



Biodiversity of pests and natural enemies in different production environments of rice and cabbage: impacts of insecticide application

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Abstract This study aimed to assess the impact of different production systems, including organic, Integrated Pest Management (IPM), and farmer's practices, on the biodiversity of pests and natural enemies in rice and cabbage fields. As noted more detail in the Supplementary Material section S.M.1, the study was conducted over three consecutive seasons during 2016–2018 in Coimbatore, Erode and The Nilgiris districts of Tamil Nadu, India. The rice field survey revealed the presence of 49 species belonging to 31 families under 10 orders, including Insecta, Arachnida, and Acari. Among these, 23 species were identified as pests, 23 as natural enemies, and the remaining as pollinators. The organic ecosystem exhibited the highest relative density, with *Scirpophaga incertulas* Walker being the most prevalent species in season I

(67%), *Cnaphalocrcis medinalis* (Guenee) in season II (82%), and season III (65%). In cabbage fields, 19 pest species and 12 natural enemies belonging to the class Insecta and Arachnida were identified. The IPM farm showed the highest Shannon-Weiner index values in season I (3), season II (2), and season III (2). The relative density was highest for *Plutella xylostella* Linnaeus in all three seasons (37% in each season). The analysis of the impact of insecticide application on biodiversity indicated that the use of older and newer molecule insecticides had a negative influence on both pests and natural enemies in rice and cabbage fields. The older molecules showed a higher negative impact compared to newer molecules during all three seasons in rice ecosystems. Similarly, in cabbage ecosystems, the use of both older and newer molecule insecticides had a significant negative impact on pests and natural enemies in all three seasons. These findings emphasize the importance of implementing sustainable production systems in agriculture to minimize ecological disturbance while maintaining yield and quality.

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Introduction

Globally, rice occupies 19 percent of the total cultivated area (~167 million hectares) with an approximate production of 755 million tonnes (Doni et al.

2022; Luo et al. 2022; Guha 2021). Currently, rice is a significant dietary source for 3 billion people worldwide, and the consistent increase in world population is creating a huge demand in the global market (Mishra et al. 2018; Li et al. 2015; Van et al. 2006). On the other hand, cabbage is an important vegetable crop that is consumed raw or cooked. India stands second in the production of cabbage, accounting for 12 percent of the world's production (Sharma et al. 2017). Cabbage is a rich source of nutrients, comprising all nine essential amino acids (histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine), vitamins (B1, B2, B3, B5, B9, C, and K), minerals (calcium, iron, magnesium, sodium, and potassium), and soluble and insoluble fiber. It is also reported to have antioxidant and anti-carcinogenic properties (Sharma et al. 2017; Kiptoo et al. 2015; Schweizer and Würsch 1979).

Although rice and cabbage belong to entirely different classes of crops, both of them are severely infested by insect pests. Rice and cabbage are recorded to be infested by 217 and 20 pest species, respectively, which are the most crucial yield-limiting biotic factors (Alcala et al. 2022; Shah et al. 2022; Ali et al. 2021; Bhatt et al. 2018; Alam 1982). Naturally, many of these pests are under control by natural enemies, but changing climatic conditions, modern agricultural practices, and knowledge gaps in farming disrupt the natural balance. As a result, farmers are forced to apply chemical pesticides for an immediate result (Kamala and Devanand 2021; Karthikeyan et al. 2020; Senguttuvan and Srinivasan 2019; Parasappa 2017). In rice and cabbage, a wide range of pesticides are used in terms of formulation and quantity (Selvaraj et al. 2014). Worldwide, chlorpyrifos, carbofuran, etofenprox, fenitrothion, pirimiphos methyl, metiocarb, diazinon, trichlorfon, teflubenzuron, and malathion are the insecticides predominantly used for the management of rice pests (Pareja et al. 2011). Similarly, in cabbage, indoxacarb, lambda-cyhalothrin, chlorpyrifos, abamectin, fenoxycarb, diafenthiuron, chlorfluzuron, fipronil, spinosad, and deltamethrin are the most widely used against cabbage pests (Amoabeng et al. 2021; Mazlan and Mumford 2005).

