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Research Article

Impact of Pesticides on Diversity and Abundance of Predatory Arthropods in Rice Ecosystem

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Rice (*Oryza sativa*) is one of the most important cereal crops with a diverse set of pests and natural enemies. Rice fields often support a high diversity of arthropods which contribute significantly to productivity. This diversity is frequently threatened due to indiscriminate applications of pesticides. Our aim was to emphasize on the predator diversity in agrochemical exposed rice field as well as on the impact of surrounding vegetation on beneficial insect diversity. Natural enemies' data were recorded from randomly selected 10 quadrates by visual observation from each treatment. A total of 5,590 individuals of predators were observed during the study period which included 27 species belonging to 16 families from five orders of arthropods during the kharif season of rice. Statistically, there were no significant differences between the population of general natural enemies such as Odonata, Coleoptera, Hymenoptera, and Araneae in plots with insecticide and control during the different growth stages of rice cultivation. Diversity indices were almost similar in fields where pesticide was sprayed and not sprayed. Our study concluded that natural enemies are conserved by ensuring crop heterogeneity, growing insect-friendly plants (with high levels of nectar and pollen) as border crops, and judicious application of granule insecticide like cartap hydrochloride in a rice agro-ecosystem.

1. Introduction

Rice (*Oryza sativa* L.) is an important staple food for more than three billion people [1, 2]. A sympatric association of different species of insect pests and natural enemies has co-evolved in rice agro-ecosystems. Rice field often supports a rich arthropod diversity which plays a significant role in the system's agricultural productivity [3, 4]. These arthropods play an important role in these ecosystems such as herbivores, predators, parasitoids, saprophytes, and pollinators [5, 6]. In complex ecosystems, the diversity and interactions between species are more numerous, and thus the abundance of natural enemies is likely to be greater. Intensive cultivation in rice ecosystem leads to the dominance of herbivore species over non-herbivore species [7–9]. Insect pests caused a major biotic stress in all rice producing countries that limits yield [10]. Approximately 300 insect species attack rice crops in India of which 20 species are the main pests [11]. Categorized as borer, sap sucking, defoliator, and foliar pests, they infest different stages of crop growth [12–14]. Both mature and immature stages of major insect pest use to cause extensive yield losses in rice [15, 16] and to increase yields, and farmers rely on synthetic pesticides available in the local market.

Many rice farmers apply synthetic pesticides injudiciously, resulting in the resurgence, replacement, and resistance of insect pests that threaten the diversity of beneficial insects and disrupt the environment as well. In recent years, pest control has evolved to become more economical, eco-friendly, and sustainable, also encouraging the activity of various beneficial organisms, including predators and pollinators [17–21]. Agronomic practices beneficial to natural enemies include weed bunds that provide shelter, application of a granular formulation of insecticides to avoid direct contact, cultivation of good surrounding nectar plants to supplement the diet source of beneficial insects, and judicious use of nitrogen fertilizers to keep the plant less succulent. Pesticides in granular formulation are safer than liquid formulation on natural enemies [22, 23] and pollinators [24, 25]. Emphasis on identifying, increasing, and conserving natural enemies (NEs) and their implementation in integrated pest management (IPM) strategy will improve the NE activities and minimize the use of harmful pesticides. Compatibility of chemicals and biological strategy is important for the implementation of IPM programs and is only possible with the use of selective insecticides [26]. The aim of this study is to understand the diversity of predators exposed to agrochemicals in rice fields and to understand the impact of surrounding vegetation on the diversity of beneficial insect.

2. Materials and Methods

2.1. Location of Experiment. The field experiment was carried out during kharif seasons of 2018 and 2019. The experimental field is located at 31° 15′N, 75° 32′E and at 228 meters above mean sea level.

