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Natural Enemies as Guardians of Crop Ecosystem with Special Emphasis on Rice and Cotton

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Authors' contributions

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

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ABSTRACT

Natural enemies, including predators, parasitoids, and pathogens, play a crucial role in the regulation of pest populations within agricultural ecosystems. This review examines the role of these biological control agents in maintaining the health and productivity of crop systems, with a specific focus on rice and cotton. In rice ecosystems, natural enemies such as spiders, dragonflies, and various insect parasitoids help manage pest populations like the rice stem borer and the planthopper. Similarly, in cotton crops, natural predators and parasitoids contribute to the control of key pests including the cotton bollworm and aphids. By integrating these natural enemies into pest management strategies, farmers can reduce reliance on chemical pesticides, enhance biodiversity, and promote sustainable agriculture. This review highlights the mechanisms through which these

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natural enemies operate, the benefits they provide to crop ecosystems, and case studies illustrating successful applications. The major emphasis is placed on understanding the interactions between these biological control agents and their environments, and how these relationships can be optimized to support resilient crop production systems and to manage these pests in cotton and rice crops.

Keywords: Biological control; natural enemies; pest management; rice ecosystem; cotton crop protection; predators; parasitoids; sustainable agriculture.

1. INTRODUCTION

Nowadays, the primary motivations for exploring non-chemical pest control methods are concerns about the environmental and health risks associated with pesticides [1]. However, with the increase in pesticide resistance, rising costs of pesticides, and the challenges in developing new, effective pesticides, the agricultural sector is increasingly signaling a shift towards biologically based pest control methods [2]. One effective alternative to chemical control is biological control, which involves utilizing natural enemies to manage pests, diseases, and weeds. The development of biological control was predicated on several key advancements and insights. Firstly, it required the acceptance that insects do not appear spontaneously, and secondly, an understanding of predation, which was documented in Chinese literature over 2,500 years ago, was essential. Additionally, the interpretation of parasitic insect behavior also plays a crucial role. Furthermore, recognition of the infection process by pathogens contributed to this development. By the 18th century, the idea of using natural enemies to manage pests had evolved. In 1800, Erasmus Darwin highlighted the beneficial role of parasitoids and predators in controlling insect pest populations. With this point of view, this review tries to give a review of natural enemies as guardians of crop ecosystems especially of rice and cotton.

1.1 Biological Control: Strategies

Natural enemies can be utilized through various release strategies, including the following:

(i) **The inoculative release method**: It is also referred to as "classical" biological control or importation, involves collecting beneficial organisms from one region and introducing them into an area where a pest problem exists. This method typically involves releasing a relatively small number of these beneficial organisms to achieve long-term pest control.

(ii) **The inundative release method**: It involves collecting and mass-rearing beneficial organisms, which are then released in large quantities to achieve immediate pest control. This approach functions similarly to a biotic insecticide, where the primary control comes from the released natural enemies rather than their offspring. Inundative releases are used in crops where maintaining viable breeding populations of the natural enemy is impractical or where rapid control is needed early in the infestation due to a low damage threshold.

(iii) **Conservation of natural enemies:** This involves modifying the environment to enhance the effectiveness of already established beneficial organisms. This can be achieved through (i) Provision of missing or inadequate resources such as alternative hosts, supplementary food, or shelter. For example, placing alternative food sources like eggs of *Ephestia kuehniella* Zeller for the nymphs and adults of the predatory bug *Macrolophus caliginosus* Wagner can sustain the predator when its preferred prey, whiteflies, are not available. (ii) Elimination or mitigation of hazards and adverse environmental factors, such as wrong cultural practices, indiscriminate use of insecticides, and other detrimental physical or biotic factors, to improve the survival and effectiveness of natural enemies. (iii) Habitat manipulation could be an effective strategy, involving modifications to the cropping system to enhance or support the natural enemies of pests. By adjusting the agricultural environment to favour these beneficial organisms, such as providing shelter, alternative food sources, or conducive conditions, farmers can boost the effectiveness of natural pest control. This approach helps sustain and increase populations of natural enemies, ultimately contributing to more effective and sustainable pest management.