Improper handling of pesticides by farmers, such as selecting inappropriate chemicals, applying excessive quantities, using the wrong combinations, and applying them at inappropriate times, can have

significant consequences for agriculture and public health (Abhilash and Singh 2009). Further, only about 0.1 percent of pesticides applied in the field reach their target, while the rest enters the environment and may impact the diversity of beneficial or harmless organisms that are essential to the ecosystem (Amoabeng et al. 2021; Gill and Garg 2014; Desneux et al. 2007; Carriger et al. 2006;).

Several efforts have been made to develop farming systems or practices that minimize chemical interference and support maximum diversity. Organic farming is a possible alternative to conventional agriculture, as it can increase species richness (~34 percent) and abundance (~50 percent) (Smith et al. 2020; Reganold and Wachter 2016; Niggli 2015; Tuck et al. 2014; Geiger et al. 2010; Bosshard et al. 2009; Badgley et al. 2007). However, organic farming typically reduces yields in all major crops by 19–25 percent (Tscharntke et al. 2021). In a developing country like India, organic farming will only be successful if it is economically viable for farmers. Therefore, a smart combination of all available pest management practices in an Integrated Pest Management (IPM) system could reduce chemical intervention without compromising yields. Hence, studies on farming systems or practices that minimize chemical interference and support maximum diversity are crucial. Although there are a few studies that report on the biodiversity of different ecosystems, they are limited to landscape architecture, land near forests, wild vegetation, and forest land converted into agricultural fields (Zhang et al. 2021; Jiménez-García et al. 2019; Katayama et al. 2019). To our knowledge, this is the first study in India that investigates the effects of farming practices, particularly pesticide use, on rice and cabbage arthropod assemblages.

Materials and methods

Field investigations were carried out to study arthropod diversity in rice and cabbage ecosystems in twelve fields of each crop: ten fields where farmers' practices were followed, one with IPM practices, and the other employing organic practices. The study was conducted during three seasons: December 2016, July 2017 (Karif), and January 2018 for cabbage, and October 2016 (late Samba), September 2017 (late Samba), and January 2018 (Navarai) for rice,

covering Coimbatore and Erode districts for rice trials and The Nilgiris district for cabbage. Additional details about field selection and the package of practices followed are described in supplemental material S.M.1.

The methodologies used for surveying and collecting arthropods were active searching and net sweeping. Each field was actively examined in the early morning for about two hours. Spiders were collected by diagonal walk, flying and jumping arthropods were collected by net sweeping in the fields. The data collected from a single field throughout the season were pooled for analysis.

Collection and identification of arthropods

A survey was conducted to assess the biodiversity of arthropods in various farmers' fields (FF1 to FF10), IPM, and organic farming fields, and diversity indices were calculated. The arthropods collected during the survey were sorted and preserved based on their taxonomic classification. Soft-bodied insects were preserved in 70% ethyl alcohol, and other arthropods were card-mounted or pinned for identification.

All arthropods collected were identified to the lowest possible taxonomic level, i.e., order, family, genus, or species. The preserved specimens were photographed using an image analyzer (Leica M205 C, Leica Microsystems Ltd.) and identified based on their taxonomic characters. Insects were identified by comparing them with the type specimens in the Biosystematics Laboratory, Department of Agricultural Entomology, Centre for Plant Protection Studies, TNAU, Coimbatore.

Measurement of diversity

The relative density and other diversity indices were calculated by using the formulae furnished in the supplementary material table S.M.2.

Impact of insecticide use on biodiversity

To investigate the correlation between pesticide application and biodiversity, we considered insecticides commercialized since 1990 as newer molecules with novel modes of action and lower dosages, while the rest were considered older molecules (Sparks et al. 2019).

To assess the impact of insecticide use on biodiversity, we employed a generalized linear mixed-effect model (GLMM) analysis, using negative binomial distribution. The response variable was the abundance of pest or natural enemy (COUNT) in each individual field, while the explanatory variables were the number of older molecules (NOM) and newer molecules (NNM) applied in the same field. Field location (SITE) where the observations were made throughout the season was considered as a random factor.