2.2. Experimental Details and Surrounding Habitat. Fifteen-day-old PR-126 rice seedlings were transplanted at a spacing of 20 cm × 15 cm during the first fortnight of July of 2018 and 2019 following the Punjab Government recommendation. Each treatment was allocated a plot size of 1 ha, consisting of T_1 = control (without insecticides) and T_2 = farmers' practices (with insecticides). In farmers' field (T_2), pesticides applied included cartap hydrochloride 4G @ 7.5 kg/acre at 45 days after transplanting (DAT) (first week of August) and fungicides included copper oxychloride 50%WP @ 200 l/acre during the first week of September in both seasons. The treatments were separated by an area of approximately 900 m. Basal application of fertilizers in the form of urea, single superphosphate, and muriate of potash was realized to achieve 30 kg N, 30 kg P_2O_5, and 30 kg K_2O per hectare, respectively. Nitrogen was applied in split doses, half as basal and remaining half in two equal splits at 35 and 55 days after transplanting (DAT). Two landscapes were categorized based on surrounding landscape features and characteristics within the buffer zone of rice ecosystem. In landscape category (1), both tall and short *Eucalyptus* trees (200–300 m) and kinnow orchard 200–300 m horticultural annuals (100 m) were present near the rice field. Alternate wetting and drying practices were followed; bunds were trimmed regularly to remove weeds and herbicide was applied once in a crop season along with manual weeding twice in the season. Rice-wheat/vegetables/mustard cropping pattern was followed in the landscape further considered as without pesticide treated plots (T_1). In landscape category (2), tall forest trees (*Eucalyptus*) surrounded the rice field. Irrigation from the tube well maintains stagnant water levels. Weed flora was maintained on bunds without herbicides throughout the growing seasons. Weeding was done manually thrice in a season. Rice-wheat cropping pattern followed by the farmers was considered as pesticide treated plots (T_2).

2.3. Collection of Predators and Their Identification. Natural enemies' abundance was recorded from 10 randomly selected spots from each treatment at 45 DAT. The predators (Odonata Zygoptera, Coleoptera, Araneae, Hymenoptera, and Diptera) were observed from randomly selected one m^2 quadrates while the Odonata Anisoptera population was counted from $10 \times 10\,m^2$ during morning hours (06:00–09:00 AM) in weekly intervals from vegetative to harvesting stage of rice by the aerial net method [27] and visual observation. Collected insect species were stored as wet (70% ethanol) or dry preservation for further identification at the laboratory. The identification of predators at species level was based on reference taxonomic key databases for Coccinella (Dr. J. Poorani), Odonata [28, 29], Hymenoptera, spiders [30, 31], and Syrphidae [32], and some online databases were also used for the identification.

2.4. Statistical Analysis. The mean of predator populations was compared between pesticide and non-pesticide treated fields by Student's *t*-test using SPSS (version 22). Relative abundance of predator populations was calculated according to Choudhury et al. [27]. Biodiversity analysis was conducted through Simpson index [33], Shannon–Weiner index [34], and Berger–Parker dominance index [35] which were calculated with online biodiversity calculator [36].

3. Results

3.1. Survey of Predators. Roving type survey was conducted on randomly selected 1 m^2 quadrates for each treatment during the kharif season of 2018 and 2019. Overall, about 5,490 individual predator populations were observed; among these, 27 species belonging to 16 families were identified during the investigation. In the Coleoptera order, we identified five species from the family Coccinellidae, as well as one species each from the Staphylinidae and Carabidae families. Within the Odonata order, we observed four species from the Coenagrionidae family and three species from the Libellulidae family. The Hymenoptera order was represented by a single species from each of the following families: Braconidae, Vespidae, Ichneumonidae, Formicidae, and Eulophidae.In addition, we recorded two species of Diptera from the Syrphidae family. In the Arachnida class, we found one species

