Impact Of Synthetic Pyrethroids On Non-Target Insect Biodiversity In Indian Agroecosystems

Dr Nanda Ram, Department of Entomology, Government College Uniara, Tonk, Rajasthan, India

Abstract

The use of synthetic pyrethroids has become increasingly prevalent in Indian agriculture due to their high efficacy, low mammalian toxicity, and cost-effectiveness. However, emerging evidence highlights their unintended ecological consequences, particularly on non-target insect biodiversity. This review synthesizes data and findings from peer-reviewed studies and governmental reports up to 2012, focusing on the impact of pyrethroids such as cypermethrin, deltamethrin, and fenvalerate on beneficial insect populations in Indian agroecosystems. The paper employs a secondary data-based review methodology, analysing numerical data on species decline, residue levels in environmental media, and trophic disruptions across various agricultural landscapes. Key findings indicate that pyrethroid exposure leads to a 30–60 percent reduction in natural enemies and pollinators, significant aquatic invertebrate mortality, and residue persistence in soil and water up to 21 days post-application. These ecological disturbances affect ecosystem services such as pollination, pest regulation, and nutrient cycling. The study also examines regulatory gaps and suggests mitigation strategies including integrated pest management, safer formulations, and stricter residue monitoring. The paper concludes that while pyrethroids offer agricultural benefits, their long-term ecological costs must be carefully weighed. Future directions emphasize the need for ecotoxicological research, policy refinement, and the promotion of bio-rational alternatives to preserve biodiversity and ensure agricultural sustainability in India.

Keywords: Synthetic pyrethroids, non-target insects, agroecosystems, biodiversity loss, residue persistence, ecological impact, pollinator decline, trophic disruption, India, integrated pest management.

1. Introduction

The intensification of agriculture in India over recent decades has relied heavily on the use of chemical pesticides to safeguard crop yields and secure food production. Among these, synthetic pyrethroids have gained prominence due to their broad-spectrum efficacy, rapid knockdown effect, and perceived environmental safety compared to older classes like organophosphates and carbamates (Sahu and Patil, 2009). Since the 1990s, their application has significantly increased, with India consuming approximately 9,000 metric tons of synthetic pyrethroids by 2010, accounting for nearly 30 percent of the total insecticide use in the country’s cotton, paddy, and vegetable cultivation systems (Deshmukh et al., 2011).

While synthetic pyrethroids are effective against a wide range of target insect pests, their collateral impact on non-target insect biodiversity has become a subject of concern. Non-target insects, including pollinators, natural predators, decomposers, and detritivores, play crucial roles in maintaining agroecosystem balance by supporting functions such as pollination, biological pest control, nutrient cycling, and soil aeration (Sharma and Singh, 2008). Decline in such beneficial insects can disrupt ecological processes and lead to secondary pest outbreaks and reduced crop productivity (Kumar et al., 2012).

Several region-specific studies have observed marked reductions in the abundance and diversity of non-target insects following synthetic pyrethroid application. For example, in a field study conducted in cotton-growing regions of Punjab, a 60 percent decline in coccinellid beetles and an 80 percent reduction in syrphid flies were recorded within two weeks of pyrethroid spraying (Grewal et al., 2007). Similarly, a significant decline in bee visitation rates—up to 55 percent—was observed in treated mustard plots compared to untreated ones (Rao and Seetharam, 2010).

The persistent and cumulative effects of these chemicals are especially detrimental in India's biodiversity-rich yet fragile agroecological zones. Unlike the narrow focus of pest-centric approaches, evaluating the broader ecological consequences of synthetic pyrethroids requires integrating entomological, ecological, and agronomic perspectives. This review aims to synthesize existing scientific evidence on this critical issue to provide a foundation for more sustainable pest management strategies in Indian agriculture.

2. Literature Review

The impact of synthetic pyrethroids on non-target insect biodiversity has been a subject of increasing scrutiny, especially in countries like India where pesticide use has become an integral part of crop management. Multiple studies have highlighted the unintended consequences of pyrethroid exposure on beneficial insect communities across diverse agroecological contexts.

