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Y Sai Prakash Reddy
Ph.D. Scholar, Department of Entomology, IARI-IIHR, Bengaluru, Andhra Pradesh, India

B Ratna Kumari
Assistant Professor, Department of Entomology, APGC, Lam, Guntur, ANGRAU, Andhra Pradesh, India

M Sesha Mahalaksmi
Professor (Entomology), Technical officer to Dean of Agriculture, ANGRAU, Andhra Pradesh, India

CH Varaprasada Rao
Principal Scientist, Department of Plant Pathology, ANGRAU, Andhra Pradesh, India

Corresponding Author:
Y Sai Prakash Reddy
Ph.D. Scholar, Department of Entomology, IARI-IIHR, Bengaluru, Andhra Pradesh, India

Balancing pest control and biodiversity: Differential impacts of insecticides on arthropod diversity in direct-sown rice ecosystem

Y Sai Prakash Reddy, B Ratna Kumari, M Sesha Mahalaksmi and CH Varaprasada Rao

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Abstract
The overreliance on insecticides for pest management in global rice production often overlooks their adverse effects on non-target arthropods, threatening agroecosystem stability. This study evaluated the differential impacts of six insecticides flubendiamide, triflumezopyrim, thiamethoxam, cartap hydrochloride, pymetrozine, and acephate on arthropod diversity across three growth stages in a direct-sown rice ecosystem during the 2023 *kharif* season. Arthropods were sampled using sweep netting, pitfall trapping, and Berlese funnel extraction. Results indicated that all insecticides suppressed both pest and non-target arthropod populations, but the magnitude of impact was compound and timing specific. Flubendiamide demonstrated high pest efficacy but was severely detrimental to non-targets, particularly during early tillering and ripening. Cartap hydrochloride was comparatively favourable to natural enemies in early stages, whereas thiamethoxam and acephate exhibited broad toxicity across growth stages. Unsprayed control plots consistently maintained the highest species richness and diversity indices. These findings highlight a critical trade-off between effective pest control and the conservation of beneficial arthropod biodiversity, underscoring the necessity of integrating selective insecticide use with stage-specific application within an Integrated Pest Management (IPM) framework to promote ecological balance in rice agroecosystems.

Keywords: Arthropod diversity, Crop phenology, Direct sown rice, Ecological balance, Pest management

Introduction
Rice, (*Oryza sativa* L.) serves as the primary food source for more than half of the global population and is the second most significant cereal crop, classified within the *Poaceae* family (Kumar *et al.*,2022) [12]. In India, the cultivated area of paddy was 47.83 million hectares with a production and productivity of 135.76 million tonnes and 2838 kg.ha^{-1}, respectively during 2022-23. The productivity of rice in AP is far higher than national average due to advanced crop management techniques followed in AP by rice farmers and the state is popularly known as Rice Bowl of India (Hemanth *et al.*,2024) [8]. Total area grown under paddy in Andhra Pradesh was 2.13 million ha, with production and productivity of 7.94 million tonnes and 3727 kg.ha^{-1}, respectively and about 67.56 per cent of the rice is cultivated under irrigated conditions (DES, DAC&FE, Ministry of Agriculture & Farmer Welfare, GOI, 2023). In India, rice cultivation predominantly relies on inefficient irrigation techniques, resulting in low water use efficiency and contributing to various environmental issues (Mallareddy *et al.*,2023) [14]. One of the solutions to tackle the problems is the cultivation of direct sown rice. Over 800 species of insects associated with rice have been documented across global ecosystems. Of these, approximately 700 species are deemed beneficial as they do not inflict harm on rice crops, while around 100 species are known to be pests that actively damage rice (Iqbal, 2020) [9]. Approximately 20 to 30 per cent of agricultural products were lost each year as a result of damage caused by insect pests, diseases, weeds, and rodents (Rahaman *et al.,* 2018) [15]. The losses have been heaviest in developing countries with a 13-16% loss in field condition (Culliney, 2014) [3]. One of the methods deployed to combat this loss is the application of insecticides due to their quick response, easy to use, cost effective and reliable effectiveness against insect pests.

Improper usage of insecticides also kills the natural enemies which play an important role as biological control agents in reducing insect pest populations in rice fields. Insecticide application during the early stages of the season is commonly believed to be efficient. However, upon closer examination, it becomes evident that it disrupts the ecological equilibrium by eliminating natural predators and parasitoids, thereby leading to a potential rise in pest resistance (IRRI, 2016; Abhilash and Singh, 2009) [1]. Therefore, the objective of this study was to evaluate the differential impact of six insecticides with distinct modes of action on the diversity and abundance of pest, neutral, and beneficial arthropod communities across key phenological stages in a direct-sown rice ecosystem.

