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Research Article

Population dynamics and diversity of pests and natural enemies in various organic rice regimes across different phenological stages in rice

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ABSTRACT: A field study was conducted at the ICAR-Indian Institute of Rice Research to investigate insect pest populations and their natural enemies in different organic rice modules during the *rabi* 2020 season. Three organic rice regimes, farmers' practice and untreated control were compared across three phenological stages in rice for the population dynamics of pests and natural enemies of Hemiptera and Hymenoptera. Sampling was done fortnightly for three months using various methods such as visual counting, sticky traps, sweep netting, and D-net. Pest and predator populations peaked during the vegetative stage, while parasitoids peaked during the reproductive stage. Pest population means were highest in untreated control during the reproductive and ripening stages exhibiting the impact of treatments. The predator population was highest in untreated control during the vegetative and reproductive stage, while parasitoid population size was highest in *Pseudomonas* treatment in the vegetative and reproduction stages of the crop and the *Trichoderma* treatment in the ripening stage. Predator diversity was highest in untreated control during vegetative and reproductive stages of the crop while parasitoid diversity was maximum during reproductive and ripening stage. Pearson's correlation coefficient between the population of pests and natural enemies was found to be positive and highly significant.

KEYWORDS: Growth stages, insect pests, *Oryza sativa*, predators, parasitoids

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INTRODUCTION

Rice (*Oryza sativa* L.) is the most important food crop for over half of the world's population, particularly in Asia and Africa. India is one of the world's largest producers of rice. In 2023, the estimated production was over 130 million metric tons (Statistica, 2023). Conventional rice cultivation has often accomplished high yields and stable crop production but has been heavily dependent on continuous and excessive inputs of chemical pesticides, which lead to pest resistance, resurgence, pesticide residue, groundwater contamination and risk to human health and animal habitats (Nagata, 1982; Hirai, 1993). This reliance has led to the depletion of potential natural enemies such as spiders, bugs and Hymenopteran parasitoids, disorganized predator-prey relationships and collapsed the ecological balance in nature leading to increased pest incidences. The dominance of secondary insect pests is a major causative factor in yield loss, either directly eating plant tissue or as a vector of plant pathogens, while natural enemies are biotic components that regulate pest insect populations in the agro-ecosystem, which consists of predators and parasitoids (Hendrival *et al*., 2017). Organic rice plays a significant role in the biocontrol of pests, offering a more environmentally friendly and sustainable approach to pest management.

Recent research has shown that organic management promotes natural pest control through the use of biocontrol agents, leading to a lower number of principal insect pests and reduced damage symptoms in rice fields (Ali *et al*., 2019). Additionally, bio-based Integrated Pest Management (IPM) is considered an important component for controlling insect pests in rice, as it is environmentally benign, effective, and economically sustainable (Fahad *et al*., 2021). Furthermore, a study has indicated that organic rice farming enhances the diversity of aquatic macroinvertebrate predators, contributing to biological pest control (Mendez *et al.,* 2023). Therefore, the role of organic components in rice cultivation leading to better biological control of pests is well-supported by scientific evidence, highlighting its potential for sustainable pest management. So, a study has been taken up to evaluate different BIPM organic treatments with farmer's practice in rice .

MATERIALS AND METHODS

The experiment was laid out at the ICAR-Indian Institute of Rice Research in Rajendranagar in plots of 900 sq. m. for each treatment, using BPT 5204 (Samba Mahsuri) rice variety. 25-day-old seedlings were transplanted into main fields with a spacing of 20 cm x 10 cm. Organic amendments were applied by specific treatments, while untreated control plots received no manures. The study included the following treatments:

(i) BIPM Organic rice treatment with *Trichoderma* (seed treatment and soil application): Nursery: Seed treatment with *Trichoderma* @ 10g/kg seed; rice husk @ 5kg/nursery bed of 8-10 sq. m. + vermicompost @ 5kg/nursery bed of 8-10 sq. m; Main field: Soil application with *Trichoderma* @ 10kg/ha at 30,60 and 90 DAT; Neem cake @ 80kg/acre + FYM @ 6 tons/acre in main field.