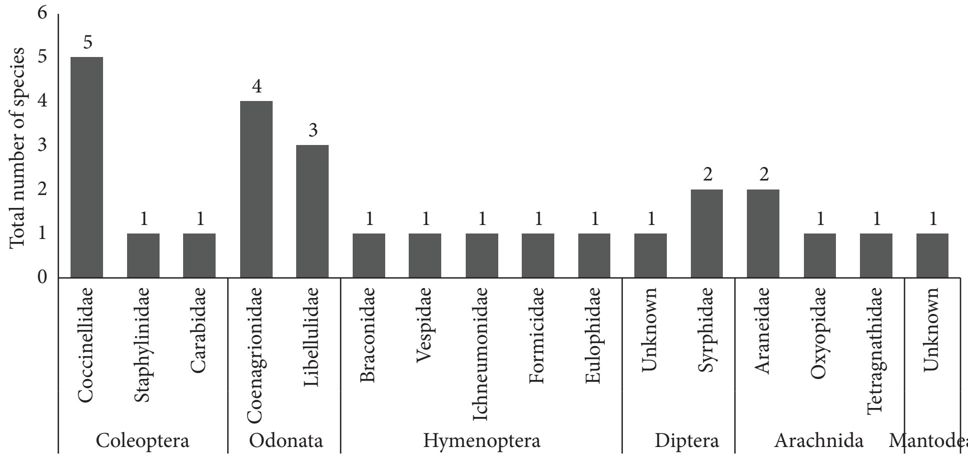

Figure 1: Familywise predatory species composition in rice during kharif season.

each from the Oxyopidae and Tetragnathidae families, along with two species from the Araneidae family (Figure 1).

3.2. Population Dynamics of General Natural Enemies in Rice. Common natural enemies' population of Coleoptera, Odonata, Hymenoptera, Diptera, Mantodea, and Arachnida was observed during the research period. The field treated by insecticide had recorded a lower individual predator population than the control field (without insecticide) during 2018 and 2019 in rice habitat (Figure 2). Average population of Odonata (both Zygoptera and Anisoptera) ranged between 7.25 and 10.75/m^2 and 6.50 and 8.50/m^2 during kharif 2018. During kharif 2019, damselfly population was 0.25–11.00/m^2 and 0.50–8.25/m^2 in control field and chemical sprayed field, respectively. In 2018, dragonfly population ranged between 4.67 and 13.33/10 m^2 and 4.33 and 16.33/10 m^2 area, while in 2019, it ranged between 1.00 and 16.33/10 m^2 and 0.33 and 15.33/10 m^2 area in natural control and chemical sprayed fields, respectively (Figure 3). The population of Odonata continuously increased and reached peak at first fortnight of September in both years (Figure 3).

Coleoptera predators during 2018 kharif season were 1.00–12.75/m^2 and 0.75–12.00/m^2 while in 2019, they were 0.75–10.50 and 0.75–7.25/m^2 in natural control and chemical sprayed field, respectively. Populations of Coccinellidae increased synchronously with crop growth and reached peak after harvesting period (last week of October) in both years (Figure 3).

Hymenopteran parasitoids during kharif 2019 in control and chemical sprayed fields were 1.67–21.00/m^2 and 1.33–17.33/m in 2018, and in 2019, they were 0.67–15.67/m^2 and 0.67–9.00/m^2, respectively. Peak activity of hymenopterans was observed at harvesting stage compared to vegetative and reproductive stage in both 2018 and 2019 (Figure 3).

The spider populations were 1.14–11.86/m^2 and 0.86–14.86/m^2 in kharif 2018 (Table1) while they were 5.29–11.86/m^2 and 3.71–10.14/m^2 in kharif 2019 in untreated and chemical treated field, respectively. In vegetative and reproductive stages, the spider population observed was the highest during the kharif season of rice in both years (Figure 3).

3.3. Effect of Insecticide and Non-Insecticide Treatments against Predator Population. 27 species of predators were observed during the study period, and higher densities were recorded in non-insecticide plot than insecticide plot, while there is no significant difference ($df = 40$, $p > 0.05$) at vegetative, reproductive, and harvesting stage in both the years (Table 2). Numerically, maximum predator populations (26.6 and 23.75 per m^2) occurred in non-insecticide plots in both the years. The abundance of natural enemies was at maximum in 2018 than 2019 (Figure 2).

3.4. Diversity Indices of Predators. Diversity indices of predators varied according to ecological niches, crop growth, vegetation availability, and application of insecticides. Odonata and Arachnid predator species were more abundant (per m^2) at vegetative stage and then continuously decreased in reproductive and harvesting stage even though Coleoptera predators and Hymenoptera parasitoids increased from vegetative to harvesting stage of crop in both the treatments (Table 1). During the vegetative stage of the non-insecticide plot, Odonata and Hymenoptera had the greatest Shannon "H," Simpson "D," Berger–Parker "h," and Margalef richness indices, while Coleoptera and Arachnid predators had the highest diversity indices in an insecticide spray field at harvesting stage (Table 1).