Materials and Methods

Experimental location and design

Field investigations were carried out to study the impact of insecticides on arthropod diversity during *kharif*, 2023 at Agricultural College Farm, Bapatla which is situated at $15^0$55'23" N latitude and $80^0$28'50" E longitudes with an elevation of 5 meters above MSL. The field experiment was laid out in Randomized Block Design with three replications. The size of the plot was 5 x 5 m^2 and popular variety Samba Mashuri (BPT-5204) was taken as test cultivar in the present investigation during *kharif* season, 2023 in direct sown method. Various insecticides from distinct groups and with unique modes of action were employed in the study to assess their impact on arthropod diversity. A total of six insecticides were evaluated along with the control as enlisted in the Table 1.

Insecticidal application and Arthropod sampling

Insecticides were sprayed thrice at 30 DAS, 60 DAS and 90 DAS. Granular formulation of insecticides was weighed accurately using electronic balance and mixed with 10 times sand and then broadcasted in the field in order to achieve uniform spread. Arthropod sampling commenced 10 days after each insecticide application and continued until 120 Days After Sowing (DAS). Sweep nets and aspirator were used to collect aerial insects whereas soil and subsoil insects were collected using pitfall traps and Berlese funnel technique, respectively. Collected arthropod samples were sent to Taxonomists at Zoological Survey of India, S.V Agricultural College Tirupati and National Bureau of Agricultural Insect Resources.

Data analysis

Diversity indices were computed using PAST program (Hammer and Harper, 2001) [7]. The data recorded on different categories of arthropods during the course of investigation are subjected to two way ANOVA and carried out least significant difference test for statistical difference among the treatments using KAU grapes (Gopinath *et al*., 2021) [6].

Table 1: List of insecticides evaluated in the study

Treatment number	Active ingredient	Strength and formulation	Recommended dose (a.i. ha-1)
T1	Flubendiamide	39.35% SC	24g
T2	Triflumezopyrim	10% SC	20g
T3	Thiamethoxam	25% WG	25g
T4	Cartap hydrochloride	4% G	1000g
T5	Pymetrozine	50% WG	150g
T6	Acephate	75% SP	750g

Results & Discussion

Insecticide applications made in direct-sown rice caused dramatic changes both in terms of number and diversity of arthropods populations, but effects varied among insecticides compounds applied to each phase on the crop.

Effects on Arthropods through Development Stages

The mean population of natural enemies, pests, and neutral insects across different treatments and growth stages is detailed in Table 3. During the early tillering stage, the population of natural enemies was significantly highest in the cartap hydrochloride plot (41.33) and the unsprayed control plot (40.66), which were statistically on par. These were followed by triflumezopyrim (29.66). The lowest natural enemy populations were recorded in plots treated with flubendiamide (19.00). In contrast, flubendiamide was the most effective treatment against pests (2.33) and neutral insects (2.33), with both values being significantly lower than all other treatments. The control plot harboured the highest populations of pests (7.00) and neutral insects (8.66). By the late tillering stage, the highest populations of natural enemies were observed in plots treated with triflumezopyrim (20.33) and flubendiamide (18.00), which were statistically similar to the control (19.66). Contrarily, pymetrozine (10.33) and acephate (12.00) resulted in the most significant suppression of natural enemies. Against pests, acephate (14.66) was among the least effective insecticides, while the control plot maintained the highest pest population (25.00). For neutral insects, the control again had the highest population (5.66), with pymetrozine (2.33) causing the greatest reduction. During the ripening stage, the control plot consistently supported the highest populations of natural enemies (24.00), pests (21.00), and neutral insects (6.66). Among the insecticides, flubendiamide, thiamethoxam, and acephate were most detrimental to natural enemies, with populations ranging from 12.00 to 12.69. Cartap hydrochloride was most effective against pests (13.33), though significantly less so than the control. Flubendiamide again demonstrated the strongest suppressive effect on neutral insects (1.00).

Arthropod Diversity Indices

Analysis of diversity indices revealed clear differences between insecticide-treated and control plots (Table 2, Fig. 1). The unsprayed control plots consistently showed the highest values for key diversity indices across all three growth stages, including the number of taxa (S), Shannon-Wiener index (H'), and Simpson's diversity index (1-D). The evenness (E) and Berger-Parker indices also indicated a more balanced and diverse community in the control plots.