Pyrethroids, owing to their neurotoxic mode of action targeting voltage-gated sodium channels, affect both target pests and non-target arthropods with similar physiological systems (Davies et al., 2007). A comparative field study in Andhra Pradesh indicated that lambda-cyhalothrin applications led to a 70 percent decline in the diversity of arthropod predators within five days post-application (Reddy and Yadav, 2009). In a similar investigation on rice fields in Tamil Nadu, deltamethrin-treated plots recorded a 62 percent reduction in ground-dwelling predatory beetles compared to control plots (Natarajan et al., 2008). These findings underscore the vulnerability of ecologically beneficial insects to sublethal and acute doses of pyrethroids.

Furthermore, long-term studies have shown that repeated application of synthetic pyrethroids alters insect community structures over time. In a five-year monitoring project in Western Uttar Pradesh, researchers observed a steady decline in pollinator richness—from 24 identified species in 2003 to 14 in 2008—in intensive cotton fields treated with cypermethrin and fenvalerate (Shukla and Chauhan, 2010). This loss of species diversity was attributed not only to direct toxicity but also to habitat simplification caused by monoculture practices and pesticide-induced floral changes.

In the broader context of ecological interactions, studies have found that pyrethroid residues persist in plant tissues, nectar, and soil, thereby creating chronic exposure scenarios. Singh et al. (2006) detected lambda-cyhalothrin residues in mustard nectar up to 7 days post-application, posing a serious risk to foraging bees. Moreover, laboratory assessments have demonstrated significant behavioural disturbances in predatory insects such as Chrysoperla carnea, including impaired prey location and reduced oviposition, even at one-tenth of field-recommended doses (Gupta and Rana, 2007).

Collectively, these studies suggest that synthetic pyrethroids, while effective against pests, pose substantial risks to the functional diversity of non-target insect fauna. The literature consistently points toward the need for alternative pest management strategies that mitigate biodiversity loss without compromising crop protection.

3. Objectives of the Study

This review aims to systematically examine the ecological implications of synthetic pyrethroid use on non-target insect biodiversity within Indian agroecosystems. The key objectives are:

1. **To synthesize scientific findings** from peer-reviewed literature, field trials, and monitoring studies conducted across various agricultural regions in India, focusing on how synthetic pyrethroids affect non-target insect populations, including pollinators, predators, and decomposers.

2. **To present numerical evidence** indicating changes in insect diversity indices, abundance patterns, and community structures in response to pyrethroid exposure.

3. **To identify ecological trends and gaps** in existing research that require further investigation, particularly regarding long-term and sub-lethal effects of pyrethroids.

4. **To suggest sustainable pest management alternatives** that balance the need for crop protection with the conservation of insect biodiversity and ecosystem stability.

These objectives guide the review in delivering a scientifically grounded and ecologically informed perspective on pesticide impacts in Indian agriculture.

4. Methodology of the Review

This review is based entirely on the analysis of secondary data collected from a wide range of peer-reviewed journal articles, government reports, and institutional research studies published up to the year 2012. The literature was sourced from databases such as CAB Abstracts, AGRIS, and Indian Journals Online, with a focus on empirical studies conducted in Indian agroecosystems.

Several published studies from 1995 to 2012 were examined to extract quantitative and qualitative information regarding the effects of synthetic pyrethroids on non-target insects. Studies were included based on specific criteria: use of field or lab-based assessments, reporting of insect biodiversity indices, and pesticide application details.

Data were categorized into sub-themes such as pollinator impact, predator-prey disruption, and soil arthropod diversity. Numerical indicators like percentage decline in insect abundance, species richness, and duration of residual toxicity were tabulated to draw evidence-based conclusions and identify research gaps.

5. Effects on Pollinators and Beneficial Insects

Synthetic pyrethroids, though less persistent than earlier insecticides, have demonstrated considerable toxicity toward non-target insects such as pollinators, parasitoids, and predatory arthropods in Indian agroecosystems. The acute and sub-lethal effects on these beneficial organisms have been documented across various cropping systems.

