International Journal of Advance and Applied Research
www.ijaar.co.in
ISSN – 2347-7075 Impact Factor – 7.328
Peer Reviewed Bi-Monthly
Vol.11 No.3 January – February 2024

Role of Beneficial Insects in Agricultural Landscapes: Ecological Significance and Agricultural Applications

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DOI - 10.5281/zenodo.22071196

Abstract:

Beneficial Insects are fundamental components of of productive, resilient, and sustainable agricultural landscapes. They perform a wide range of ecosystem services, including pollination, biological control of insect pests, decomposition, nutrient cycling, soil improvement, and maintenance of ecological interactions. Pollinators such as honey bees, bumble bees, solitary bees, butterflies, moths, hoverflies, beetles, and other insects contribute directly to the reproduction and productivity of numerous crops. Predators such as ladybird beetles, lacewings, predatory bugs, ground beetles, and predatory flies suppress herbivorous pests, while parasitoids, particularly many hymenopterans and tachinid flies, regulate pest populations through specialized host relationships. This review examines the diversity and ecological functions of beneficial insects, their importance in crop pollination, ecosystem stability, biological control and influence of agricultural landscape structure.

Keywords: Beneficial Insects, Ecosystem, Agriculture, Pest, Diversity.

Introduction:

In order to ensure the long-term sustainability of both agricultural and natural ecosystems, sustainable agriculture aims to strike a balance between productivity, environmental health, and socioeconomic viability. It emphasizes concepts like resource conservation, soil health, and biodiversity in order to meet current requirements without compromising the capacity of future generations to meet their own. Concerns about climate change, soil degradation, water scarcity, and the detrimental effects of conventional farming methods which can largely rely on chemical inputs and monocultures are driving up demand for sustainable techniques worldwide. Conventional agricultural systems are characterized by intensive use of chemical fertilizers and pesticides, monoculture practices, and high resource consumption, leading to significant environmental issues such as soil erosion, water pollution, and loss of biodiversity (Muhie, 2022). Biodiversity is essential to the stability of food production and the functioning of agroecosystems. Ironically, though, one of the primary factors contributing to the loss of biodiversity worldwide today is traditional feeding systems. The current agrifood system intensifies competition for land to produce food, feed, and fuel and strains already scarce resources because 30-40% of all food produced is wasted throughout the production chain. It is essential to switch from a paradigm of a single linear food system to one made up of several circular food systems that include more sustainable nutrition sources and more efficiently recycle waste in order to preserve biodiversity and lessen human impact on ecosystems (Van Zanten *et al*., 2019). To promote efficient ecosystem management, it is crucial to comprehend local biodiversity and its ecological functioning as well as technology innovation. In turn, this could help create resilient, sustainable, and locally adapted biodiversity-based food systems that preserve species and habitats. In this regard, insects offer a potent but little-studied sustainability tool. Their remarkable diversity enhances the resilience, complexity, and health of ecosystems around the world. With an estimated 5.5 million species worldwide, at least 1 million of which are recognized by the general public, insects have evolved to occupy nearly every ecological niche. Furthermore, insects are important in all four types of ecosystems. The Millennium Ecosystem Assessment (MEA) defines ecosystem services (ES) as providing, regulating, supporting, and cultural services. These contributions have led to an increase in interest in insects as agents to guarantee food security and enhance agrifood sustainability. Because they provide crucial ecosystem services including pollination, pest control, and improved soil health, beneficial insects are vital to sustainable agriculture. By feeding on harmful insects like aphids and caterpillars, predatory insects like lady beetles (Coccinellidae) and lacewings (Chrysopidae) naturally decrease pest populations and lessen the need for chemical pesticides. Wasps from the Ichneumonidae and Braconidae families are examples of parasitoids that deposit their eggs inside or on host insects, eventually killing them and offering efficient biological control. These natural enemies are essential to Integrated insect Management (IPM) techniques, which reduce insect outbreaks and increase crop output without the negative impacts of chemical inputs. The integration of beneficial insects into crop production systems not only enhances ecological health but also offers economic benefits.

Types of Beneficial Insects:

Predators: While they drastically decrease pest populations, predatory insects are essential to both natural and agricultural ecosystems. In order to control pest density and stop pest outbreaks, they actively hunt and eat a variety of dangerous insects. The lady beetles (Coccinellidae), one of the most well-known families of predatory insects, mostly consume soft-bodied pests like scale insects and aphids. In a similar vein, lacewings (Chrysopidae) are efficient generalist predators that help control pests and boost crop yields by eating a range of agricultural pests, such as mites, caterpillars, and aphids (Berryman, 2012). Another broad species of predatory insects that are well-known for their ability to manage soil-dwelling pests like cutworms and root maggots are ground beetles (Carabidae). Another significant group of predators that can reduce pest concentrations are spiders (Araneae), which consume a wide range of bug species at various stages of life. Spiders are often associated with lower levels of pest populations in both conventional and organic systems because they are opportunistic feeders and can adapt to a range of agricultural conditions.