(ii) BIPM Organic rice with *Pseudomonas* (seed treatment and sprays): Nursery: Seed treatment with *Pseudomonas* @ 10g/kg seed; rice husk @ 5kg/nursery bed of 8-10 sq. m + vermicompost @ 5kg/nursery bed of 8-10 sq. m; Main field: Spray of *Pseudomonas* -10g/l at 30,60 and 90 DAT; Neem cake @ 80kg/acre + FYM @ 6 tons/acre in main field.

(iii) Farmers' practices: Nursery: Carbofuran 3 G granules in nursery @ 200g/cent nursery; Main field: Foliar sprays with Cartap Hydrochloride @ 2g/l when YSB or Leaf folder crossed ETL, Spray of Chlorpyriphos @ 2.5 ml/l for Hispa beetle.

(iv) Organic rice without seed treatment: Nursery: Rice husk @ 5kg/nursery bed of 8-10 sq. m + vermicompost @ 5kg/nursery bed of 8-10 sq. m in nursery. Main field: Neem cake @ 80kg/acre + FYM@ 6 tons/acre in main field.

(v) Untreated control: Observations on pests and natural enemies were recorded in the treatments at 30 (vegetative stage), 45, 60 (reproductive stage), 90 and 120 DAT (ripening stage) between 7.00 a.m. and 9.00 a.m. by using five methods of collection *viz.,* visual counts, yellow pan traps, yellow sticky traps, sweep net and D-net collections. Ecological indices such as the Average Population Size, Shannon Diversity Index, Evenness, and Richness were also calculated by using the following formulae.

(a) Pielou's Evenness Index (E) (Pielou, 1966)

$$E = H / \ln S$$

where, H = Shannon – Wiener diversity index,

S = Total number of taxa in the sample and

Ln = Natural logarithm

(b) Species richness = S-1/ log N

where, S = Number of species present in the community

N= Number of individuals in the community

(c) Species diversity (H) was calculated using the Shannon-Weaver index (1949).

$$\text{Species diversity (H)} = \sum_{i=1}^{s} (pi)(\ln pi)$$

where, pi = Proportion of ith species in the total sample

pi = fi/n

n = Total number of specimens in the sample

fi = Number of specimens of the ith species

s = Total number of species

ln = Natural logarithm (loge)

RESULTS AND DISCUSSIONS

Results revealed that insect pests of 15 families belonging to 6 orders *viz*., Lepidoptera, Hemiptera, Coleoptera, Diptera, Thysanoptera, and Orthoptera were observed, while 13 families of Hemipteran predators and 16 families of Hymenopteran natural enemies were recorded in the study. Results are discussed based on the stage of the crop as below:

Insect pests

The pest complex was dominated by insects of four families *viz*., Crambidae, Acrididae, Delphacidae and Cicadellidae. The lowest pest population was recorded in farmers' practice (23.30) during the vegetative stage, whereas in the reproductive stage, it was least (15.20) in organic plots without seed treatment followed by *Pseudomonas* treatment (11.60) in the ripening stage indicating the efficacy of *Pseudomonas* and Organic plot in managing the pests. Shannon Diversity index was lowest in *Trichoderma* treatment (1.46) in the vegetative stage while it was 1.33 and 1.42 in farmers' practice in reproductive and ripening stages respectively exhibiting good management of pest population compared to organic treatments and untreated control. The evenness of pest spread was found to be similar in all the treatments in the vegetative stage ranging from 0.70-0.79. Organic rice without seed treatment recorded 10 pest species in the vegetative stage and untreated control recorded 12 pest species in the reproductive and ripening stages respectively indicating the importance of inputs to the pests. Evenness was higher in untreated control and farmers' practice compared to organic treatments. Species richness was found to be higher in organic treatments compared to untreated control and farmers' practices (Table 1).