We used the R function "confint.glmmTMB" in the glmmTMB package with the "method=Wald" parameter to calculate the 95% confidence interval (CI) of the estimated coefficient for each explanatory variable. The analysis was performed using the glmmTMB package (Magnusson et al. 2017) in R software (version 3.5.1) (CoreTeam 2017).

Results

Diversity of arthropods in different production ecosystems of rice

Arthropods belonging to 49 species, 31 families under 10 orders including Acarina and Araneae were recorded during entire study period, which included 23 pest species, 23 natural enemies and 3 pollinators.

Insecta being the dominant class, the most common orders observed were Coleoptera, Hemiptera and Lepidoptera. The most prevalent family in Lepidoptera was Crambidae. The species-wise relative density analysis revealed that the yellow stem borer, *Scirpophaga incertulas* Walker, was highly abundant (67.10%) in season I. In season II, the relative density was higher for the leaf folder, *Cnaphalocrcis medinalis* (Guenee) (82.92%), and was the least for the spider, *Argiope ansuja* Thorell (2.33%). In season III, *C. medinalis* was highly abundant (65.67%), followed by *Nephotettix virescens* (Distant) (54.78%), while the syrphid, *Chrysotoxum baphyrum* Walker, had the minimum relative density (1.00%) (refer to Supplementary material table S.M.3).

In season I, 10 arthropod orders were observed, including 21 pest species, 14 natural enemies, and three pollinators. Table 1 lists the biodiversity indices, such as the Simpson index, Shannon Wiener index, Margalef index, and Pielou's index, for all

Table 1 Biodiversity of arthropods in different production ecosystems of rice

Production ecosystem	Season I					Season II					Season III				
	<i>SDI</i>	<i>H'</i>	<i>D</i>	<i>EI</i>	<i>R</i>	<i>SDI</i>	<i>H'</i>	<i>D</i>	<i>EI</i>	<i>R</i>	<i>SDI</i>	<i>H'</i>	<i>D</i>	<i>EI</i>	<i>R</i> (%)
FF1	0.07	2.89	4.89	0.83	17.56	0.09	2.67	3.97	0.83	21.28	0.06	2.94	4.64	0.88	11.93
FF2	0.06	2.96	4.94	0.85	19.28	0.08	2.83	4.75	0.81	17.33	0.06	2.99	4.58	0.87	13.81
FF3	0.07	2.88	5.05	0.85	12.40	0.07	2.9	4.61	0.89	10.00	0.11	2.68	5.36	0.78	6.74
FF4	0.06	3.02	5.8	0.85	8.94	0.07	2.87	4.74	0.88	13.35	0.08	2.66	4.45	0.85	5.65
FF5	0.06	2.94	4.97	0.84	18.58	0.07	2.88	4.68	0.84	18.74	0.06	2.88	4.47	0.82	13.88
FF6	0.06	2.97	4.77	0.86	20.00	0.07	3.01	5.11	0.86	18.09	0.05	3.03	4.52	0.90	16.00
FF7	0.06	2.99	4.9	0.85	19.82	0.08	2.89	4.85	0.83	17.39	0.06	3.04	5.07	0.87	15.52
FF8	0.07	2.93	5.66	0.85	7.53	0.12	2.59	4.57	0.79	10.59	0.09	2.6	4.36	0.87	2.85
FF9	0.12	2.33	3.29	0.86	5.87	0.23	1.78	2.2	0.74	8.00	0.18	1.95	2.69	0.74	6.14
FF10	0.07	2.85	5.31	0.83	8.90	0.1	2.61	4.19	0.82	9.46	0.06	2.88	5.02	0.89	5.88
IPM	0.08	2.81	4.66	0.82	19.68	0.07	2.98	4.76	0.86	18.28	0.06	2.88	4.52	0.85	14.60
ORGANIC	0.06	3.05	5.56	0.84	20.30	0.06	3.07	4.51	0.88	25.30	0.06	2.96	4.5	0.85	27.88