3.5. Species Composition. The number of individuals of entomophagous predators was higher in the control field (1642 and 1339) than in the field sprayed by insecticides (1495 and 1014) in both the years 2018 and 2019, respectively (Figure 1). Four predatory insect orders recorded from both the plots were especially abundant: Arachnid (38% and 40%), Odonata (34% and 34%), Hymenoptera (16% and 13%), and Coleoptera (12% and 9%), in both the treatments during 2018. Similar trend was observed during 2019 (Figure 4).

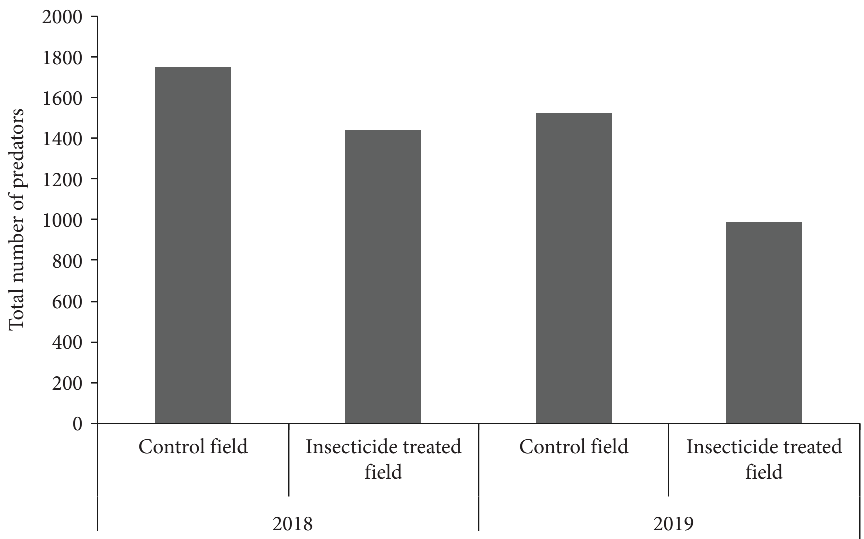

Figure 2: Total predator population in rice during kharif season.

4. Discussion

Species richness and abundance of natural enemies in an ecosystem play a vital role in pest management. Natural enemies' abundance depends on a set of conditions, such as host availability, suitable environment factors, crop heterogeneity, photoperiod, soil properties, judicious application of nitrogenous fertilizers, recommended and minimal dosage of chemical pesticides, use of selective pesticides, and NE's friendly cultural practices. In the present investigation, 27 species of predators were recorded, exceeding Mondal et al. [37] who recorded 15 predators from rice field in West Bengal, India, from vegetative to harvesting period of rice; *Ischnura aurora* (Brauer) of Zygoptera, *Orthetrum sabina* (Drury) of Anisoptera, *Forficularia decipiens* (Gene.) of Dermaptera, *Andrallus spinidens* (Fabricius) of Hemiptera, *Ophionea nigrofasciata* (Scht-Gobel), *Paederus fuscipes* (Curtis), and *Coccinella transversalis* (Fabricius) of Coleoptera dominated. Moreover, various predatory arthropods like *Micraspis discolor* (Fabricius) (Coleoptera: Coccinellidae), *Tetragnatha* sp. (Araneae: Tetragnathidae), and *Agriocnemis pygmaea* Rambur (Odonata: Agrionidae) were found dominant in pesticide and non-pesticide rice field [38].

Similar treads were observed in predator population dynamics in pesticide and non-pesticide treated fields due to friendly vegetation present around the field. The presence of entomophagous in the field was positively influenced by the existence of vegetation, with no significant changes in their abundance [4]. The result agreed with Rattanapum (2012) that there was no relation with predator population in pesticide treated and untreated rice plots. However, the predator's population trends gradually increased and reached peak at grain formation stage in rice [22].