Table 1. Abundance of insect pests in different organic rice regimes across three phenological stages of the crop

Pest taxa	Vegetative stage					Reproductive stage					Ripening stage				
	T1	T2	T3	T4	T5	T1	T2	T3	T4	T5	T1	T2	T3	T4	T5
Lepidoptera															
Crambidae	15.0	30	15	21	34	9	6	24	2	32	14	14	8	15	36
Hesperiidae	5.0	0	15	14	30	0	7	1	1	6	0	1	0	0	0
Nymphalidae	0	0	0	1	3	1	0	2	1	1	2	0	0	0	0
Noctuidae	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0
Erebidae	0	0	2	1	1	0	0	1	2	2	0	1	0	0	5
Hemiptera															
Delphacidae	58	78	59	43	33	51	59	43	50	89	17	15	13	27	122
Cicadellidae	126	101	93	101	149	92	57	166	52	147	18	31	82	24	50
Pentatomidae	6	8	12	12	25	9	20	12	22	32	27	32	20	40	25
Alydidae	0	0	0	3	5	8	4	3	5	23	9	12	20	16	14
Pyrrhocoridae	0	0	0	0	0	0	0	0	0	0	6	10	0	0	0
Coleoptera															
Chrysomelidae	10	13	14	6	21	2	2	0	0	4	0	0	0	0	0
Diptera															
Ephydridae	0	0	3	0	9	0	0	0	0	0	0	0	0	0	0
Cecidomyiidae	1	6	2	0	2	1	0	0	1	1	0	3	0	0	2
Thysanoptera															
Thripidae	0	0	0	0	0	7	9	7	12	21	7	2	0	0	10
Orthoptera															
Acrididae	53	23	18	42	64	12	10	16	19	20	8	7	11	11	13
$P_{avg.}$	34.30	37.0	23.30	24.40	26.40	19.20	19.30	27.50	15.20	31.50	12.0	11.60	25.70	22.20	34.0
H	1.46	1.54	1.72	1.69	1.76	1.52	1.68	1.33	1.73	1.79	2.01	1.99	1.42	1.70	1.61
Evenness	0.70	0.79	0.75	0.73	0.71	0.66	0.77	0.58	0.72	0.72	0.92	0.83	0.79	0.95	0.78
Richness	8	7	10	10	12	10	9	10	11	12	9	11	6	6	8

T1= *Trichoderma* treatment, T2 = *Pseudomonas* treatment, T3 = Farmers' practice, T4 = Organic rice without seed treatment, T5 = Untreated control, $P_{avg.}$ = Average population, H = Shannon diversity index

Untreated control plots exhibited the highest pest population levels during all phases (26.4 and 31.50 in vegetative and reproductive phases respectively), peaking in the reproductive period (34.00) indicating that all treatments managed pest population adequately. *Trichoderma* treatment displayed peak pest abundance in the vegetative stage, which decreased towards maturity. *Pseudomonas* treatment had the highest pest population during the vegetative stage, with a modest drop in the reproductive phase which could be due to the enhanced effect of bioagent in inducing resistance as the plant matures (Figure 1).

Hemipteran predators

In the vegetative stage of the crop, the higher average population size of predators was recorded in *Pseudomonas* treatment (124.0) while the lowest numbers were seen in farmers' practice (46.80) highlighting the toxicity of farmers' practices to predators. Diversity in untreated control treatment was found to be highest (0.99) as reflected in the Shannon diversity index and it was least in *Trichoderma* treatment (0.41). Evenness was more in the untreated control (0.55) and farmers' practices, while it was less (0.21-0.23) in other treatments. The richness of species was almost the same in all the treatments.

In the reproductive stage, a higher population size (71.50) was recorded in the Organic treatment followed by the *Trichoderma* treatment (66.30), while the rest of the treatments recorded lesser predator numbers (44.00-51.70). Higher Shannon diversity index value and higher species evenness in the untreated control (0.92 and 0.73, respectively) indicated stable predatory assemblage, which was possible due to the absence of treatment applications, while the diversity index ranged between 0.38-0.80 in the

Table 2. Abundance of hemipteran predator taxa in different organic rice regimes across three phenological stages of the crop