SDI Simpson index, *H'* Shannon Wiener index, *D* Margalef index, *EI* Pielou's evenness index, *R* Relative density

three seasons. The Simpson index ranged from 0.06 to 0.12, and the Shannon Wiener index ranged from 2.33 to 3.05. It was observed that the minimum Simpson index and maximum Shannon Wiener index were found in the organic farming field (0.06 and 3.05, respectively), while the maximum Simpson index and minimum Shannon Wiener index were found in the farmer's field (FF9) (0.12 and 2.33, respectively). The Margalef index ranged from 3.29 (FF9) to 5.80 (FF4), and Pielou's index ranged from 0.82 (IPM) to 0.86 (FF9). The relative density ranged from 5.87% to 20.30%, with the highest value found in the organic field (20.30%), followed by FF6 (20.00%), FF7 (19.82%), and the lowest value found in FF9 (5.87%).

In Season II, 18 pest species and 15 natural enemies were observed belonging to eight orders. The Simpson and Shannon Wiener indices ranged from 0.06 to 0.23 and 1.78 to 3.07, respectively. The Margalef and Pielou's indices ranged from 2.2 (FF9) to 4.85 (FF7) and 0.74 (FF9) to 0.89 (FF3), respectively. The relative density ranged from 8.00 to 25.30 per cent. The minimum Shannon Wiener (1.78), Margalef (2.2), and Pielou's indices (0.74) and relative density (8.00%) were found in FF9. The maximum Shannon Wiener index and relative density were found in the organic farming field (3.07 and 25.30%, respectively).

In Season III, seven orders were represented by 19 pests and 18 natural enemies. The Simpson, Shannon Wiener, Margalef, Pielou's, and relative density indices were calculated. The Simpson index ranged

from 0.05 (FF6) to 0.18 (FF9), while the Shannon Wiener index ranged from 1.95 (FF9) to 3.04 (FF7). The Margalef index and Pielou's index were lower in FF9 (2.69 and 0.74) and higher in FF3 (5.36) and FF6 (0.90), respectively. The relative density ranged from 2.85 (FF8) to 27.88 per cent (Organic field) (Table 1).

Diversity of arthropods in different production ecosystems of cabbage

The survey conducted during season I revealed the presence of 19 pest species and 12 natural enemies belonging to the classes Insecta (7 orders) and Arachnida (1 order) (refer to Supplementary material table S.M.4). Biodiversity indices were calculated for this season as well. The Simpson index ranged from 0.16 to 0.50, with the minimum value (0.16) found in the IPM field. The Shannon Wiener index ranged from 1.64 to 3.09, with the maximum value (3.09) found in the IPM farm. The Margalef and Pielou's indices ranged from 2.01 to 3.28 and 0.11 to 1.04, respectively. The Pielou's index was the lowest for organic farming (0.11). Among the pests, the highest relative density was observed for *P. xylostella* Linnaeus (37.94%), followed by *Myzus persicae* Sulzer (25.49%), *Brevicoryne brassicae* Linnaeus (19.95%), and *Caunaca cera* Meyrick (3.17%). The relative density of natural enemies ranged from 0.27% (*Micraspis discolor* Fabricius) to 1.62% (*Cotesia plutellae* Kurdjumov).

The data for the second season comprised a total of 30 species, out of which 18 were pests and 12 were natural enemies. A total of eight orders, including Acarina, were recorded during season II, and Lepidoptera was the most represented order. The alpha diversity values represented by Simpson and Shannon Wiener indices ranged from 0.13 to 0.40 and 1.57 to 2.56, respectively. The Margalef index ranged from 2.36 to 4.33 in FF1 and FF7, respectively. The minimum Simpson index (0.13) and maximum Shannon Wiener index (2.56) were found in organic cabbage farming, which also had the highest Pielou’s index (0.76). The relative density for the pests of cabbage in season II revealed that *P. xylostella* was highly abundant (37.3%) followed by *M. persicae* (18.34%) > *B. brassicae* (11.18%) > *C. cera* (3.59%) and *D. semiclausum* (3.17%). The relative density of pest populations ranged from 0.09 (*T. ni*) to 37.3% (*P. xylostella*), whereas for natural enemies, it was in the range of 0.38% (*C. nigrita*) to 3.17% (*D. semiclausum*).