Cartap hydrochloride, a nereistoxin analog having contact and stomach poison properties, significantly affects rice pest at low concentration [39]. The present study shows that the application of granular formulation cartap hydrochloride had no negative impact on terrestrial predators. Similarly, Ghosal and Hati (2019) evaluated new generation insecticides on soil arthropods and showed no significant detrimental effect on the Collembola population present in soil when applied cartap in rice maize ecosystems. In contrast, results of cartap hydrochloride affect negatively on several soft body hymenopteran parasitoids [40–42]. General predatory species like coccinellid beetles, carabid beetles, dragonflies, and damselflies reduced 20–50% following cartap hydrochloride application in rice ecosystems [43]. Impacts of agrochemicals including insecticides and herbicides on beneficial arthropods were poorly studied [44]. Furthermore, the abundance of phytophilous predators is more likely to decrease than that of benthic, nektonic, and neustonic predators when the agrochemical was applied because of high lethal toxicity especially fipronil [45].

Nitrogenous fertilizer plays important role directly and indirectly in rapid pest development and abundance of their natural enemies. Higher dose of nitrogen fertilizers makes plants more succulent and stimulates the pest development of rice which also attracts parasitoids and predator community in rice ecosystems [46, 47]. Odonata, a group of versatile predators commonly found in rice fields, exhibit higher abundance than other cereal crops. This is primarily attributed to their preference for stagnant water, which is ideal for oviposition. Consequently, their population experiences a gradual increase starting in July, reaching its peak in September and October. However, as November arrives and the rice crop is harvested, the absence of stagnant water in fields leads to a decline in the Odonata population [48].

The natural enemies' diversity and richness were higher at tillering than reproductive growth stage of rice [46]; Bakar and Khan 2016. Krauss et al. [49] indicated that predator and pollinator richness increased more in organic fields than in conventional fields because sprayed insecticides have a short-term impact on pests while having a long-term unfavourable impact on natural enemies. The total number of predators between non-insecticide and insecticide plots at vegetative and reproductive stages of rice growth