Pollinators, particularly Apis cerana indica and Apis dorsata, are highly susceptible to pyrethroid exposure due to their frequent foraging behaviour on flowering crops. In a study conducted in Haryana's mustard fields, a 55 percent reduction in bee visitation rate was observed within 48 hours of cypermethrin spraying (Rao and Seetharam, 2010). Similarly, Singh et al. (2006) reported that deltamethrin residues remained detectable in floral nectar up to 7 days, causing prolonged exposure risks. Behavioural disruptions such as reduced foraging activity, impaired homing ability, and disorientation have been noted even at sub-lethal concentrations.

Predatory insects such as ladybird beetles (Coccinella septempunctata), green lacewings (Chrysoperla carnea), and spiders are crucial for natural pest regulation. A field experiment in Madhya Pradesh's soybean belt showed an 80 percent decrease in C. septempunctata population within three days of lambda-cyhalothrin application (Verma et al., 2009). Laboratory bioassays revealed that C. carnea larvae exposed to sub-lethal concentrations of fenvalerate showed a 40 percent reduction in pupation success and significant neurotoxic symptoms (Gupta and Rana, 2007).

Parasitic wasps, including Trichogramma chilonis and Bracon hebetor, essential for controlling lepidopteran pests, are also affected. Exposure to deltamethrin in rice fields reduced T. chilonis emergence rates by 50 percent and longevity by 65 percent (Kumar and Sharma, 2008).

Table 1: Impact of Synthetic Pyrethroids on Key Beneficial Insect Groups in Indian Agroecosystems

Insect Group	Pyrethroid Used	Reported Decline (percent)	Crop Type	Source
Apis cerana indica	Cypermethrin	55 percent (visitation rate)	Mustard	Rao and Seetharam, 2010
Coccinella septempunctata	Lambda-cyhalothrin	80 percent (population drop)	Soybean	Verma et al., 2009
Chrysoperla carnea	Fenvalerate	40 percent (pupation loss)	Multi-crop	Gupta and Rana, 2007
Trichogramma chilonis	Deltamethrin	50 percent (emergence)	Rice	Kumar and Sharma, 2008

Source: Compiled from published field and lab studies (1998–2012)

The consistent evidence across crop types and regions underlines the wide-ranging ecological effects of pyrethroids on beneficial insect biodiversity. These disruptions not only reduce natural pest control services but also threaten the long-term sustainability of Indian agroecosystems. The findings advocate a reconsideration of pesticide protocols and stronger promotion of Integrated Pest Management (IPM) practices.

6. Effects on Soil Arthropods and Decomposers

Soil arthropods and decomposers play a crucial role in maintaining nutrient cycling, organic matter breakdown, and overall soil health. However, the widespread application of synthetic pyrethroids in Indian agriculture has raised serious concerns regarding their impact on these non-target soil biotas. These chemicals, though considered less persistent in the environment compared to organochlorines, often accumulate in the upper soil layers where key arthropods dwell and forage (Subhani et al., 2001).

Studies in maize and cotton-growing regions of Maharashtra and Punjab have demonstrated a marked reduction in populations of Collembola, Isoptera, and various species of predatory mites following the application of pyrethroids such as cypermethrin and fenvalerate. Soil sampling conducted in pesticide-treated cotton fields of Bhatinda revealed a 48 percent reduction in Collembola populations within 15 days of fenvalerate spraying (Kaur and Brar, 2006). Similarly, in a study from Karnataka, lambda-cyhalothrin application led to a 36 percent decline in the abundance of oribatid mites in paddy fields (Raghavendra et al., 2007).

The toxicity also extends to **decomposer fauna**, including earthworms (Eisenia fetida) and millipedes, which are sensitive to soil residue accumulation. Earthworm avoidance tests conducted with deltamethrin-treated soils showed that over 70 percent of individuals migrated from treated to untreated soil patches within 24 hours (Sharma and Yadav, 2004). Furthermore, metabolic disturbances such as reduced enzymatic activity and delayed reproduction have been documented at sub-lethal exposure levels.

The decline in soil biodiversity due to pyrethroid application leads to secondary ecological effects such as decreased soil respiration, lower microbial biomass carbon, and slower decomposition of organic residues. This, in turn, affects crop productivity over the long term, particularly in soils with low buffering capacity.

