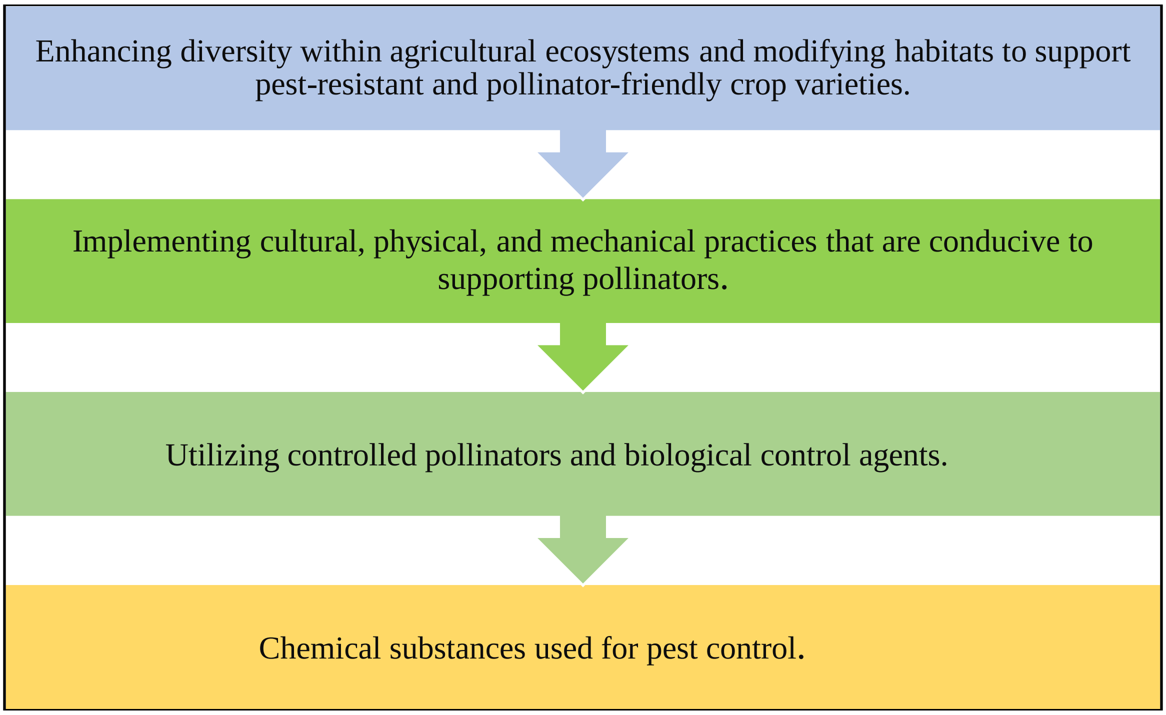

Fig. 3. IPPM Pyramid [78]

4. CONCLUSION

To maintain the health and sustainability of ecosystems, conservation of pollinators is important. Pollinators including bees, butterflies, birds and bats play a crucial role in the reproduction of flowering plants, which in turn sustains biodiversity. The decline in pollinator populations due to factors such as habitat loss, pesticide use, climate change, and diseases poses a significant threat to global food security, economic aspects and ecosystem stability. Urgent conservation efforts are required to protect and restore pollinator habitats, reducing the use of harmful pesticides, and raise awareness about the importance of these vital species. Collaborative initiatives involving government, communities, and organizations are essential to ensure the long-term survival of pollinators and the ecosystems they support. Ultimately, the conservation of pollinators is not just an environmental imperative but also a key component of securing a resilient and thriving planet for future generations.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Buadu E. Landscape influence on bee abundance and diversity in the forest savannah transition zone of Ghana and community knowledge of pollinators and pollination (Doctoral dissertation, University of Cape Coast); 2016.
2. Abrol DP. Non bee pollinators-plant interaction. Pollination biology: biodiversity conservation and agricultural production. 2012;265-310.
3. Buchmann SL, Nabhan GP. The forgotten pollinators. Island Press; 2012.
4. Das A, et al. A review on: Importance of pollinators in fruit and vegetable production and their collateral jeopardy from agro-chemicals. Journal of Entomology and Zoology Studies. 2018;6(4):1586-1591.