In the third season, a total of 26 species were recorded, comprising of 16 pests and 10 natural enemies. The details are presented in Table 2. Biodiversity indices indicated the Simpson index ranged from 0.13 to 0.24, with the minimum value of 0.13 found in IPM. The Shannon Wiener index ranged from 1.84 to 2.42, with the maximum value of 2.42 found in the IPM field. The Margalef index and Pielou’s indices ranged from 2.40 to 3.56 and 0.67 to 0.76,

respectively. In the case of Pielou’s index, both IPM and organic farming had the lowest values (0.67). The relative density of the pest and natural enemy populations for season III ranged from 0.21 (*A. proxima*) to 30.15% (*P. xylostella*) and from 0.51 (Tachinidae) to 5.39% (*C. plutellae*), respectively (Table 2).

Impact of insecticide use on biodiversity

Rice

The results indicate that the explanatory variable (number of older/newer molecules) had a negative influence on the response variable (pests and natural enemies), as shown in Table 3. The effect of the number of insecticide molecules applied on the pest population resulted in estimates of -0.332, -0.326, and -0.435 for older molecules and -0.615, -0.643, and -0.511 for newer insecticides in season I, II, and III, respectively. Regarding natural enemies, older molecules showed estimates of -0.323, -0.473, and -0.288, and newer molecules had estimates of -0.506, -0.368, and -0.649 during season I, II, and III, respectively.

Cabbage

The application of older and newer molecules resulted in estimated values of -0.37 and -0.44 with standard errors of 0.22 and 0.20, respectively, for the pest population and for the natural enemy population,

Table 2 Biodiversity of arthropods in different production ecosystems of cabbage

Production ecosystem	Season I					Season II					Season III				
	SDI	H'	D	EI	R	SDI	H'	D	EI	R	SDI	H'	D	EI	R (%)
FF1	0.21	2.74	3.02	1.04	20.42	0.29	1.76	2.36	0.56	11.78	0.19	2.04	2.78	0.71	24.94
FF2	0.29	2.19	2.61	0.81	14.33	0.40	1.57	3.35	0.53	11.68	0.18	2.15	2.49	0.76	36.24
FF3	0.26	2.50	3.02	0.81	48.14	0.30	1.79	3.30	0.62	7.11	0.18	2.03	2.40	0.72	46.53
FF4	0.24	2.67	3.28	0.11	46.17	0.32	1.69	2.87	0.59	15.53	0.18	2.15	2.92	0.72	33.60
FF5	0.27	2.38	2.79	0.81	33.63	0.37	1.58	3.20	0.55	11.33	0.24	1.86	2.52	0.67	23.94
FF6	0.33	2.22	2.58	0.77	40.44	0.30	1.81	3.44	0.59	16.10	0.17	2.18	3.10	0.72	30.38
FF7	0.27	2.28	2.31	0.82	41.13	0.18	2.35	4.33	0.70	18.21	0.22	2.08	3.56	0.67	16.59
FF8	0.29	2.24	2.89	0.74	33.90	0.24	2.08	3.95	0.72	5.17	0.17	2.33	3.45	0.73	33.00
FF9	0.50	1.64	2.06	0.66	17.42	0.23	1.81	3.14	0.61	21.25	0.22	2.12	3.53	0.67	27.96
FF10	0.36	1.93	2.01	0.75	30.54	0.24	2.00	3.69	0.66	10.76	0.24	1.84	2.91	0.68	22.93
IPM	0.16	3.09	3.15	1.03	20.90	0.17	2.26	3.80	0.69	21.84	0.13	2.42	3.34	0.76	30.00
ORGANIC	0.23	2.79	3.22	0.11	69.04	0.13	2.56	3.91	0.76	44.21	0.18	2.18	3.25	0.67	85.69

SDI Simpson index, H' Shannon Wiener index, D Margalef index, EI Pielou’s evenness index, R Relative density