Family	Vegetative stage					Reproductive stage					Ripening stage				
	T1	T2	T3	T4	T5	T1	T2	T3	T4	T5	T1	T2	T3	T4	T5
Miridae	406.0	572.0	152.0	459.0	428.0	237.0	213.0	92.0	245.0	126.0	88.0	114.0	22.0	79.0	54.0
Pentatomidae	0.0	0.0	0.0	0.0	0.0	24.0	34.0	57.0	34.0	78.0	43.0	36.0	30.0	42.0	57.0
Geocoridae	0.0	0.0	0.0	0.0	0.0	3.0	1.0	6.0	4.0	13.0	2.0	2.0	1.0	1.0	0.0
Reduviidae	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Veliidae	9.0	20.0	72.0	13.0	24.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mesoveliidae	26.0	22.0	6.0	16.0	14.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Corixidae	1.0	3.0	3.0	6.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Notonectidae	2.0	0.0	0.0	4.0	60.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gerridae	0.0	0.0	0.0	1.0	77.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hydrometridae	0.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Coreidae	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nebidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	1.0	0.0	0.0	0.0	0.0	0.0
Saldidae	1.0	0.0	1.0	2.0	0.0	1.0	1.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
$P_{avg.}$	63.90	124.0	46.80	71.60	101.0	66.30	50.0	51.70	71.50	44.0	44.30	50.70	17.70	40.70	55.50
H	0.41	0.36	0.82	0.41	0.99	0.38	0.47	0.80	0.49	0.92	0.70	0.61	0.76	0.69	0.69
Evenness	0.21	0.23	0.51	0.21	0.55	0.28	0.29	0.73	0.36	0.57	0.64	0.56	0.69	0.63	0.99
Richness	7	5	5	7	6	4	5	3	4	5	3	3	3	3	2

T1= *Trichoderma* treatment, T2 = *Pseudomonas* treatment, T3 = Farmers' practice, T4 = Organic rice without seed treatment, T5 = Untreated control, $P_{avg.}$ = Average population, H = Shannon diversity index.

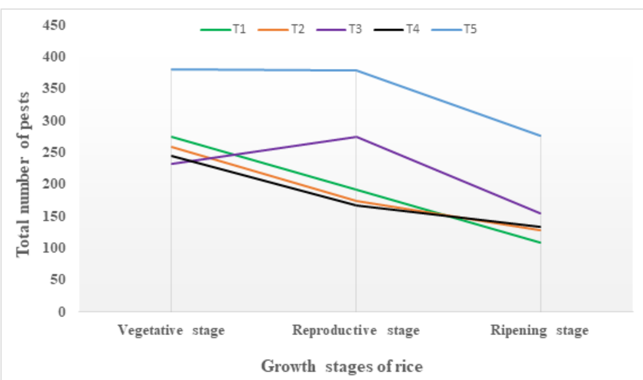

Figure 1. Population dynamics of pests in various growth stages of rice in different organic rice regimes. (T1 - *Trichoderma* treatment, T2 - *Pseudomonas* treatment, T3 - Farmers' practice, T4 - Organic rice without seed treatment T5 - Untreated control).

rest of the treatments and evenness was between 0.28-0.57 in the other treatments.

In the ripening stage, untreated control yet again registered the highest average population (55.50) followed by *Pseudomonas* (50.70) and it was lowest in farmers' practices (17.70) highlighting the impact of treatments on predator density. However, due to similar evenness and species richness of Hemipteran predators, similar predator diversity and species richness were observed across all treatments. Species evenness, however, was found to be highest (0.99) in untreated control plots, while it was lower (0.56-0.69) in the rest of the treatments. Details of families recorded under Hemiptera are given in Table 2.

Hemipteran predators were found to be more abundant in all stages irrespective of treatments, except in farmers' practices, which had the lowest predator population. Pesticides adversely affected predator populations, with a higher impact observed in farmers' practices. Predator dynamics in the entire crop growth period peaked in the vegetative stage and decreased as the crop matured and this is correlated with the pest population size. *Pseudomonas* and untreated control treatments experienced a significant decline in predator populations after the vegetative stage (Figure 2).