5. Potts SG, et al. The assessment report on pollinators, pollination and food production: summary for policymakers. Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services; 2016.
6. De Vos JM, et al. Estimating the normal background rate of species extinction. Conservation biology. 2015;29(2):452-462.
7. Raghavendra KV, et al. Insects: biodiversity, threat status and conservation approaches. Current Science. 2022;122(12):1374-1384.
8. Kurze S, et al. Nitrogen enrichment in host plants increases the mortality of common Lepidoptera species. Oecologia. 2018;188(4):1227-1237.
9. Chakrabarti P, et al. Evaluating effects of a critical micronutrient (24-methylenecholesterol) on honey bee physiology. Annals of the Entomological Society of America. 2020;113(3):176-182.
10. Shegaw T, et al. Assessment on pesticides utilization and its effect on beekeeping in Kafa and Benchi-Sheko Zones, South-Western Region, Ethiopia. Cogent Food and Agriculture. 2022;8(1):2079209.
11. Alvernaz S. The price of pesticides: Environmental and economic impacts of using neonicotinoids in agriculture. Journal of Environmental Law and Litigation. 2023;38:233.
12. Yang Y, et al. Global honeybee health decline factors and potential conservation techniques. Food Security. 2023;1-21.
13. Vasiliev D, Greenwood S. Pollinator biodiversity and crop pollination in temperate ecosystems, implications for national pollinator conservation strategies: Mini review. Science of the Total Environment. 2020;744:140880.
14. Koleoglu G. Effect of the parasitic mite *Varroa destructor* on the immune system of africanized and european honey bees at the molecular and cellular levels (Doctoral dissertation, University of Guelph); 2014.
15. Annoscia D, et al. Mite infestation during development alters the in-hive behaviour of adult honeybees. Apidologie. 2015;46:306-314.
16. Sammataro D, et al. Parasitic mites of honey bees: life history, implications, and impact. Annual Review of Entomology. 2000;45(1):519-548.
17. Jones JI, et al. The impact of fine sediment on macro-invertebrates. River Research and Applications. 2012;28(8):1055-1071.
18. Malone LA, et al. Impact of genetically modified crops on pollinators. Environmental Impact of Genetically Modified Crops. 2009;199-222.
19. Dai PL, et al. Bt toxin Cry1Ie causes no negative effects on survival, pollen consumption, or olfactory learning in worker honey bees (Hymenoptera: Apidae). Journal of Economic Entomology. 2016;109(3):1028-1033.
20. Dai P, et al. The effect of Bt Cry9Ee toxin on honey bee brood and adults reared in vitro, *Apis mellifera* (Hymenoptera: Apidae). Ecotoxicology and Environmental Safety. 2019;181:381-387.
21. Shi X, et al. The impact of heavy metal pollution on wild bee communities in smallholder farmlands. Environmental Research. 2023;116515.
22. Karthik S, et al. Climate change and its potential impacts on insect-plant interactions. The Nature, Causes, Effects and Mitigation of Climate Change on the Environment. 2021;10.
23. Electrosmog DN. Bees, birds and mankind; 2007.
24. Price PW. Insect ecology. John Wiley and Sons; 1997.
25. Chauhan T, et al. Review on honeybee: Miracle agent of pollination. Plant Archives. 2021;21(1):2205-2209.
26. Abrol DP. Neonicotinoids–environmental risk assessment to natural enemies and pollinators. Journal of Palynology. 2022;58:23-62.
27. Yourstone J, et al. High dependency of chilli fruit set on wild pollinators in southern India. Journal of Pollination Ecology. 2021;28:65-74.
28. Kumar J, et al. Effect of honey bee pollination on onion (*Allium cepa* L.) seed production; 1989.
29. Perera S, Karunaratne I. Floral visits of the wild bee, *Lithurgus atratus*, impact yield and seed germinability of okra, abelmoschus esculentus, in srilanka. Journal of Pollination Ecology. 2019;25:1-6.
30. Partap U. Conservation of endangered Himalayan honeybee, *Apis cerana* for crop pollination. Asian Bee Journal. 1999a;1:44–49.
31. Partap U. Foraging behaviour of *Apis cerana* on sweet orange (*Citrus sinensis* var. Red Junar) and its impact on fruit production; 2000.