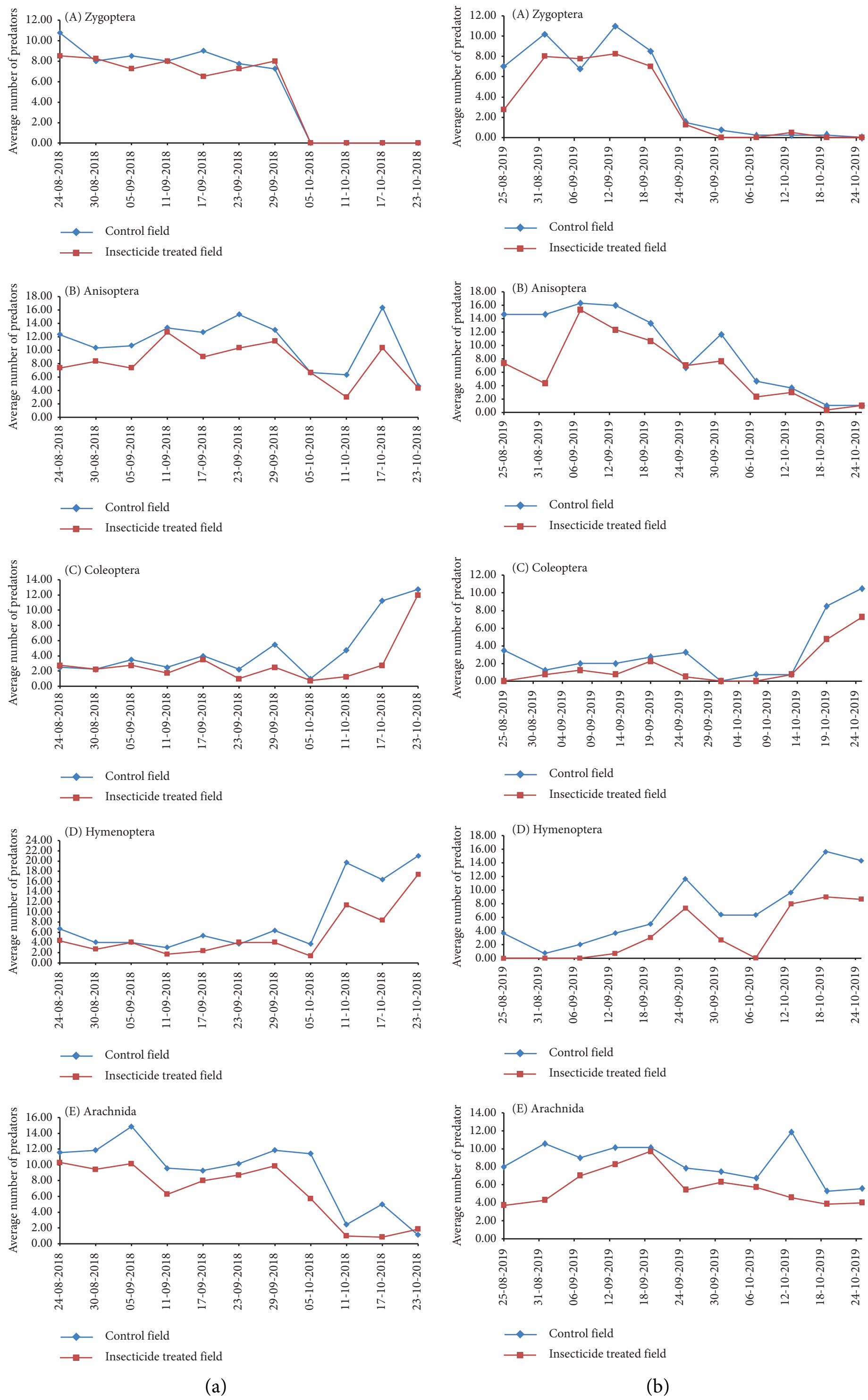

Figure 3: Population dynamics of general predators in the rice ecosystem. (a) Kharif-2018. (b) Kharif-2019.

showed no significant differences [38]. The finding is similar in the present study, since there was no significant effect observed on predator diversity when cartap hydrochloride was applied due to its indirect exposure to predators as a granular formulation. Furthermore, our results agree with Sarao and Mahal [23] who evaluated different formulations against rice predators and revealed that cartap hydrochloride 4G was safe to predators since granular insecticides do not reach directly arthropods. The presence of liquid formulation pesticides such as chlorpyrifos and methyl parathion has been observed to have a negative impact on predator activity within the rice ecosystem. This adverse effect can occur either through direct exposure to the sprayed liquid or indirectly through the consumption of prey contaminated

Table 1: Diversity indices of predators in different growth stages of rice during kharif season.

Insect order/suborder	Crop stage	Total population		Shannon index "H"		Simpson index "D"		Reciprocal Simpson index "d"		Berger–Parker "h"		Margalef richness index		Dominant species
		T_1	T_2	T_1	T_2	T_1	T_2	T_1	T_2	T_1	T_2	T_1	T_2	
Zygoptera	V	176	145	1.146	1.236	0.617	0.677	2.611	3.097	0.563	0.473	0.580	0.602	*Ischnura aurora*
	R	36	34	1.147	1.265	0.629	0.706	2.696	3.400	0.568	2.188	0.831	0.844	
	AH	0	0	—	—	—	—	—	—	—	—	—	—	
Anisoptera	V	202	142	0.981	0.984	0.589	0.589	2.430	2.432	0.559	0.566	0.377	0.403	*Crocothemis servilia*
	R	102	77	0.909	0.930	0.547	0.558	2.206	2.265	0.608	1.660	0.432	0.459	
	AH	35	24	0.979	1.051	0.598	0.663	2.490	2.970	0.571	0.440	0.563	0.621	
Coleoptera	V	51	36	0.906	0.903	0.559	0.566	2.269	2.304	0.529	0.487	0.763	0.831	*Coccinella septempunctata*
	R	37	14	1.178	1.116	0.692	0.648	3.249	2.844	0.405	0.571	0.831	1.137	
	AH	86	54	0.870	0.794	0.505	0.442	2.022	1.791	0.651	0.722	0.674	0.752	*Paederus fuscipes*
Hymenoptera	V	57	28	0.978	0.844	0.609	0.532	2.559	2.137	0.448	0.621	0.493	1.611	*Ropalidia* sp.
	R	101	57	0.949	0.945	0.566	0.569	2.304	2.320	0.598	0.597	0.432	0.495	*Ichenemoide* sp.
	AH	101	65	0.904	0.960	0.551	0.576	2.229	2.357	0.588	0.591	0.432	0.477	
Arachnid	V	356	282	1.832	1.758	0.827	0.802	5.783	5.056	0.263	0.325	1.020	1.063	*Tetragnatha* sp.
	R	239	171	1.761	1.886	0.808	0.845	5.217	6.466	0.300	0.208	1.095	1.164	*Oxyopes salticus*
	AH	60	37	0.814	1.070	0.538	0.664	2.166	2.979	0.517	0.447	0.489	0.550	*Neoscona theisi*