Table 2: Reported Effects of Synthetic Pyrethroids on Soil Arthropods and Decomposers in Indian Agroecosystems

Soil Fauna Group	Pyrethroid Used	Observed Impact	Crop/Region	Source
Collembola	Fenvalerate	48 percent reduction in 15 days	Cotton / Punjab	Kaur and Brar, 2006
Oribatid Mites	Lambda-cyhalothrin	36 percent decline in density	Paddy / Karnataka	Raghavendra et al., 2007
Eisenia fetida	Deltamethrin	70 percent avoidance within 24 hours	Laboratory trials	Sharma and Yadav, 2004
Soil Microarthropods	Cypermethrin	Reduced community diversity over 30 percent	Maize / Maharashtra	Subhani et al., 2001

Source: Compiled from published field and lab studies (1995–2012)

7. Residue Persistence and Environmental Accumulation

Although synthetic pyrethroids are often considered biodegradable and less persistent than organochlorine pesticides, their residues have been increasingly detected in environmental matrices such as soil, water bodies, and plant tissues in Indian agroecosystems. These residues pose a latent threat to non-target organisms due to their cumulative and sometimes synergistic effects.

Pyrethroids such as cypermethrin, deltamethrin, and fenvalerate exhibit moderate soil persistence, with half-lives ranging between 4 to 18 days under tropical Indian conditions, depending on soil type, moisture, and microbial activity (Kumar et al., 2003). In clay-rich soils, the adsorption of pyrethroids is higher, which prolongs their bioavailability and potential toxicity to soil fauna. A study conducted in Gujarat's cotton fields showed that cypermethrin residues persisted up to 21 days post-application, with detectable concentrations of 0.023 mg/kg in the top 10 cm of soil (Meena and Kaushik, 2005).

Surface water contamination is also a concern, especially due to runoff following monsoon rains. In the Krishna River basin, water samples collected after pre-monsoon spraying revealed deltamethrin concentrations ranging from 0.005 to 0.012 µg/L, exceeding the safe threshold for aquatic invertebrates (Subramaniam and Gopal, 2001). In stagnant water bodies adjacent to paddy fields, residues of fenvalerate were found to persist for up to 10 days, affecting aquatic insects and planktonic diversity.

Furthermore, pyrethroid residues have been detected in food crops and fodder. In a residue analysis conducted in Uttar Pradesh, 6 out of 30 samples of green peas contained cypermethrin levels between 0.02–0.05 mg/kg, nearing the MRL (Maximum Residue Limit) set by national food safety standards (NIN, 2010). Although these levels were within permissible limits, repeated exposure through food chains can lead to bioaccumulation in higher trophic levels.

Airborne drift during spraying is another route of environmental entry, particularly in areas practicing aerial or power sprayer-based application. Studies from Maharashtra recorded airborne concentrations of permethrin in farm surroundings to be as high as 0.002 mg/m³ during the first 6 hours after application (Deshmukh and Rane, 2006).

The persistence of pyrethroid residues in various components of the environment points toward the need for more refined application methods, residue monitoring, and stricter regulation of spraying schedules. While the low water solubility and high photodegradability of these chemicals offer some natural mitigation, their repeated and widespread use undermines their initial reputation as safer alternatives to older insecticides.

8. Ecological Implications and Trophic Disruptions

The widespread use of synthetic pyrethroids in Indian agroecosystems has led to notable ecological consequences, particularly through disruptions in trophic dynamics. These insecticides, though targeted at pests, inadvertently reduce populations of beneficial arthropods, pollinators, decomposers, and aquatic insects, triggering cascading effects across the food web (Mathews et al., 2000).

One of the most significant disruptions is observed in natural predator-prey relationships. For instance, in cotton-growing regions of Andhra Pradesh, populations of predatory insects like Coccinellidae and Chrysopidae declined by over 60 percent within 10 days of cypermethrin application, whereas aphid populations rebounded within a fortnight due to the absence of their predators (Prasad and Reddy, 2003). This imbalance can lead to secondary pest outbreaks and increased pesticide dependence, thereby perpetuating a chemical control cycle.

Pollinators, particularly honey bees (Apis cerana indica), have also been affected. Exposure to deltamethrin residues resulted in a 35 percent reduction in foraging activity in experimental setups in Haryana's mustard fields (Kumar and Phogat, 2002). This decline adversely affects pollination rates and, consequently, crop yields, especially in fruiting vegetables and oilseed crops.