32. Partap UP. Pollination management of mountain crops through beekeeping. Trainers' resource book. 1999b;117.
33. Meena NK, et al. Pollinator's diversity and abundance on cumin (*Cuminum cyminum* L.) and their impact on yield enhancement at semi-arid regions. Journal of Entomology and Zoology Studies. 2018;6:1017-1021.
34. Kumar M, Jaiswal BK. Effect of honeybee (*Apis mellifera* L.) pollination on yield and quality in coriander. Indian Journal of Entomology. 2012;74(3):281-284.
35. Kumar M, singh R. Role of honeybees in the pollination of fennel (*Foeniculum vulgare* L.). Journal of Pharmacognosy and Phytochemistry. 2017;6(1):214-218.
36. Devi D. Studies on nesting material and carbon dioxide narcosis on domiciliation of bumblebee (*Bombus haemorrhoidalis* Smith) (Doctoral dissertation, M. Sc. Thesis. Department of Entomology, Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan); 2019.
37. Chambó ED, et al. Honey bee visitation to sunflower: effects on pollination and plant genotype. Scientia Agricola. 2011;68:647-651.
38. Durant JL, Ponisio LC. A regional, honey bee-centered approach is needed to incentivize grower adoption of bee-friendly practices in the almond industry. Frontiers in Sustainable Food Systems. 2021;5:628802.
39. Stankus T. A review and bibliography of the literature of honey bee Colony Collapse Disorder: A poorly understood epidemic that clearly threatens the successful pollination of billions of dollars of crops in America. Journal of Agricultural and Food Information. 2008;9(2):115-143.
40. Hegde JN. Diversity of hymenopteran parasitoids in different crop ecosystems. International Journal of Environment and Climate Change. 2024;14(3): 585-607.
41. Tuma J. The effect of tropical land use change on soil dwelling ants and termites, their interaction and on ecosystem processes they affect (Doctoral dissertation, PhD thesis. University of South Bohemia); 2020.
42. Benjamin A, McCallum B. The good bee: A celebration of bees–and how to save them. Michael O'Mara Books.
43. Lineburg B. The Storing of Pollen by the Honey Bee. Bee World. 2019;5(9):137-138.
44. Houston T. A guide to native bees of Australia. Csiro Publishing; 2018.
45. Rader R, et al. Non-bee insects as visitors and pollinators of crops: Biology, ecology, and management. Annual Review of Entomology. 2020;65:391-407.
46. Foba CN, et al. Species composition, distribution, and seasonal abundance of *Liriomyza* leaf miners (Diptera: Agromyzidae) under different vegetable production systems and agroecological zones in Kenya. Environmental Entomology. 2015;44(2):223-232.
47. Karolyi F, et al. Adaptations for nectar-feeding in the mouthparts of long-proboscid flies (Nemestrinidae: Prosoeca). Biological Journal of the Linnean Society. 2012;107(2):414-424.
48. Celep F, et al. Flies as pollinators of *Melittophilous Salvia* species (Lamiaceae). American Journal of Botany. 2014;101**(**12):2148-2159
49. Sajjad H. Terrestrial insects as bioindicators of environmental pollution: A Review. UW J Sci Technol. 2020;4:21-25.
50. Walton RE, et al., Nocturnal pollinators strongly contribute to pollen transport of wild flowers in an agricultural landscape. Biology letters. 2020;16(5):20190877.
51. Wright GA, Schiestl FP. The evolution of floral scent: The influence of olfactory learning by insect pollinators on the honest signalling of floral rewards. Functional Ecology. 2009;23(5):841-851.
52. Macgregor CJ, et al. Pollination by nocturnal L epidoptera, and the effects of light pollution: A review. Ecological Entomology. 2015;40(3):187-198.
53. Hernandez-Vera G, Navarrete-Heredia JL, Vazquez-Garcia JA. Beetles as floral visitors in the Magnoliaceae: An evolutionary perspective. Arthropod-Plant Interactions. 2021;15(3):273-283.
54. Sayers TD, Steinbauer MJ, Miller RE. Visitor or vector? The extent of rove beetle (Coleoptera: Staphylinidae) pollination and floral interactions. Arthropod-Plant Interactions. 2019;13:685-701.
55. Dasgupta J, Pal TK, Hegde VD. An appraisal of range and evolutionary significance of flower-beetle association, with special reference to sap beetles (Coleoptera: Nitidulidae). In Proceedings of