An often-ignored aspect of biological control is natural control. Many potential pest organisms are kept at levels well below damage thresholds by the natural enemies present in the field. In natural ecosystems, a diverse array of natural enemy species helps maintain plant-eating insects at low population densities. Even within agroecosystems, many potential pests are kept in check at non-damaging levels by the naturally occurring beneficial organisms. According to DeBach and Rosen [3], over 90% of all agricultural pest species are regulated by natural control mechanisms. However, Integrated Pest Management (IPM) programs that rely heavily on biological control offer significant advantages for agriculture, rural quality of life, and consumer health. By reducing the need for insecticides, acaricides, and herbicides, farmers can lower production costs and move towards more sustainable agricultural practices. This reduction in pesticide use also benefits rural communities by decreasing contamination of ground and surface water, minimizing impacts on non-target species, and enhancing the safety of farm workers. In India, numerous parasitoids and predators have been identified, evaluated, and recommended for field releases to combat agricultural pests [4]. Technologies for the production and application of these biological control agents are well-established [4,5]. The country has several success stories in the field of biological pest suppression, demonstrating the effective use of these natural enemies to manage crop pests [6]. However, developing countries stand to increase significantly from the development, utilization, and expansion of parasitoids and predators for pest management. The beneficial insects were best exploited in India for some such as rice, cotton, citrus, and several other crops [6,7].

2. PREDATORS

Insect predators are crucial for managing pest populations and ensuring the health of major crops such as rice and cotton in India. Predatory spiders like *Oxyopes cutis*, Koch are key in managing rice pests, which helps reduce reliance on chemical pesticides and supports sustainable farming practices [8,9]. Similarly, in cotton farming, biological control agents like coccinellids and green lacewings, *Chrysoperla carnea* are essential for controlling pests like the cotton bollworm (*Helicoverpa armigera*) and aphids (*Aphis gossypii* Glover) [10,11]. These predators effectively manage pest populations and lessen farmers' financial burden by decreasing the need for expensive chemical treatments [12,13]. The presence of insect predators also contributes significantly to biodiversity and ecosystem balance by preventing any single pest species from dominating and causing ecological disruption [14,15]. Furthermore, their role in reducing chemical pesticide use supported both environmental and human health by minimizing risks associated with chemical exposure [16,17]. By supporting natural pest control mechanisms, insect predators help conserve natural resources and maintain ecological integrity, making them an integral component of sustainable agricultural practices in India [18,19]. Overall, the use of insect predators underscores their importance in enhancing crop protection, economic stability, and environmental sustainability in rice and cotton farming. In India, numerous predators have been identified as potential biocontrol agents. For example, over 60 arthropod species are known to prey on *Helicoverpa armigera* (Hübner). Among the key predators of this pest are chrysopids, anthocorids, ants, coccinellids, and spiders [20,21,22]. However, important indigenous coccinellids in India include *Coccinella septempunctata* Linnaeus, *Scymnus coccivora* Ayyar, *Chilocorus nigrita* Fabricius, *Cheilomenes sexmaculata* (Fabricius), and *Brumoides suturalis* Fabricius. Among syrphids, notable species are *Ischiodon scutellaris* (Fabricius), *Paragus serratus* (Fabricius), and *Paragus yerburiensis* Stuckenberg. The *C. sexmaculata* play significant roles in controlling pest populations such as *Aphis gossypii* [11] and *Bemisia tabaci* [23] *Scymnus coccivora* on *Phenacoccus solenopsis* [24] in the cotton ecosystem. *C. nigrita* has been utilized through inundative release not only against *Melanaspis glomerata* (Green) but also against various other diaspine scales, including the red scale of citrus [25]. Other significant coccinellids in this context are *Pharoscymnus horni* (Weise) and *Scymnus coccivora*. These species play a crucial supportive role for the major coccinellids *C. nigrita* and *Cryptolaemus montrouzieri*, respectively, in different fruit crops. Due to their small size, *P. horni* and *S. coccivora* can access leaf sheaths and bark crevices, where they feed on the crawlers of coccids at the early stages of crop infestation [26]. The coccinellid predator *C. montrouzieri*, although exotic, has established itself well and has proven to be highly effective against the grape mealybug, *Maconellicoccus hirsutus* [27].

