J. Trop. Plant Pests Dis.
Vol. 26, No. 2, September 2026
Pages: 485–497

ISSN: 1411-7525
E-ISSN: 2461-0399
DOI : 10.23960/j.hptt.226485-497

RESEARCH PAPER

Field evaluation of biorational insecticides for managing major rice pests and conserving natural enemies in South Sulawesi, Indonesia

Jumardi[1], Desriani[1], Muh Sandy[1], Erwin Erwin[2], Nurasiah Djaenuddin[3], & Andi Nasruddin[2]

Manuscript received: 22 November 2025. Revision accepted: 01 January 2026. Available online: 29 July 2026

ABSTRACT

The brown planthopper (*Nilaparvata lugens*), green leafhopper (*Nephotettix virescens*), and yellow stem borer (*Scirpophaga incertulas*) are among the most destructive insect pests of rice in Indonesia. This study evaluated the field performance of four biorational insecticides (abamectin, azadirachtin, *Beauveria bassiana*, and *Metarhizium anisopliae*) and two synthetic insecticides (carbofuran and demihipo) in a rice field in Belawa, Wajo Regency, South Sulawesi, Indonesia. The experiment was arranged in a split-plot randomized complete block design. All biorational insecticides significantly reduced pest populations compared with the untreated control. Abamectin provided the greatest suppression of *N. lugens* (84.1%), whereas abamectin, carbofuran, and demihipo were the most effective treatments against *N. virescens*, reducing populations by 71.8%, 69.2%, and 82.4%, respectively. Against *S. incertulas*, azadirachtin and abamectin achieved the highest reduction in dead-heart incidence (91.9% and 85.7%, respectively). Predator populations, particularly *Coccinella* spp., were largely conserved in plots treated with azadirachtin, *B. bassiana*, and *M. anisopliae*, indicating good compatibility with beneficial arthropods. Weekly applications provided pest suppression comparable to twice-weekly applications, suggesting that insecticide inputs can be reduced without compromising efficacy. Overall, the findings demonstrate that biorational insecticides can be effectively integrated into rice IPM programs to suppress major pests, conserve beneficial arthropods, and reduce reliance on conventional synthetic insecticides, thereby supporting more sustainable rice production.

Keywords: Biorational insecticides, integrated pest management, *Nilaparvata lugens, Nephotettix virescens, Scirpophaga incertulas*

INTRODUCTION

Rice (*Oryza sativa* L.) is one of the world's most important staple crops, providing food for more than half of the global population (IPPC, 2022). In Indonesia, rice has exceptional socio-economic importance, with approximately 98.3% of the population relying on it as their primary staple food (Center for Agricultural Data and Information System, 2023). Maintaining stable rice production is therefore essential for ensuring national food security. However, rice production in Indonesia declined from 54.60 million tons of milled dry grain in 2019 to 53.63 million tons in 2023 (BPS-Statistics Indonesia, 2023). This decline has been attributed to multiple interacting factors, including climate variability, suboptimal crop management practices, and increasing pressure from insect pests and plant diseases (Ansari et al., 2023).

Although more than 800 insect species have been reported from rice ecosystems, only a small proportion cause economically significant yield losses (Horgan et al., 2021). Among these, the brown planthopper (*Nilaparvata lugens* Stål) (Hemiptera: Delphacidae), the green leafhopper (*Nephotettix virescens* Distant) (Hemiptera: Cicadellidae), and the rice yellow stem borer (*Scirpophaga incertulas* Walker) (Lepidoptera: Crambidae) are regarded as the most destructive pests in tropical Asian rice production systems.

The brown planthopper (BPH) is one of the most damaging rice pests because it causes both direct and indirect losses. Direct feeding on phloem sap induces hopperburn, resulting in plant wilting, desiccation, and eventual death (Garrood et al., 2016; Wu et al., 2018). In addition, BPH serves as an efficient vector of Rice grassy stunt virus (RGSV) and Rice ragged stunt virus (RRSV), thereby amplifying crop losses during outbreaks (Chen et al., 1982; Heong et al., 2015; Khoa

Corresponding author:
Jumardi (jumardiunisan@gmail.com)

[1]Study Program of Plant Protection, Faculty of Agriculture, Universitas Ichsan, Sidenreng Rappang, Sulawesi, Indonesia 91611
[2]Department of Plant Pest and Disease, Faculty of Agriculture, Hasanuddin University, Makassar, Sulawesi, Indonesia 90245
[3]Food Crop Research Center, National Research and Innovation Agency (BRIN), Cibinong, Indonesia 16911

et al., 2018; Wang et al., 2022). Severe infestations have repeatedly occurred in Indonesia; for example, in 2010, approximately 128,738 ha of rice fields along the northern coast of Java were infested, with 4,602 ha experiencing complete crop failure (Sofyan et al., 2019).