Diversity of Beneficial Insects

Parasitoids: Insects known as parasitoids have larvae that live as parasites and eventually kill their host. Because of their unique life cycles and host specificity, they are among the most potent biological control agents. Parasitoids are mostly represented by numerous types of wasps and flies. Aphids, beetles, caterpillars, and many other agricultural pests are known to be parasitized by hymenopteran parasitoids, such as those belonging to the families Ichneumonidae and Braconidae. For instance, the braconid wasp *Aphidiuscolemani* is a common parasitoid used in greenhouses to control aphid populations in vegetable crops. Tachinid flies (Tachinidae) are another important group of dipteran parasitoids that parasitize a variety of pest insects, including caterpillars and beetles. Tachinid flies are known for their capacity to locate host insects using chemical cues and their ability to parasitize pests in diverse agricultural settings. Many parasitoids have a high degree of host specificity, which reduces the possibility of damaging non-target organisms and preserves ecological balance, making them useful companions in focused pest management operations.

Pollinators: Pollinators are vital for the reproduction of many flowering plants, including a large proportion of global food crops. They play a crucial role in enhancing crop quality and yield by facilitating the transfer of pollen, which is essential for fruit set and seed production. The most well-known pollinators are bees, particularly the European honeybee (*Apis mellifera*), which is used globally for the pollination of a wide range of crops such as almonds, apples, and berries. Their presence enhances agroecosystems' overall biodiversity and ecological resilience.

In a comparable direction, flies (Diptera), especially hoverflies (Syrphidae), have been identified as efficient pollinators of numerous crops, such as onions, carrots, and a variety of blooming plants.

Flies can be particularly significant in areas where bee populations are dropping because of their versatility (Patrício-Roberto and Campos, 2014). Plant diversity in agricultural settings can benefit bees and other pollinators by increasing the availability and continuity of floral supplies, according to Nicholls *et al.* (2012). Additionally, they emphasized pesticide exposure, monoculture, and habitat destruction as significant stresses on pollinator populations. Crucially, insects that are not bees should not be disregarded. In their analysis of pollination by non-bee insects, Rader *et al.* (2020) found that flies, beetles, butterflies, moths, wasps, and other insect species visit a variety of crops. When bee abundance is restricted, their contribution may be very significant.

Soil Engineers and Decomposers: By breaking down organic matter and promoting nutrient cycling, soil-dwelling insects often referred to as soil engineers and decomposers play a critical role in preserving soil fertility and health. These include termites (Isoptera), ants (Formicidae), and beetles (Coleoptera), all of which aid in the aeration of soil, the breakdown of plant wastes, and the improvement of soil structure (Culliney, 2013). Dung beetles (Scarabaeidae) are particularly important for breaking down animal feces, which recycles nutrients back into the soil, enhances soil fertility, and reduces the spread of pests and diseases associated with livestock waste. Ants, due to their complex nesting and foraging behaviors, contribute to soil aeration and nutrient distribution, which improves water infiltration and root growth. Their activities help create soil microhabitats that promote microbial activity and the establishment of beneficial soil organisms. Insects that live in the soil support a healthy soil ecosystem, which is necessary for crop production that is sustainable. In line with the objectives of sustainable agriculture, these insects promote plant development and lessen the need for artificial fertilizers by enhancing soil structure and nutrient availability. They are essential parts of agroecosystems because of their ability to improve soil health, which promotes both immediate productivity and long-term sustainability.

Table 1: Important Beneficial Insects Reported from Telangana Regions

Functional Group	**Beneficial Insects group**	**Quantitative evidence**	**References**
Predators	Coccinellidae, Chrysopidae, Miridae, predatory Hemiptera, Mantodea, predatory Diptera	15 insect-predator species in maize; 920 predators from 14 families in rice	Mallesh (2023)
Parasitoids	Braconidae, Eulophidae, Platygastridae and other Hymenoptera	3,587 parasitoid individuals from 15 families in rice; Eulophidae 53.28%	Chaitanya *et al.* (2024)
Pollinators	Bees and other flower-visiting insects	Dedicated cucumber pollinator-diversity study conducted at Rajendranagar, Hyderabad	Teena *et al.* (2024)
Spiders associated with beneficial arthropod fauna	Araneidae and other predatory spiders	276 spiders recorded in maize ecosystems, including two species in the reported dataset	Mallesh (2023)

Role of Beneficial Insects:

Agroecosystem Stability: The presence of a diverse range of beneficial insects increases the stability and resilience of agroecosystems. By providing a range of ecosystem services, including as pollination, pest management, and soil health maintenance, beneficial insects enhance the complexity and effectiveness of agricultural landscapes. As a result, the landscapes are less vulnerable to environmental stressors and insect outbreaks. For example, it has been shown that farms with a range of natural enemies, such as predatory beetles and parasitoid wasps, have more consistent pest suppression and fewer pest outbreaks than farms that solely use chemical control. Diverse insect populations contribute to the stability of agroecosystems by promoting functional redundancy, in which multiple species perform similar functions within the ecosystem.