"V" = vegetative; "R" = reproductive; "AH" = after harvesting; T_1 = control field (without insecticide); T_2 = farmers' field (insecticide spray).

Table 2: Effect of insecticide and non-insecticide treatment against general predators during the kharif season in the rice ecosystem.

Treatments	Kharif 2018				Kharif 2019			
	V	R	H	Average	V	R	H	Average
T_1	40.76 ± 6.35	27.57 ± 4.06	14.95 ± 5.04	27.76	39.29 ± 8.94	21.38 ± 5.82	11.81 ± 3.64	24.16
T_2	34.14 ± 5.01	20.14 ± 2.71	9.48 ± 3.55	21.25	26.05 ± 7.50	13.33 ± 3.47	7.62 ± 2.52	15.67
Fcal	0.913	0.985	0.206		0.083	1.643	5.255	
t value	0.818	1.521	0.888		1.134	0.1.187	0.947	
$p = 0.05$	0.418^{NS}	0.136^{NS}	0.380^{NS}		0.264^{NS}	0.242^{NS}	0.349^{NS}	
Df	40	40	40		40	40	40	

"V" = vegetative; "R" = reproductive; "AH" = after harvesting; T_1 = control field (without insecticide); T_2 = insecticide treated field, NS = Non-significant.

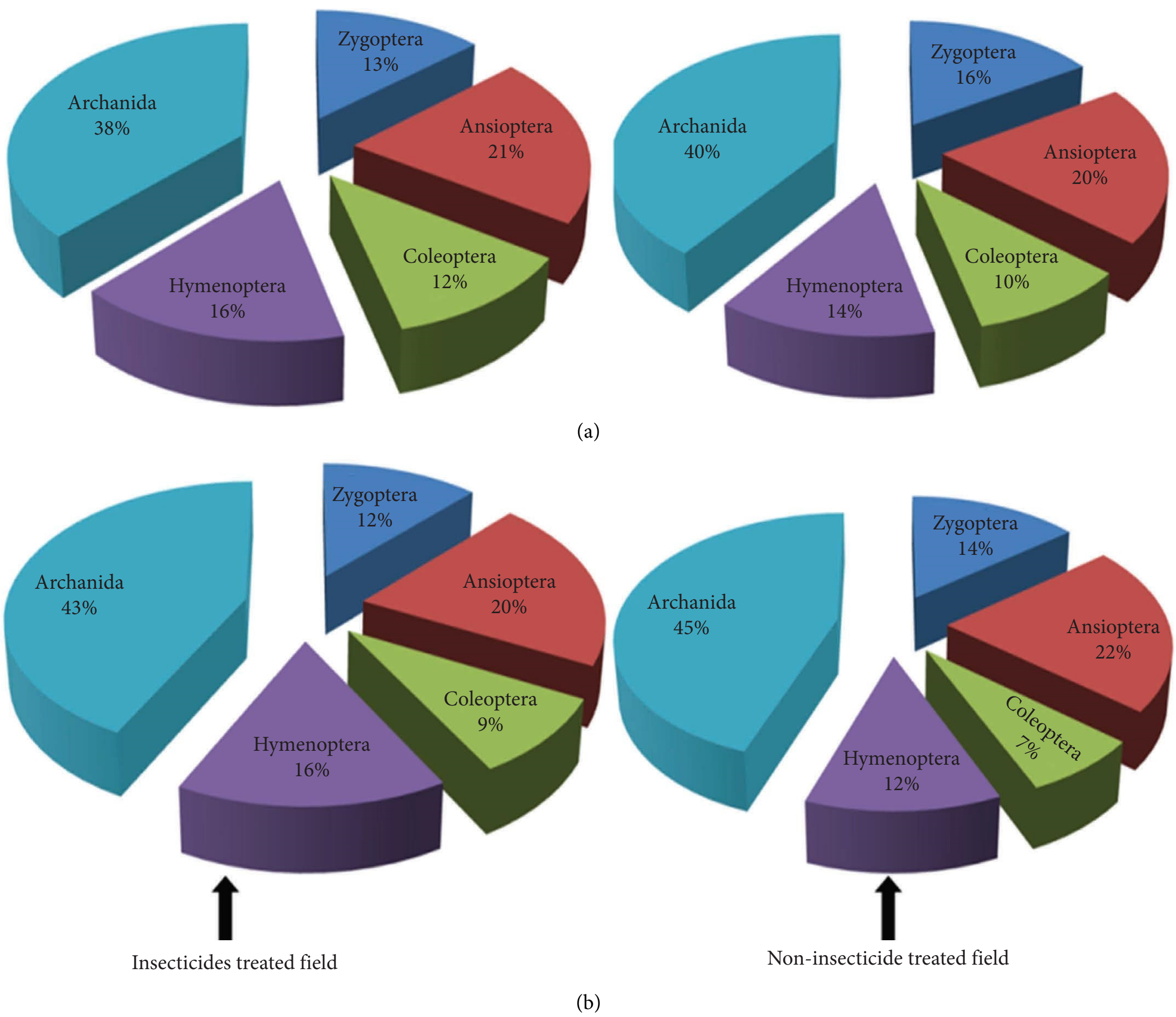

Figure 4: Species composition of natural enemies in rice field during kharif season. (a) Kharif-2018. (b) Kharif-2019.

by pesticides [22, 23]. The herbicide application did not show any negative impact on phytoplanktons and zooplanktons while significantly likely decreased phytophilous diversity as indirect effect of herbicides [45].

We recorded four predatory arthropod groups from the pesticide treated and untreated rice field during field trials. There was no change in aquatic insect diversity or abundance between pesticide and non-insecticide treated rice fields [38, 50–52], but insecticide application resulted in a loss in species richness [7]. The parasitism rate and predators' activity were significantly higher in organic rice field than conventional [53]. In conventional field, insecticide caused adverse effect on the arthropod community after spraying and recovered quickly; however, Yu et al. [54] reported no negative effects of Bt soybean on the arthropod community in the short