Natural enemies of Hymenoptera

Population sizes of Hymenopteran parasitoids were found to be much higher than those of pests and Hemipteran predators in general. In the vegetative stage, the average population size of parasitoids belonging to Hymenoptera varied depending on the treatment; *Pseudomonas* had the largest count (112.00), followed by farmers' practice (106.00), *Trichoderma* treatment (100.00), untreated control (92.30), and organic rice without seed treatment (77.10). According to the Shannon diversity index, the most diverse parasitoid population was found in *Trichoderma* treatment (1.17), followed by *Pseudomonas* treatment (1.08), while

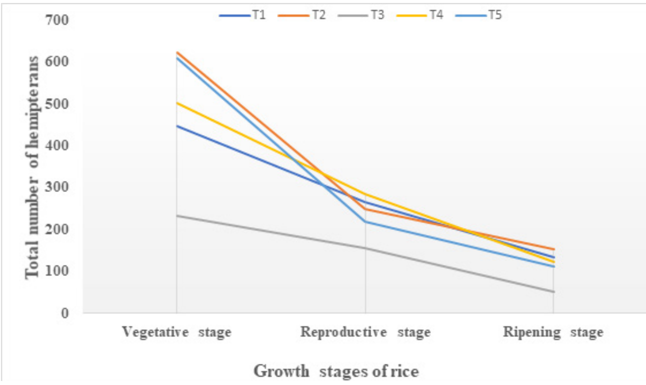

Figure 2. Population dynamics of Hemipterans in various growth stages of rice in different organic rice regimes.

other treatments recorded similar diversity levels (0.95-0.96). Species evenness was found to be almost similar in all treatments in this crop stage. Richness, however, was higher (12) in the *Pseudomonas* treatment and untreated control compared to (7) in the Farmers' practice. A higher average of Hymenopteran natural enemies was spotted in the *Pseudomonas* and farmers' practices treatments, while intermediate numbers were found in the *Trichoderma* and organic rice without seed treatment. Untreated control showed the lowest numbers with a higher Shannon diversity index and was lower in the *Pseudomonas* treatment. Details of families recorded under Hymenoptera are furnished in Table 3.

In the reproductive stage, *Pseudomonas* treatment recorded the highest average population of Hymenopteran natural enemies at 197, followed by farmers' practice (173) while the untreated control had the least at 78.40. The diversity index was highest in untreated control (1.32) followed by 1.20 in *Trichoderma* treatment, while others recorded lesser diversity. Species richness was higher in the untreated control and *Trichoderma* treatment (11) compared to other treatments.

In the ripening stage of the crop, the average population size of parasitoids was highest in *Trichoderma* treatment (70.40) followed by others (32.2-66.00). Untreated control exhibited the highest Shannon diversity index (1.35) and highest evenness (0.59) suggesting higher overall diversity.

Table 3. Abundance of hymenopteran taxa in different organic rice regimes across three phenological stages of the crop

Hymenopteran taxa	Vegetative stage					Reproductive stage					Ripening stage				
	T1	T2	T3	T4	T5	T1	T2	T3	T4	T5	T1	T2	T3	T4	T5
Eulophidae	510.0	898.0	511.0	645.0	803.0	543.0	968.0	586.0	548.0	480.0	378.0	325.0	367.0	351.0	175.0
Platygastridae	232.0	208.0	131.0	65.0	43.0	135.0	155.0	345.0	94.0	69.0	63.0	67.0	78.0	28.0	37.0
Trichogrammatidae	61.0	93.0	57.0	54.0	106.0	111.0	143.0	191.0	100.0	156.0	57.0	58.0	122.0	51.0	72.0
Braconidae	2.0	8.0	2.0	2.0	2.0	4.0	2.0	0.0	2.0	4.0	0.0	0.0	1.0	3.0	3.0
Ichneumonidae	3.0	2.0	0.0	12.0	7.0	2.0	1.0	0.0	3.0	9.0	1.0	3.0	0.0	0.0	7.0
Diapriidae	4.0	8.0	3.0	3.0	13.0	9.0	4.0	1.0	4.0	14.0	8.0	3.0	1.0	3.0	5.0
Mymaridae	82.0	108.0	30.0	46.0	127.0	95.0	111.0	58.0	79.0	120.0	51.0	70.0	17.0	29.0	18.0
Dryinidae	6.0	9.0	0.0	11.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Eurytomidae	0.0	1.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Platygastridae	0.0	3.0	5.0	6.0	1.0	1.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0	1.0	2.0
Formicidae	1.0	0.0	0.0	2.0	0.0	1.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0
Bethylidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0
Torymidae	0.0	2.0	0.0	2.0	1.0	0.0	0.0	0.0	1.0	2.0	0.0	1.0	1.0	1.0	2.0
Ceraphronidae	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	1.0	2.0	0.0	0.0	1.0	1.0	1.0
Cynipidae	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Chalcididae	0.0	1.0	0.0	0.0	2.0	1.0	1.0	0.0	0.0	3.0	4.0	1.0	1.0	1.0	0.0
$P_{avg.}$	100.0	112.0	106.0	77.10	92.30	82.20	173.0	197.0	92.40	78.40	70.40	66.0	65.40	42.70	32.2
H	1.17	1.08	0.96	0.95	0.96	1.20	0.97	1.16	1.08	1.32	1.08	1.15	1.05	0.93	1.35
Evenness	0.53	0.44	0.49	0.39	0.39	0.50	0.47	0.65	0.49	0.55	0.52	0.56	0.48	0.39	0.59
Richness	9	12	7	11	12	11	8	6	9	11	8	8	9	11	10