Biological Control of Agricultural Pests: Among the most significant beneficial insects for crop protection are natural enemies. Without direct human involvement, predators and parasitoids can lower pest abundance by attacking pests at various phases of life. There are three types of biological control: conservation, augmentative, and classical. Because conservation biological control concentrates on improving and safeguarding naturally occurring natural enemies, it is particularly pertinent to agricultural environments. Through direct ingestion or parasitism, predators and parasitoids can reduce pests; nevertheless, their efficacy is dependent on the larger ecological context. Natural enemies may be disproportionately impacted by agricultural intensification because they may be more vulnerable to habitat disruption than some pest species. Dainese *et al.* (2019) discovered a positive correlation between biological pest control and natural-enemy richness. According to their findings, the sustainability of pest-control services depends on the maintenance of various natural-enemy communities. The significance of preserving semi-natural habitat in agricultural landscapes was further supported by Rusch *et al.* (2016), who demonstrated that landscape simplification can lessen natural pest control.

Enhance Agricultural Production: Beneficial insects, especially pollinators and natural enemies of pests, have a direct and measurable impact on crop yields and quality. Pollinators such as bees, butterflies, and hoverflies are responsible for the pollination of approximately 75% of globally important food crops, contributing significantly to the quantity and quality of fruits, vegetables, and nuts. Studies indicate that crops such as almonds, apples, and blueberries exhibit increased fruit set and improved quality when pollinated by a diverse community of wild and managed pollinators (Nicholson and Ricketts, 2019).

Reduce Agrochemical Uses: Beneficial insects like pollinators, parasitoids, and predators greatly lessen the need for chemical inputs in agriculture, especially pesticides, which are frequently employed for pest control. These insects naturally reduce pest populations by feeding on or parasitizing dangerous pests, offering a sustainable substitute for chemical pest control methods. For instance, it has been demonstrated that lady beetles (Coccinellidae) and predatory lacewing beetles (Carabidae) manage aphid, mite, and caterpillar populations, reducing the need for insecticides. In a similar vein, parasitoid wasps like *Aphidius colem*ani are often employed in greenhouses to control aphid infestations, successfully lowering chemical treatments and related expenses. This reduction not only mitigates the risk of pesticide residues in food but also supports healthier agroecosystems that are more resilient to pest outbreaks. The presence of pollinators such as bees and butterflies can indirectly reduce the need for chemical inputs by promoting plant health and vigor, making plants less susceptible to diseases and pests. Enhanced pollination leads to more robust plant growth and improved resilience against biotic and abiotic stressors, further contributing to reduced dependency on chemical treatments.

Agricultural Landscape Structure and Beneficial Insects:

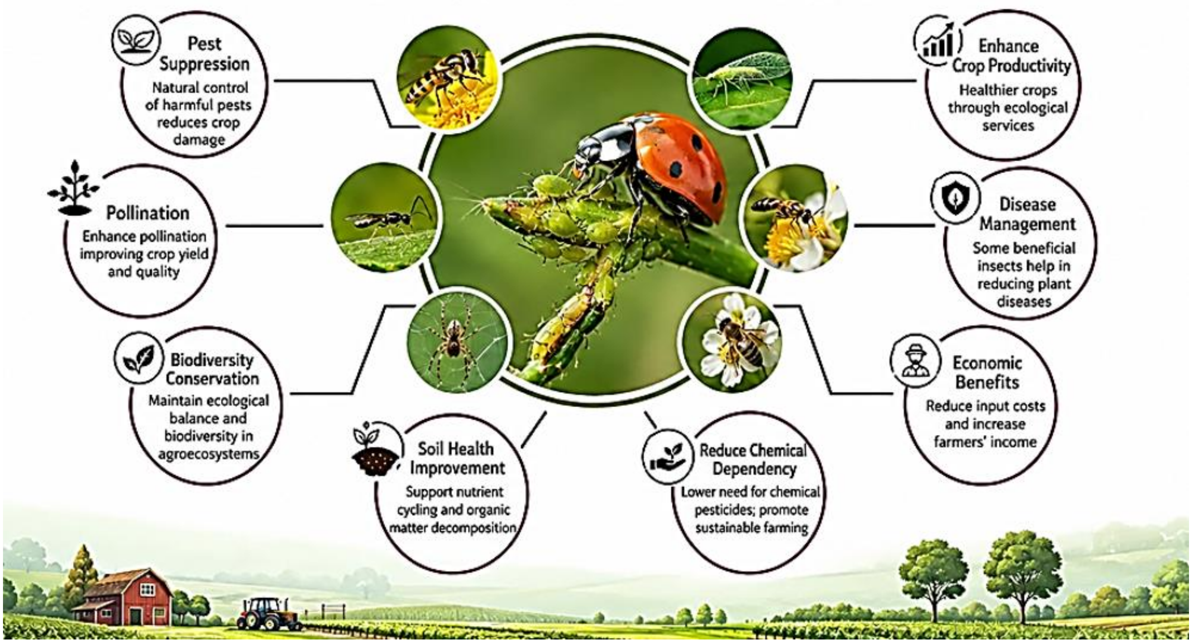
Landscape structure strongly influences beneficial insects because many species use resources outside crop fields during different stages of their life cycle. Crops may provide abundant food for a short period, whereas semi-natural habitats can provide resources before and after crop flowering or pest availability. Important landscape elements include:

- Hedgerows
- Flower strips
- Grasslands
- Forest patches
- Agroforestry systems
- Field margins
- Riparian vegetation
- Cover crops
- Uncultivated areas
- Diverse home gardens
- Vegetation around irrigation channels

These habitats can provide nectar, pollen, alternative prey, nesting sites, shelter, overwintering locations, and favorable microclimates. Flower strips are increasingly used as a conservation tool. They provide floral resources and habitat within or adjacent to agricultural fields. The effectiveness of flower strips depends on plant species composition, flowering duration, strip size, management, pesticide exposure, and landscape context. Agroforestry combines trees with crops and/or livestock and can create structurally diverse agricultural landscapes. Trees provide nesting and shelter resources, moderate microclimates, and support a wider range of insects than simplified crop systems. Similarly, Sutter *et al.* (2018) found that in oilseed rape fields, increasing landscape-scale greening initiatives led to an increase in insect-mediated pollination and pest predation. However, more crop services are not a given just because flowers are planted. Local pollinator communities, flowering times, resource quality, and the potential to unintentionally support pests should all be taken into account when choosing a plant. Therefore, ecological knowledge is essential for managing habitats. According to a recent synthesis, agroforestry may help pollination more successfully than simplified agricultural systems and can lessen some of the detrimental effects of traditional agriculture on pollination (Centeno-Alvarado *et al.*, 2023). In areas where farms must concurrently produce crops, preserve biodiversity, lessen erosion, and increase climate resilience, the advantages of agroforestry are especially pertinent.

Emerging Technologies and Beneficial-Insect Conservation:

In agricultural environments, new digital technologies are opening up new possibilities for beneficial insect monitoring and conservation. The detection, identification, and long-term evaluation of insect populations can be enhanced by computer vision, artificial intelligence (AI), automated sensors, acoustic monitoring, radar, molecular techniques, and Internet-of-things (IoT) platforms. While machine-learning algorithms can help detect pollinators and natural enemies in addition to pest species, computer vision systems can analyze photos from smart traps and identify insect taxa. By continuously providing information on insect activity, abundance, and seasonal variations, automated monitoring can minimize the labor-intensive nature of traditional field sampling. In order to increase the geographical, temporal, and taxonomic coverage of insect monitoring, Van Klink *et al.* (2022) identified computer vision, auditory monitoring, radar, and molecular techniques as suitable technologies. IoT-connected sensors in agricultural systems can provide environmental data and insect observations to cloud platforms, enabling real-time evaluation of beneficial insect populations and habitat quality. Farmers can use this information to assess conservation efforts, make the best pesticide choices, and pinpoint places that need habitat repair.



Conclusion:

Beneficial insects are becoming more widely acknowledged and studied in relation to sustainable agriculture. These insects greatly increase agricultural productivity and environmental resilience by acting as organic matter recyclers, pollinators, and natural pest control agents.

In order to encourage wider adoption, future approaches should concentrate on integrating pollinator and pest management, utilizing cutting-edge technologies for monitoring and control, and putting supportive legislation and education into place. The conservation of beneficial insects therefore requires coordinated management at field, farm, and landscape scale. Future agriculture should acknowledge helpful insects as biological infrastructure. Artificial intelligence, automated insect monitoring, remote sensing, precision agriculture, and ecological modeling can all help improve their management. Protecting beneficial insects is not only a biodiversity goal but, it is also an investment in pollination, pest management, crop resilience, environmental sustainability and long-term food security.

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