3. PARASITOIDS

Parasitoids play a crucial role in the management of pests in agricultural systems, particularly in rice and cotton cultivation. In rice fields, parasitoids such as *Anagrus nilaparvatae* have been instrumental in controlling the brown planthopper (*Nilaparvata lugens*), which is a significant pest affecting rice productivity [28]. Similarly, *Tetrastichus japonicus* has been used effectively against the rice stem borer (*Scirpophaga incertulas*), contributing to a balanced ecosystem and reducing the reliance on chemical pesticides [29]. This approach line up with sustainable agricultural practices by mitigating the adverse effects of chemical insecticides [30]. In cotton cultivation, parasitoids like *Trichogramma* spp. target the eggs of the cotton bollworm (*Helicoverpa armigera*), significantly reducing pest populations and promoting higher yields and better-quality cotton [31]. Moreover, *Aphidius colemani* is employed to manage cotton aphids (*A. gossypii*), further decreasing the necessity for chemical controls and enhancing crop health [32]. The integration of these biological control agents not only supports pest management but also aids in maintaining ecological balance and promoting sustainable farming practices [33]. Studies have consistently shown that effective parasitoid management can lead to substantial reductions in pest populations and decreased pesticide use, benefiting both crop yield and environmental health [28,29,30,31,32,33]. The role of parasitoids in agriculture is underscored by their ability to control pests naturally, thus contributing to more resilient and sustainable agricultural systems [34-36].

4. EFFICACY OF PREDATORS AND PARASITOIDS IN RICE

In rice cultivation, predation and parasitism significantly influence pest populations and contribute to integrated pest management strategies. Predation by natural enemies such as spiders, beetles, and ants has been shown to play a crucial role in controlling rice pests. For instance, Heong and Schoenly [30] demonstrated that these predators can reduce pest populations by 40-50%, particularly targeting pests like the brown planthopper (BPH) (*N. lugens*) and the green leafhopper (*Nephotettix virescens*). Additionally, the effectiveness of predation in reducing pest densities, emphasizes that diverse predator populations are vital for maintaining pest control in rice fields [37]. Parasitism is another critical factor in managing rice pests. The egg parasitoid *Anagrus nilaparvatae* has been observed to parasitize up to 70% of BPH under favorable conditions [28] Similarly, the effectiveness of the larval parasitoid *Tetrastichus japonicus*, which can achieve parasitism rates of 30-50% for the rice stem borer (*Scirpophaga incertulas*) [29]. Further, it has been emphasized that integrating natural enemies, including both predators and parasitoids, into pest management programs can significantly reduce the need for chemical pesticides, achieving up to 60% reductions in pest densities [38]. Field observations also confirmed these findings, showing that a well-balanced ecosystem with high natural enemy diversity can lead to reductions in pest populations by 50-70% [39]. Overall, the combined effects of predation and parasitism underscore the importance of utilizing biological control methods to manage rice pests sustainably and effectively.

Table 1. List of some natural enemies recommendation in rice

Natural Enemy	Target Pests	Recommended Numbers	References
Nesidiocoris tenuis (Predatory bug)	*Nilaparvata lugens* (BPH)	1-2 predators per square meter	[40-42]
Trichogramma japonicum (Trichogrammatidae)	*Scirpophaga incertulas* (Yellow stem borer)	50,000-100,000 parasitoids per hectare	[43-46]
Tetrastichus sp. (Eulophidae)	*Schoenobius giganteus* (Rice gall midge)	15,000-20,000 parasitoids per hectare	[45,46,47]
Opius spp. (Braconidae)	*Chilo suppressalis* (Leaf folder)	1-2 parasitoids per plant	[48,49]
Nephotettix virescens (Green leafhopper)	*Nephotettix* spp. (Leafhoppers)	Release natural enemies as needed to suppress the population	[50,51]