Table 3 Estimated parameter values based on the generalized linear mixed model (GLMM) for the relationships among number of pesticide application and biodiversity of rice ecosystem

Variable	SEASON I					SEASON II					SEASON III										
	Est	SE	Z	P		Est	SE	Z	P		Est	SE	Z	P		Est	SE	Z	P		
PESTS																					
Intercept	3.339	0.197	16.964	<2E ⁻¹⁶	2.953	3.724	3.530	0.218	16.214	<2E ⁻¹⁶	3.103	3.957	3.244	0.185	17.567	<2E ⁻¹⁶	2.882	3.606			
NOM	-0.332	0.148	-2.248	0.025	-0.622	-0.043	-0.326	0.163	-1.996	0.046	-0.646	-0.006	-0.435	0.149	-2.924	0.003	-0.726	-0.143			
NNM	-0.615	0.190	-3.238	0.001	-0.987	-0.243	-0.643	0.219	-2.940	0.003	-1.072	-0.214	-0.511	0.194	-2.633	0.008	-0.891	-0.131			
Intercept	3.396	0.192	17.730	<2E ⁻¹⁶	3.021	3.772	3.589	0.214	16.755	<2E ⁻¹⁶	3.169	4.009	3.258	0.176	18.470	<2E ⁻¹⁶	2.913	3.604			
TNM	-0.451	0.088	-5.141	0.000	-0.622	-0.279	-0.455	0.096	-4.728	0.000	-0.643	-0.266	-0.466	0.077	-6.080	0.000	-0.617	-0.316			
NATURAL ENEMIES																					
Intercept	2.956	0.110	26.914	<2E ⁻¹⁶	2.741	3.171	2.886	0.114	25.269	<2E ⁻¹⁶	2.662	3.110	2.444	0.197	12.385	<2E ⁻¹⁶	2.057	2.830			
NOM	-0.323	0.079	-4.076	0.000	-0.479	-0.168	-0.473	0.083	-5.703	0.000	-0.635	-0.310	-0.288	0.153	-1.879	0.060	-0.588	0.012			
NNM	-0.506	0.107	-4.718	0.000	-0.717	-0.296	-0.368	0.111	-3.309	0.001	-0.586	-0.150	-0.649	0.202	-3.220	0.001	-1.044	-0.254			
Intercept	2.984	0.110	27.073	<2E ⁻¹⁶	2.768	3.200	2.873	0.112	25.598	<2E ⁻¹⁶	2.653	3.093	2.507	0.200	12.529	<2E ⁻¹⁶	2.114	2.899			
TNM	-0.396	0.054	-7.266	0.000	-0.502	-0.289	-0.432	0.055	-7.873	0.000	-0.540	-0.325	-0.437	0.091	-4.777	0.000	-0.616	-0.258			

*NOM No. of older molecules, NNM No. of newer molecules, TNM Total no. of molecules, Est. Estimate, SE Standard Error

*The 95% confidence interval for each fixed variable was calculated using “confint.glmTMB (method = ‘Wald’)” function of the R glmTMB package

-0.85 and -0.51 with standard errors of 0.18 and 0.20 for older and newer insecticides, respectively, in season I. The estimated effects on pests in season II were -0.19 and -0.77 with standard errors of 0.10 and 0.23, respectively, and -0.68 and -0.40 with standard errors of 0.10 and 0.17 for natural enemies. In season III, the estimated effects were -0.21 and -0.33 with a standard error of 0.15 for pests and -0.35 and -0.41 with a standard error value of 0.12 for natural enemies in both cases (Table 4).

Discussion

Rice

A survey conducted in various rice fields following IPM and organic practices revealed the presence of arthropods belonging to 49 species, 31 families under 10 orders including Acarina and Araneae, which can be categorized under 23 pest species, 23 natural enemies, and three pollinators. The species-wise relative density revealed that *Scirpophaga incertulas* Walker in season I and *Cnaphalocrocis medinalis* Guenee in season II (82.92%) and III (65.67%) were highly abundant.