the Zoological Society. Springer India. 2018;71:170-177.
56. Macgregor CJ, Scott-Brown AS. Nocturnal pollination: An overlooked ecosystem service vulnerable to environmental change. Emerging Topics in Life Sciences. 2020;4(1):19-32.
57. Lederer R. Beaks, Bones, Bird Songs: How the struggle for survival has shaped birds and their behavior. Timber Press; 2016.
58. Mann CF, Cheke RA. Sunbirds: A guide to the sunbirds, flowerpeckers, spiderhunters and sugarbirds of the world. Bloomsbury Publishing; 2010.
59. Fleming TH, Geiselman C, Kress WJ. The evolution of bat pollination: a phylogenetic perspective. Annals of Botany. 2009;104(6):1017-1043.
60. Kumar R, Rajput GS, Ahmad S. Assessment of dearth periods for honey bees (*Apis mellifera*) in Gwalior (MP), India. Munis Entomology and Zoology. 2013;8(2):745-8.
61. Mallinger RE, Gibbs J, Gratton C. Diverse LANDSCAPES have a higher abundance and species richness of spring wild bees by providing complementary floral resources over bees' foraging periods. Landscape Ecology. 2016;31:1523-1535.
62. Antoine CM, Forrest JR. Nesting habitat of ground-nesting bees: A review. Ecological Entomology. 2021;46(2):143-159.
63. Polidori C, et al. Sunny, hot and humid nesting locations with diverse vegetation benefit Osmia bees nearby almond orchards in a mediterranean area. Journal of Insect Conservation. 2024; 28(1):57-73.
64. Catania R, et al. Are botanical biopesticides safe for bees (Hymenoptera, Apoidea). Insects. 2023;14(3):247.
65. Gimenez-Martinez P, et al. Lethal concentrations of *Cymbopogon nardus* essential oils and their main component citronellal on *Varroa destructor* and *Apis mellifera*. Experimental Parasitology. 2022;238:108279.
66. Johansen CA, Mayer DF. How to reduce bee poisoning from pesticides. Washington State University Cooperative Extension; 1986.
67. Ricroch A, et al. Assessing the environmental safety of transgenic plants: honey bees as a case study. In Advances in Botanical Research. 2018; 86:111-167.
68. Yi D, Fang Z, Yang L. Effects of Bt cabbage pollen on the honeybee *Apis mellifera* L. Scientific Reports. 2018;80(1):482.
69. Mommaerts V, Jans K, Smagghe G. Impact of bacillus thuringiensis strains on survival, reproduction and foraging behaviour in bumblebees (*Bombus terrestris*). Pest Management Science. 2010;66(5):520-525.
70. Cooper M. Creating A Buzz, Victoria University of Wellington; 2017.
71. Moore LJ, Kosut M. Buzz: Urban beekeeping and the power of the bee. NYU Press; 2013.
72. Kasina JM, et al. Economic benefit of crop pollination by bees: a case of Kakamega small-holder farming in western Kenya. Journal of economic entomology. 2009;102(2):467-473.
73. Bhandari G, et al. Factors affecting pesticide safety behaviour: The perceptions of Nepalese farmers and retailers. Science of the Total Environment. 2018;631:1560-1571.
74. Isaacs R, et al. Integrated crop pollination: Combining strategies to ensure stable and sustainable yields of pollination-dependent crops. Basic and Applied Ecology. 2017;22:44-60.
75. Egan PA, et al. Delivering integrated pest and pollinator management (IPPM). Trends in Plant Science. 2020;25(6):577-589.
76. Mull A, et al. Integrated Pest and Pollinator Management; 2022.
77. Saunders ME, et al. Pollinators, pests, and predators: Recognizing ecological trade-offs in agroecosystems. Ambio. 2016;45:4-14.
78. Biddinger DJ, Rajotte EG. Integrated pest and pollinator management—adding a new dimension to an accepted paradigm. Current Opinion in Insect Science. 2015;10:204-209.
79. Merle I, Hipolito J, Requier F. Towards integrated pest and pollinator management in tropical crops. Current Opinion in Insect Science. 2022;50:100866.
80. Van der Sluijs JP, et al. Neonicotinoids, bee disorders and the sustainability of pollinator services. Current Opinion in Environmental Sustainability. 2013;5(3-4):293-305.
81. Dainese M, et al. A global synthesis reveals biodiversity-mediated benefits for crop production. Science Advances. 2019;5(10):eaax0121.

82. Klein AM, et al. Importance of pollinators in changing landscapes for world crops. Proceedings of the royal society B: Biological Sciences. 2007;274(1608):303-313.

83. Garibaldi LA, et al. Wild pollinators enhance fruit set of crops regardless of honey bee abundance. Science. 2013;339(6127): 1608-1611.

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