Table 2. Efficacy of natural enemies of rice pests in rice ecosystem

Pest	Predation Rate (%)	Parasitisation Rate (%)	Natural Enemies	References
Brown Planthopper	10-30%	15-25%	Predators: *Chrysoperla carnea, Coccinella septempunctata* *Parasitoids: Xanthopimpla stemmator, Anagrus nilaparvatae*	[52]
Rice Stem Borer	25-40%	20-35%	Predators: Praying mantids, Spiders Parasitoids: *Cotesia flavipes, Trichogramma japonicum*	[53,54]
Rice Leaf Folder	15-25%	10-20%	Predators: Ladybird beetles, Lacewings Parasitoids: *Neochrysocharis formosa, Apanteles ruficrus* Parasitoids: *Chrysonotomyia* sp. *Tetrastichus schoenobii*	[55,56]

5. EFFICACY OF PREDATORS AND PARASITOIDS IN COTTON

In the management of cotton pests, biological control methods, particularly predation and parasitism, play crucial roles in reducing pest populations and minimizing reliance on chemical pesticides. Predators, such as lady beetles, lacewings, and spiders, are essential in this ecological control. Lady beetles, like *Hippodamia convergens, C. septempunctata*, and *C. sexmaculata* are effective against aphids and other soft-bodied pests, with some species capable of consuming up to 50 aphids/day [57]. Lacewing larvae, especially those from the *Chrysoperla* genus, prey on a variety of pests including aphids, thrips, and whiteflies, significantly impacting pest densities [58]. Spiders, which are generalist predators, help control diverse pest species, including moths and beetles, by capturing them in their webs [59]. However, Parasitoid wasps, such as *Trichogramma* spp. and *Encarsia formosa*, target pests like cotton bollworms (*H. armigera*) and whiteflies (*B. tabaci*). *Trichogramma* wasps parasitize the eggs of bollworms, preventing them from hatching, while *Encarsia* wasps parasitize whitefly eggs, disrupting their development and reducing infestations [60,61]. Tachinid flies, which lay their eggs on or in their lepidopteran hosts, are another crucial biological control agent. The larvae feed on and eventually kill the host, reducing pest populations [62]. The integration of these natural enemies into Integrated Pest Management (IPM) strategies enhances ecological balance and provides sustainable pest control solutions. IPM involves monitoring pest populations, understanding pests' and natural enemies' life cycles, and strategically employing biological control agents to manage pest outbreaks effectively [63]. Through these methods, cotton farmers can achieve effective pest control while minimizing environmental impacts and chemical use.

Table 3. List of some natural enemies recommendation in cotton

Natural Enemy	Target Pests	Recommended Dose	References
Parasitoid wasp, *Trichogramma chilonis*	*Helicoverpa armigera* (Cotton bollworm)	100,000-150,000 parasitoids per hectare	[64,65,66]
Parasitoid wasp, *Eretmocerus* spp.	*Bemisia tabaci* (Whitefly)	10,000-20,000 parasitoids per hectare	[67,68,69]
Parasitoid wasp, *Encarsia formosa*	*Bemisia tabaci* (Whitefly)	5,000-10,000 parasitoids per hectare	[70,71,72]
Green lacewing, *Chrysoperla carnea*	*Aphids* and *Thrips*	2,000-5,000 larvae per hectare	[73,74,75]
Predatory mite, *Amblyseius* spp.	*Tetranychus urticae* (Spider mite)	1,000-2,000 mites per hectare	[71,76,77]
Predatory mite, *Phytoseiulus persimilis*	*Tetranychus urticae* (Spider mite)	1,500-3,000 mites per hectare	[66,71,78]