T1= *Trichoderma* treatment, T2 = *Pseudomonas* treatment, T3 = Farmers' practice, T4 = Organic rice without seed treatment, T5 = Untreated control, $P_{avg.}$ = Average population, H = Shannon diversity index

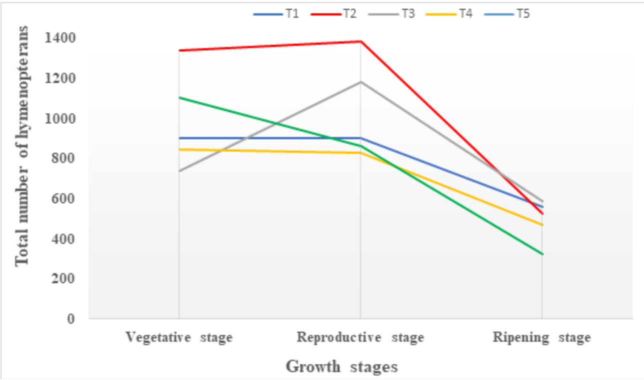

Figure 3. Population dynamics of Hymenopterans in various growth stages of rice in different organic rice regimes.

However, a greater number of species were observed in organic rice without seed treatment (Table 3). Hymenopteran natural enemies peaked during the vegetative stage, almost similar tendency was observed till the reproductive stage and then a sharp decline towards the ripening stage of rice occurred and this correlated with the pest dynamics (Figure 3).

Correlation between pests and natural enemies

Pearson's correlation coefficient between the population of pests and natural enemies was found to be positive and highly significant and suggested that the population dynamics of natural enemies bore a resemblance to that of the pests as the correlation significance was highly significant at a 5% level (Table 4). This surge in the population of predators and parasitoids resulting from the increase in pest population enhanced the chances of better biological control of pests.