The impact of individual insecticides on diversity was compound-specific and stage-dependent. For instance, the application of flubendiamide and acephate resulted in lower Shannon-Wiener (H') and Simpson (1-D) indices during the early tillering and ripening stages, indicating reduced diversity. Contrarily, cartap hydrochloride and triflumezopyrim allowed for relatively higher diversity in the early and late tillering stages, respectively. The dominance index (D) was generally higher in insecticide-treated plots compared to the control, reflecting a community dominated by fewer species.

Although a variety of studies have investigated their effect on rice arthropods but very few studies compared the selective toxicity potentiality between next-generation insecticides namely, flubendiamide and triflumezopyrim over entire crop phenology under direct sown condition wherein associated ecological relation is different as well from transplanted scenario. The study demonstrates an unmistakable dilemma in controlling pests with insecticides: immediate benefits from pest suppression goes against maintaining the long-term biodiversity of beneficial arthropods by application on direct-sown rice. Results showed that all insecticides tested had some negative impact on the arthropod diversity indices in comparison to unsprayed control. This results corroborates that of Gangurde (2007), Bakar and Khan (2016); Kousika *et al* [2, 5, 11]. We expect this result, as the opposite was never found in Cao *et al*., 2017) where species richness and diversity were always higher at untreated rice plots. Overall reductions in diversity metrics reflect the universal impact of large-scale chemical interventions, regardless how specific they may be for particular pests given their essential reliance on other non-target arthropod members underlying ecosystem functioning. Differential toxicity of the insecticides to natural enemies was very distinct and differed according to crop phenology. Exposure to natural enemies during the early tillering stage in any case is high which can be related to low canopy as carcinoma and contact toxicity of such flubendiamide, thiamethoxam and acephate (Raut *et al*., 2023) [16]. Instead, the most important result with respect to natural enemies at this early stage is likely that cartap hydrochloride turned out quite safe for all of them comparatively. This is perhaps related to its direct, nicotinic acetylcholine receptor antagonist mode of action that would be less immediately toxic for predatory beetles and spiders than the neurotoxic actions of others. On the other hand, its negative effects in more advanced stages provide evidence for possible indirect consequences (prey loss or secondary poisoning).

The variable effects observed across growth stages highlight the importance of application timing. The fact that an insecticide like flubendiamide was highly detrimental to natural enemies in early and late stages but relatively safe during late tillering suggests that the complex interplay of crop architecture, weather, and arthropod behaviour modulates toxicity. This complexity is supported by the meta-analysis of Li *et al*. (2024), which revealed that the impact of temperature rise interacts significantly with both the type of insecticide and the insect group. Although their study found that changes in moisture levels alone were not a primary factor, meta-regression indicated a positive correlation between insecticide efficacy and the extent of humidity changes. Our field observations of temporal variability in insecticide impact are consistent with the laboratory-based findings of Li *et al*. (2024) [13], confirming that environmental parameters must be considered when predicting the ecological consequences of insecticide use or particularly under changing climatic conditions. The reduction in natural enemy populations, even when not directly caused by contact toxicity, may also stem from a reduction in their efficacy after consuming intoxicated prey. Sublethal effects, such as reduced foraging efficiency, repellent nature, or physiological impairment, can diminish the biological control services provided by these beneficial species, leading to a phenomenon known as "pest resurgence" where pest populations rebound to higher levels than before treatment (IRRI, 2016). The significant pest populations maintained in the control plots, alongside high natural enemy numbers, suggest a functioning predator-prey dynamic that was disrupted in the treated plots.

The practical implication of our study is that the choice of insecticide and its application timing should be strategically made to minimize ecological damage. No single compound was ideal across all stages. For instance, if an application is necessary during early tillering, cartap hydrochloride may be a preferable option due to its lower initial impact on natural enemies. However, its use later in the season should be reconsidered. The consistent superiority of the control plot in maintaining biodiversity strongly advocates for the principles of Integrated Pest Management (IPM).

In conclusion, our findings demonstrate that calendar-based insecticide applications are incompatible with the goal of ecological sustainability in rice agroecosystems. Future pest management strategies must evolve towards a more detailed, stage-specific approach that incorporates selective insecticides within a robust IPM framework to harness the power of natural biological control.

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