Table 4. Efficacy of natural enemies of cotton pests in cotton ecosystem

Natural Enemy	Target Pests	Efficacy	References
Lady Beetles (*H. convergens*, *C. septempunctata*)	Aphids, scale insects	Up to 80% reduction in aphid populations.	[57]
Lacewings (*C. carnea*, *Chrysopa* spp.)	Aphids, thrips, whiteflies	Can reduce aphid populations by 50-90%.	[58]
Spiders	Various insects, including moths and beetles	Can contribute to up to 40% reduction in pest populations.	[59]
Predatory Bugs (*Geocoris punctipes*, *Orius* spp.)	Thrips, spider mites, small beetles	Effective against thrips with up to 70% reduction.	[79]
Hoverflies (Syrphids)	Aphids, small insects	Larvae can reduce aphid populations by up to 80%.	[80]
Parasitic Wasps (*Trichogramma* spp.)	Cotton bollworms (*Helicoverpa armigera*)	Can achieve up to 90% parasitism of bollworm eggs.	[60]
Parasitic Wasps (*Encarsia formosa*)	Whiteflies (*Bemisia tabaci*)	Can achieve up to 85% control of whitefly populations.	[61]
Tachinid Flies (*Hemyda* spp., *Eutrichoidea* spp.)	Cotton bollworms (*H. armigera*)	Effective with up to 60-80% reduction in bollworm populations.	[62]
Braconid Wasps (*Microplitis croceipes*)	Cotton bollworms (*H. armigera*)	Can reduce caterpillar populations by up to 75%.	[81]
Ichneumon Wasps (*Ichneumonidae* family)	Various lepidopteran pests	Can achieve up to 70% reduction in lepidopteran pest populations.	[82]
Damsel Bugs (*Nabis* spp.)	Thrips, aphids, mites	Effective with up to 60% reduction in thrips and aphids.	[83]
Minute Pirate Bugs (*Orius insidiosus*)	Thrips, spider mites	Can reduce thrip populations by up to 80%.	[84]
Green Lacewings (*Chrysoperla* spp.)	Aphids, mealybugs, whiteflies	Effective with up to 85% reduction in aphid populations.	[85]
Praying Mantises (*Mantodea*)	Various insects, including pests like moths and beetles	Can reduce pest populations by up to 50%.	[86]
Rove Beetles (Staphylinidae family)	Various insects, including mites and aphids	Can reduce mite and aphid populations by up to 60%.	[87]

Table 5. List of some natural enemies in some important crops

Crop	Natural Enemies	Type	Target Pests	References
Grapes	*C. montrouzieri*	Predator	*Maconellicoccus hirsutus* (Grape mealybug)	[88,89,90]
	Scymnus spp.	Predator	Scales, aphids	
	Anagyrus pseudococci	Parasitoid	Mealybugs (*Planococcus ficus*)	
Tomato	*P. persimilis*	Predator	*Tetranychus urticae* (Spider mites)	[71,91,92]
	C. septempunctata	Predator	Aphids	[4,71,92]
	Encarsia formosa	Parasitoid	Whiteflies (*B. tabaci*)	
Apple	*C. carnea*	Predator	Aphids, caterpillars	[70,93,94]
	C. septempunctata	Predator	Aphids	
	Aphidius colemani	Parasitoid	Apple aphid (*Aphis pomi*)	
Peanuts	*C. septempunctata*	Predator	Aphids, soft-bodied pests	[4,95,96]
	Syrphid flies	Predator	Aphids	
	Trichogramma spp.	Parasitoid	*Spodoptera litura* (Lepidopteran pests)	
Beans	*Phytoseiulus persimilis*	Predator	*Tetranychus* spp. (Spider mites)	[4,97,98]
	Coccinella septempunctata	Predator	Aphids	
	Bracon spp.	Parasitoid	*Helicoverpa armigera* (Lepidopteran pests)	
Corn	*Orius* spp.	Predator	Thrips	[4,99,100]
	C. septempunctata	Predator	Aphids	
	Trichogramma spp.	Parasitoid	*Ostrinia nubilalis* (European corn borer)	

6. CONSERVATION OF NATURAL ENEMIES

Conserving natural enemies in rice and cotton cultivation is crucial for effective pest management and minimizing chemical pesticide use [101,102]. In rice farming, habitat management practices, such as planting cover crops and flowering plants around fields, support beneficial insects like dragonflies, damselflies, and spiders, which prey on pests [103,104,105]. Non-tillage practices and careful water management can further help preserve these natural enemies by maintaining their habitats and reducing disturbances [104,106]. Similarly, in cotton cultivation, implementing Integrated Pest Management (IPM) strategies is essential for supporting natural enemy populations and includes practices such as selective pesticide use, habitat enhancement through cover crops, and avoiding broad-spectrum pesticides [101,107,108]. Protecting natural enemies involves providing refuge areas and educating farmers on the benefits of these beneficial organisms [101,109,110]. These practices not only improve pest control efficacy but also promote ecological balance and reduce the environmental impact of pest management strategies [70,102,111].