The comparison of arthropods in fields with farmer's practices, IPM, and organic practices revealed that organic farming had the highest relative density of 20.30%, 25.30%, and 27.88% in season I, II, and III, respectively. Similarly, a study by Poolprasert and Jongjitvimol (2014) on the diversity of insect pests and natural enemies in organic rice fields in Thailand showed the presence of 34 insect species with a higher dominance of natural enemies (23 natural enemies and 11 pest species). The minimum relative density (2.85%) was observed in season III in the farmer's field (FF8), which indicated the possibility of pesticide impact on arthropods. In the present study, the maximum Shannon–Wiener index (3.07) was observed in organic farming practiced rice fields. Yuan et al. (2019) reported that the Shannon–Wiener index was higher in organic fields (2.40) than in conventional fields (2.20) of rice. The results are also in line with Kousika et al. (2017) who recorded arthropods belonging to 11 orders in tetranilprole treated plots of tomato and reported that the diversity in terms of Shannon–Wiener index was higher in unsprayed fields (3.28) than sprayed fields

(3.16), indicating a higher number of arthropods in untreated plots.

Arthropod diversity in fields where newer and older insecticides were applied was observed during a particular season, and data were analyzed using GLMM. The effects indicated that the pesticides had a negative impact on the insects of rice. Katayama et al. (2019) reported the highest richness and abundance of insects in organic fields compared to conventional and low-input fields and also recorded the negative impact on spiders and dragonfly diversity in the rice ecosystem. Nakanishi et al. (2020) also reported that the annual increase in the application of systemic insecticides such as imidacloprid, fipronil, and chlorantranilprole had a negative impact, in terms of the coefficient (-0.060), on the population growth rate of dragonfly (*Sympetrum frequens* Selys).

Cabbage

The taxonomic composition of cabbage at the generic level showed the presence of 19 pest species and 12 natural enemies, belonging to seven insect orders and a non-insect order Acarina. These findings are in close agreement with those of Senguttuvan and Kuttalam (2018), who also listed eight insect orders in the cabbage ecosystem. Sabado et al. (2004) mentioned that insects dominate the cabbage ecosystem compared to other arthropods. In a comparative study between modified organic systems and conventional vegetable farming by Meyling et al. (2013), a higher level of natural enemy diversity was observed in organic farming than in conventional farming.

The Shannon–Weiner index was higher in the IPM adopted field than in the other 11 fields in season I (3.09) and season III (2.42), whereas organic farming showed the maximum value during season II (2.56). It can be inferred that the minimum use of pesticides could favor the harboring of a greater number of arthropods in the open field ecosystem. The difference in the Shannon–Weiner index value between organic farming and the farmer's field accounted for a 7% increase. Reddy and Giraddi (2019) explained how the diversity of pesticide use pattern affected the biodiversity of insect pests in the farmer's field of vegetables, including cabbage, which revealed that the Simpson index was maximum in the pesticide-sprayed field (0.62) compared to the unsprayed field (0.26) of cabbage. This agrees well with our findings

Table 4 Estimated parameter values based on the generalized linear mixed model (GLMM) for the relationships among number of pesticide application and biodiversity of cabbage ecosystem