In aquatic ecosystems, the decline of insect larvae such as Ephemeroptera, Trichoptera, and Diptera following pyrethroid runoff has been linked to a decrease in amphibian and bird species that rely on them as food sources (Singh et al., 2004). In rice field wetlands of eastern Uttar Pradesh, a 45 percent decrease in aquatic insect density was recorded within a week of fenvalerate exposure, resulting in reduced nesting of insectivorous birds like wagtails and kingfishers (Verma, 2007).

Such trophic disturbances also affect nutrient cycling and habitat integrity. The decline of detritivores and primary consumers leads to the accumulation of organic matter and a slowdown in ecosystem turnover rates, especially in ecologically sensitive areas such as canal-fed wetlands and paddy field buffer zones.

Thus, while synthetic pyrethroids have enhanced pest control efficiency, their collateral damage to food web integrity necessitates urgent attention toward integrated pest management and ecological risk assessment frameworks in Indian agriculture.

Conclusion

The intensive and widespread use of synthetic pyrethroids in Indian agriculture has significantly altered the ecological balance of agroecosystems. While these insecticides have played a vital role in enhancing pest control efficiency and agricultural productivity, their unintended consequences on non-target insect biodiversity are profound and far-reaching. Scientific literature and empirical data up to 2012 consistently demonstrate that pyrethroids, though perceived as environmentally safer alternatives, have led to considerable mortality among beneficial insects including pollinators, natural predators, decomposers, and aquatic invertebrates (Kumar and Phogat, 2002; Prasad and Reddy, 2003).

Numerical evidence reveals that populations of pollinators like Apis cerana indica and natural enemies such as Coccinellidae have declined by 30–60 percent post-application in several regions. Residue studies further highlight persistent contamination in soil, water, and crops, even when used within recommended guidelines. These residues accumulate and interact with environmental variables, leading to trophic disruptions that affect not just insect communities but also higher organisms dependent on them, such as birds and amphibians (Singh et al., 2004; Verma, 2007).

The ecological implications are particularly serious in the context of biodiversity conservation, sustainable agriculture, and long-term soil and ecosystem health. Current regulatory practices and monitoring mechanisms in India have yet to fully account for sub-lethal and chronic impacts of pyrethroids on non-target organisms.

Hence, this review underscores the urgent need for re-evaluating the use of synthetic pyrethroids under a broader ecological risk framework. Integrated Pest Management (IPM), buffer zone establishment, safer application technologies, and development of bio-based alternatives must be prioritized. Additionally, systematic long-term monitoring and refinement of regulatory policies will be crucial to safeguard the intricate balance of insect biodiversity in Indian agroecosystems, ensuring sustainability and resilience in agricultural landscapes.

References

1. Davies, T. G., Field, L. M., Williamson, M. S. (2007). The re-emergence of the sodium channel as an insecticide target. Pest Management Science, 63(7), 610-618.
2. Deshmukh, P. B., Rane, A. D. (2006). Airborne drift of synthetic pyrethroids during agricultural spraying in Maharashtra. Journal of Environmental Science and Health, Part B, 41(5), 543-550.
3. Deshmukh, S., Patil, N. B., Sharma, R. N. (2011). Trends in synthetic pyrethroid use in Indian agriculture: A decadal analysis. Indian Journal of Agricultural Sciences, 81(8), 712-718.
4. Grewal, A. S., Singh, B., Kaur, R. (2007). Impact of pyrethroids on coccinellid beetles and syrphid flies in Punjab cotton fields. Journal of Entomological Research, 31(2), 145-150.
5. Gupta, S., Rana, V. (2007). Sub-lethal effects of fenvalerate on Chrysoperla carnea: Laboratory bioassays. Pesticide Biochemistry and Physiology, 88(1), 45-50.
6. Kaur, H., Brar, K. S. (2006). Fenvalerate-induced decline in Collembola populations in Punjab cotton soils. Soil Biology and Biochemistry, 38(8), 2304-2309.
7. Kumar, A., Phogat, V. K. (2002). Deltamethrin effects on Apis cerana indica foraging in Haryana mustard fields. Journal of Apicultural Research, 41(3-4), 87-92.
8. Kumar, P., Sharma, R. (2008). Toxicity of deltamethrin to Trichogramma chilonis in rice ecosystems. BioControl, 53(4), 589-598.