7. CONCLUSIONS

In conclusion, natural enemies play a crucial role as guardians of crop ecosystems, particularly in rice and cotton farming, by maintaining ecological balance and providing effective pest control. These beneficial organisms, including predators, parasitoids, and pathogens, contribute significantly to pest regulation, reducing the need for chemical pesticides and supporting sustainable agricultural practices. In rice cultivation, the presence of natural enemies such as dragonflies and spiders helps manage pest populations and promotes ecosystem health. Similarly, in cotton farming, natural enemies like lacewings and ladybugs contribute to controlling pests and enhancing crop resilience. By fostering environments that support these natural predators, such as through habitat management and the implementation of Integrated Pest Management (IPM) strategies, farmers can enhance crop protection while minimizing environmental impact. Emphasizing the role of natural enemies not only improves the effectiveness of pest control but also supports biodiversity, soil health, and overall sustainability in agricultural systems. Thus, integrating natural enemies into pest management practices represents a holistic approach to safeguarding crop ecosystems and achieving long-term agricultural sustainability.

8. FUTURE THRUSTS

- ❖ **Integrated Pest Management (IPM) strategies:** Future research should focus on developing more refined and region-specific IPM strategies that synergistically incorporate natural enemies. This includes optimizing the timing and methods of releasing biological control agents and integrating them with other pest management techniques, such as resistant crop varieties and cultural practices.
- ❖ **Enhancement of natural enemy efficacy:** Investigating the factors that influence the effectiveness of natural enemies in rice and cotton ecosystems is crucial. This involves exploring the role of habitat management, such as the use of cover crops and conservation tillage, in enhancing the abundance and effectiveness of natural enemies.
- ❖ **Genetic improvement and biocontrol agents:** Advances in genetic engineering and biotechnology can be leveraged to develop natural enemies with enhanced traits, such as increased resilience to environmental stressors or improved predation rates. Research should focus on the safe and effective deployment of genetically improved biocontrol agents.
- ❖ **Impact of climate change:** Understanding how climate change affects the interactions between natural enemies and their prey is essential. Future research should assess how shifts in temperature, humidity, and other climatic factors impact the efficacy of biological control agents and the dynamics of pest populations.
- ❖ **Ecosystem services and biodiversity:** The role of natural enemies in providing broader ecosystem services, such as pollination and soil health, should be explored. Enhancing biodiversity in rice and cotton cropping systems can improve the resilience of these ecosystems and support the sustainability of natural pest control.

9. GAPS IN KNOWLEDGE

- ➢ **Incomplete understanding of natural enemy interactions:** There is a need for more detailed studies on the interactions between different natural enemies and their prey, as well as among various natural enemy species. This includes understanding their niche requirements, competitive interactions, and the impact of interspecific relationships on pest control efficacy.

- **Lack of long-term data:** There is a paucity of long-term studies that track the effectiveness of natural enemies over multiple growing seasons. Long-term data is essential to understand the sustainability and adaptability of biological control methods in changing environmental conditions.
- **Inadequate models for predicting outcomes:** Predictive models that incorporate natural enemies and their interactions with pests are underdeveloped. Improved modeling tools are needed to forecast the outcomes of biological control interventions under varying conditions and to guide decision-making.
- **Socioeconomic considerations:** The socioeconomic aspects of implementing biological control in rice and cotton farming systems are not well-explored. Research should address the economic feasibility, farmer acceptance, and potential barriers to adopting biological control practices.

Addressing these future thrusts and filling these gaps in knowledge will be crucial for advancing the use of natural enemies in sustainable crop protection strategies for rice and cotton.

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 manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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