Variable	SEASON I					SEASON II					SEASON III									
	Est	SE	Z	P		Est	SE	Z	P		Est	SE	Z	P		Est	SE	Z	P	
					2.50%					2.50%					2.50%					2.50%
PESTS																				
Intercept	4.36	0.28	15.54	<2E ⁻¹⁶	3.808	4.908	3.72	0.26	14.43	<2E ⁻¹⁶	3.214	4.225	4.38	0.29	15.26	<2E ⁻¹⁶	3.815	4.940		
NOM	-0.37	0.22	-1.69	0.091	-0.842	-0.041	-0.19	0.10	-1.93	0.05365	-0.384	0.003	-0.21	0.15	-1.35	0.176	-0.511	0.094		
NNM	-0.44	0.20	-2.16	0.031	-0.807	0.060	-0.77	0.23	-3.37	0.000741	-1.222	-0.324	-0.33	0.15	-2.17	0.030	-0.632	-0.032		
Intercept	4.37	0.27	16.25	<2E ⁻¹⁶	3.845	4.900	3.57	0.24	15.00	<2E ⁻¹⁶	3.103	4.036	4.39	0.29	15.28	<2E ⁻¹⁶	3.827	4.953		
TNM	-0.41	0.11	-3.88	1.05E ⁻⁰⁴	-0.616	-0.202	-0.32	0.07	-4.30	1.68E ⁻⁰⁵	-0.463	-0.173	-0.27	0.08	-3.35	0.001	-0.429	-0.112		
NATURAL ENEMIES																				
Intercept	2.82	0.23	12.37	<2E ⁻¹⁶	2.371	3.264	2.86	0.20	14.53	<2E ⁻¹⁶	2.476	3.249	3.45	0.24	14.52	<2E ⁻¹⁶	2.982	3.913		
NOM	-0.85	0.18	-4.72	2.39E ⁻⁰⁶	-1.199	-0.495	-0.68	0.10	-6.94	3.83E-12	-0.870	-0.487	-0.41	0.12	-3.28	0.001	-0.648	-0.163		
NNM	-0.51	0.20	-2.58	0.009	-0.894	-0.122	-0.40	0.17	-2.31	0.0209	-0.742	-0.061	-0.35	0.12	-2.82	0.005	-0.593	-0.106		
Intercept	2.79	0.23	12.34	<2E ⁻¹⁶	2.348	3.235	2.90	0.20	14.63	<2E ⁻¹⁶	2.508	3.284	3.44	0.24	14.56	<2E ⁻¹⁶	2.980	3.907		
TNM	-0.69	0.10	-6.93	4.28E ⁻¹²	-0.885	-0.495	-0.59	0.07	-8.85	<2E ⁻¹⁶	-0.725	-0.462	-0.38	0.07	-5.59	2.33E ⁻⁰⁸	-0.510	-0.245		

*NOM No. of older molecules, NNM No. of newer molecules, TNM Total no. of molecules, Est. Estimate, SE Standard Error

* The 95% confidence interval for each fixed variable was calculated using “confint:glmmTMB (method = ‘Wald’)” function of the R glmmTMB package

where IPM (0.16) possessed a lower Simpson index indicating the lesser use of pesticides.

The relative density of *P. xylostella* Linnaeus was found to be higher than all other arthropods, with 37.94% in season I, 37.3% in season II, and 30.15% in season III. This result was consistent with the findings of Jat et al. (2017) who reported a higher relative density for cutworms and *P. xylostella* in cabbage ecosystems. The relative density of arthropods in the organic field was 30% higher than in all of the farmers' fields. Similarly, Senguttuvan and Kuttalam (2018) found that unsprayed cabbage fields harbored a maximum number of arthropods (997 individuals) compared to lufenuron-treated fields.

GLMM analysis showed that the newer insecticides had a higher impact than the older insecticides on arthropod diversity in cabbage fields. Chemical control through pesticide usage had a direct effect on arthropod biodiversity. These results are consistent with the findings of Bianchi et al. (2008), who explained the dependence of parasitoid biodiversity on pest management.

Conclusion

Biodiversity analysis in different production systems of rice and cabbage shows that organic farming or fields with minimum chemical interference (IPM adopted) harbor rich diversity. It is also evident that the application of both older and newer insecticides in rice and cabbage ecosystems has a negative impact on pest and natural enemy populations. Furthermore, fields with minimum or no chemical interference could improve diversity in agro-ecosystems, and the trade-offs and benefit loss may be compensated for by the environmental/ecological loss incurred by the indiscriminate use of pesticides in agriculture. Therefore, we believe that production systems with minimum or no chemical interference could benefit both the environment and ecosystem. Further research is needed to refine the production system to attain maximum economic and ecological benefits for the farmers while minimizing the yield losses. This study could be an important contribution to the knowledge for optimizing biological farming through an integrated pest management approach for sustainable agriculture.

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Data availability The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

Competing interests The authors declare no competing interests.

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