period. Cartap hydrochloride was found to be safe to predators while liquid formulation pesticides were found to be toxic in rice ecosystems in Punjab [23]. The present result was more or less similar to that of Bambaradeniya and Edirisinghe [22] who revealed that Arachnida species were more abundant followed by Coleoptera, Hemiptera, and Odonata in rice habitat. The

Odonata dominance index was high in rice and grassland ecosystem because of vegetation diversity which provides alternative shelter for predators [55]. However, managing vegetation near rice plot influences the predatory activity in habitat because of the surrounding environmental conditions or anthropogenic factors [56].

5. Conclusion

Our study concluded that the predator diversity and abundance are compatible with application of cartap hydrochloride 4G, and partial weedy bund provides additional habitat to terrestrial arthropods in rice ecosystems. However, the terrestrial arthropod abundance did not suffer drastic changes while exposed to granular formulation pesticides; however, their impact needs to be investigated on soil arthropods. Thus, natural enemies will conserve through providing crop heterogeneity, growing insect-friendly plants as border crops, and judicious application of insecticide and fertilizers to restore the sustainability in a rice ecosystem.

Abbreviations

NEs: Natural enemies
IPM: Integrated pest management
DAT: Days after transplanting
SPSS: Statistical Package for the Social Sciences.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

RS carried out the experiments for his postgraduate research. AMR, ANB, and JW conceptualized the study and wrote the manuscript. AMR and MAS analyzed the experimental data, provided technical guidance, and edited the manuscript. CR, AMR, WA, and KS edited the final manuscript. All authors have read and approved the final manuscript.

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