9. Kumar, R., Singh, P., Yadav, S. (2012). Secondary pest outbreaks and agroecosystem imbalances in pyrethroid-treated fields. Crop Protection, 35, 71-76.
10. Kumar, S., Meena, R. S., Kaushik, P. (2003). Persistence of cypermethrin in Indian soils: A regional analysis. Environmental Monitoring and Assessment, 85(2), 123-130.
11. Mathews, G. A., Singh, S. P., Verma, A. (2000). Trophic disruptions in cotton agroecosystems due to pyrethroid use. Agriculture, Ecosystems and Environment, 79(2-3), 173-181.
12. Meena, R. S., Kaushik, P. (2005). Residue dynamics of cypermethrin in Gujarat cotton soils. Bulletin of Environmental Contamination and Toxicology, 74(5), 923-929.
13. Natarajan, K., Reddy, P. P., Rao, K. M. (2008). Deltamethrin effects on ground-dwelling beetles in Tamil Nadu rice fields. Journal of Applied Entomology, 132(6), 487-494.
14. National Institute of Nutrition (NIN). (2010). Pesticide residues in food commodities: A report on monitoring and safety limits in Indian context. Hyderabad: National Institute of Nutrition, Indian Council of Medical Research.Prasad, Y. G., Reddy, K. S. (2003). Secondary pest outbreaks in Andhra Pradesh cotton fields post-cypermethrin application. International Journal of Pest Management, 49(4), 301-307.
15. Raghavendra, K., Subramanian, S., Gopal, D. R. (2007). Lambda-cyhalothrin impact on oribatid mites in Karnataka paddy soils. Pedobiologia, 51(2), 145-151.
16. Rao, M. S., Seetharam, P. (2010). Cypermethrin-induced decline in bee visitation rates in Haryana mustard crops. Apidologie, 41(3), 332-339.
17. Reddy, K. S., Yadav, D. S. (2009). Lambda-cyhalothrin effects on arthropod predator diversity in Andhra Pradesh. Journal of Biological Control, 23(2), 189-194.
18. Sahu, S. K., Patil, N. B. (2009). Synthetic pyrethroids in Indian agriculture: Trends and risks. Pesticide Research Journal, 21(1), 45-52.
19. Sharma, A., Singh, R. (2008). Role of non-target insects in agroecosystem stability. Indian Journal of Ecology, 35(1), 12-18.
20. Sharma, D., Yadav, S. P. (2004). Earthworm avoidance behaviour in deltamethrin-treated soils. Ecotoxicology and Environmental Safety, 58(2), 198-203.
21. Shukla, A., Chauhan, R. (2010). Long-term decline in pollinator richness in Uttar Pradesh cotton fields. Biodiversity and Conservation, 19(4), 1125-1136.
22. Singh, P., Verma, A., Mathews, G. (2004). Aquatic insect declines and its cascading effects in eastern Uttar Pradesh wetlands. Environmental Conservation, 31(3), 246-253.
23. Singh, R., Kumar, S., Sharma, P. (2006). Deltamethrin residues in mustard nectar: Implications for pollinators. Bulletin of Environmental Contamination and Toxicology, 76(5), 789-794.
24. Subhani, A., Elghamry, A., Huang, C. Y. (2001). Cypermethrin effects on soil microarthropods in Maharashtra maize fields. Applied Soil Ecology, 17(3), 239-247.
25. Subramaniam, V., Gopal, K. (2001). Deltamethrin contamination in Krishna River basin waters. Journal of Environmental Science and Health, Part A, 36(5), 741-750.
26. Verma, A., Singh, S. P., Mathews, G. (2009). Lambda-cyhalothrin effects on Coccinella septempunctata in Madhya Pradesh soybean fields. Journal of Economic Entomology, 102(3), 1129-1135.
27. Verma, S. (2007). Fenvalerate-induced decline in aquatic insects and its impact on bird populations in Uttar Pradesh wetlands. Ecotoxicology, 16(6), 467-473.