Organic farming offers a feasible alternative to conventional agriculture, potentially increasing species richness by approximately 34% and abundance by around 50% (Smith *et al*., 2020; Reganold & Wachter, 2016; Niggli, 2015; Tuck *et al*., 2014). In the present study, no single treatment recorded lesser pest averages and higher natural enemy averages in all stages of the crop, except untreated control, which recorded more pest averages and higher diversity of natural enemies in a few crop stages. Organic without seed treatment, *Pseudomonas* and *Trichoderma* treatments, however, recorded lesser pest averages throughout the crop stages. However, there was no difference in the insect diversity between conventional and organic farming practices. Since, the present study was taken up for one season, probably, with the use of these eco-friendly inputs for longer periods like 2-3 years, differences between treatments would have been more apparent and results would be the same in all stages of crop. The diversity and population dynamics of natural enemies in organic rice fields can be influenced by various factors, such as vegetation management and phenological stages of crops. Population variations of natural enemies in all treatments were positively correlated to pest populations which indicated that the population of pests and natural enemies depends on each other and leads to effective natural biological control. Koh *et al.* (2021) reported that in simplified environments, farming practices might not have an impact on insect biodiversity during pest-control interventions. Natural enemies can effectively reduce pest populations when they coincide spatially and temporally with those populations. Many biotic and abiotic factors influence the spatial and temporal association between pests and natural enemies (Karimzadeh & Sciarretta, 2022). In organic rice fields, Hemiptera was found to comprise the highest number of taxa, followed by Odonata and Diptera in the early period (30 DAT) (Thongphak & Iwai, 2016). In the present study, predator dynamics peaked in the vegetative stage of the crop and decreased as the crop matured. Similarly, a study recorded Hemiptera as the most dominant insect group in the rice field until the flowering stage (Hashim *et al*., 2017). Further, Poolprasert and Jongjitvimol (2014) examined insect pests and natural enemies in organic treatment and reported that species diversity (H') across all rice stages was notably high, with a calculated value of 2.54. Significant variations in species diversity indices among the eight rice planting stages were observed in all comparisons ($p<0.05$). Likewise, Bambaradeniya and Edirisinghe (2008) reported a significant positive relationship between the number of Hemiptera and other insect groups, such as predators, parasitoids, and visitors/pollinators. Observations on the population of primary pests indicated a milder fluctuation in organic rice fields compared to conventionally cultivated ones. Conversely, subordinate pest species showed minimal distinctions between these two types of fields. and the number of natural enemies was higher in organic rice fields than in conventionally cultivated ones (Huang *et al*., 2005). In a study conducted in Brazil, the most abundant Hymenoptera

Table 4. Correlation coefficients of pests with Hemipteran and Hymenopteran natural enemies in various organic rice regimes

Treatments	Hemipteran natural enemies	Hymenopteran natural enemies
Trichoderma treatment	0.995	0.865
Pseudomonas treatment	0.988	0.738
Farmers' practice	0.697	0.899
Organic rice without seed treatment	0.989	0.761
Untreated control	0.688	0.959

families were Mymaridae and Eulophidae, with a total of 3,184 parasitoids in the irrigated organic rice (Pires *et al*., 2016). However, in our study, the highest abundance and highest diversity of parasitoids were exhibited by farmers' practice and *Trichoderma* treatment, respectively, during the reproductive stage. Ikhsan *et al.,* (2020) observed richness and abundance of parasitoids with peak abundance during the vegetative period in Indragiri Hilir District, Indonesia. Xin *et al*. (2019) reported that species richness, predator and parasitoid evenness were higher in organic fields than in conventional rice fields in across four sites in China. They also found that plant hopper density showed a significant negative relationship with increased richness and evenness for both predators and parasites. Shannon–Weiner index was higher in organic fields than in conventional counterparts in the tillering stage and milking stage. As the Shannon–Weiner index increased, the number of planthoppers decreased, $Y = 2.4116 - 0.2229 H'$ (n = 69, R2 = 0.1608, adjusted R2 = 0.1483, root mean square error = 0.4608. In the current study, predators and parasitoids showed a positive correlation with the insect pests, likewise, yellow stem borer had a positive significant correlation with Hymenopterans (r=+0.452), gall midge had a positive but nonsignificant correlation with Hymenopterans (r=+0.336), BPH had a positive and significant with mirids (r=+0.770) and nonsignificant correlation with Hymenopterans (r=+0.189). The leaf folder indicated a non-significant correlation with mirids (r=+0.328) and Hymenopterans (r=+0.264) (Parasappa *et al*., 2017).

CONCLUSION

The present study was an attempt to sample and study population dynamics of pests and natural enemies of Hemiptera and Hymenoptera in various organic treatments through different stages of rice in a season. The organic plot without seed treatment, *Pseudomonas* and *Trichoderma* treatments recorded lesser pest incidence and *Pseudomonas* and *Trichoderma* treatments supported higher species diversity and species richness of natural enemies in different stages of the crop. This reduced pest incidence could be due to increased natural enemy abundance supported by the application of organic amendments. These different modules can be combined into a single treatment based on the feasibility and recommended to farmers for management of insect pests effectively and also maintain ecosystem balance.

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