The green leafhopper (GLH), *N. virescens*, generally causes limited direct feeding damage but is recognized as the principal vector of Rice tungro virus (RTV), one of the most destructive viral diseases affecting rice production in South and Southeast Asia (Widiarta et al., 2004; Thresh, 1989; Wang et al., 2022). Recent studies also demonstrated that the demographic performance of *N. virescens* varies among rice varieties, further emphasizing the importance of effective vector management (Hutasoit et al., 2025). Meanwhile, the rice yellow stem borer (*S. incertulas*) attacks plants throughout both vegetative and reproductive growth stages. Larval feeding inside rice stems disrupts water and nutrient transport, resulting in "dead heart" symptoms during vegetative growth and "white head" symptoms during grain filling. Yield losses may reach 60–87.7% under severe infestations (Baehaki, 2015; Pallavi et al., 2017; Horgan et al., 2021; Subedi et al., 2024). Because the larvae remain concealed inside the stem, effective management using conventional foliar insecticides is often difficult.

Control of these pests in Indonesia continues to rely predominantly on repeated applications of broad-spectrum synthetic insecticides. Excessive and prophylactic insecticide use has accelerated the development of insecticide resistance, disrupted biological control through the elimination of natural enemies, increased the risk of pest resurgence, and generated environmental and food safety concerns (Heong et al., 2015; Isman, 2020). These challenges have reinforced the need for environmentally sustainable pest management strategies that effectively suppress pest populations while conserving beneficial arthropods.

Biorational insecticides have emerged as promising alternatives because of their selective modes of action and relatively low environmental impact. These products include microbial insecticides based on entomopathogenic fungi such as *Metarhizium anisopliae* and *Beauveria bassiana*, botanical insecticides derived from neem (*Azadirachta indica*), and microbially derived insecticides such as abamectin and spinosyn (Tang et al., 2019; Bamisile et al., 2021; Isman, 2020; Irsad et al., 2023). Unlike many conventional insecticides, biorational products may act through multiple mechanisms, including direct toxicity, antifeedant activity, repellency, growth regulation, and pathogenic infection, while generally exerting lower adverse effects on non-target organisms. Consequently, they are considered compatible with Integrated Pest Management (IPM) programs.

Previous studies have demonstrated that entomopathogenic fungi can significantly reduce populations of brown planthoppers and leafhoppers under laboratory and field conditions, whereas neem-based products effectively suppress feeding, oviposition, and population development of several rice pests (Tang et al., 2019; Bamisile et al., 2021; Irsad et al., 2023). Nevertheless, the effectiveness of biorational insecticides under farmers' field conditions often varies according to environmental factors, pest pressure, cropping practices, and interactions with local natural enemy communities. Furthermore, most previous studies have focused on individual pests or single classes of biorational insecticides, with relatively little attention given to their simultaneous performance against multiple major rice pests while evaluating their compatibility with beneficial arthropods under field conditions.

In South Sulawesi, one of Indonesia's major rice-producing regions, farmers still depend largely on synthetic insecticides for routine pest management. However, comprehensive field evaluations comparing commercially available biorational insecticides against the principal rice pests while simultaneously assessing their effects on natural enemies remain limited. Such information is essential for developing locally adapted IPM strategies that balance effective pest suppression with biodiversity conservation.

Therefore, the present study evaluated the field performance of several commercial biorational insecticides against the three major rice pests—brown planthopper (*N. lugens*), green leafhopper (*N. virescens*), and rice yellow stem borer (*S. incertulas*)—under rice field conditions in South Sulawesi, Indonesia. Specifically, the study aimed to (1) compare the efficacy of different commercial biorational insecticides in suppressing pest populations and stem borer damage, and (2) determine their compatibility with beneficial arthropods. The findings are expected to support the integration of biorational insecticides into sustainable IPM programs for rice production in Indonesia.

MATERIALS AND METHODS

Research Site. The experiment was conducted during the dry season (May to September 2024) in a farmer's rice field located in Belawa, Wajo Regency, South Sulawesi, Indonesia (3°58'29" S, 119°54'29" E; 62.2 m above sea level). The area is one of the major rice-producing regions in South Sulawesi and is supplied with irrigation throughout the year. The study site is endemic to the brown planthopper (*N. lugens*), green leafhopper (*N. virescens*), and rice yellow stem borer (*S. incertulas*). Therefore, pest populations developed naturally during the experiment, and no artificial infestation was performed. Average monthly rainfall during the experimental period (May–September 2024) was 55.0, 96.0, 65.2, 71.8, and 63.8 mm, respectively (BMKG, 2024).

Layout and Experiment Design. The field experiment was arranged as a split-plot in a randomized complete block design with three replications. Commercial insecticide served as the main-plot factor with six treatment levels, whereas application interval served as the subplot factor with three levels (Table 1). In addition, one untreated control plot was included in each replication. Each experimental plot measured 3 × 4 m (12 m^2) and consisted of ten rows of rice. In total, the experiment comprised 57 plots (54 treatment plots plus three untreated control plots), covering an effective experimental area of 684 m^2.

Crop Establishment and Field Management. Rice cv. Inpari 6 was established using the direct-seeding (tabela) method, a common planting practice in South Sulawesi employing a perforated drum seeder. Before planting, the field was cleared of weeds, flooded, and tilled twice using a hand tractor. Chicken manure was incorporated at 2 t/ha before sowing.

To establish a healthy seedling population before differential treatments began, rice seeds cv. Inpari 6 were soaked in a mixture of insecticide Marshal 25 DS (a.i.: carbosulfan) and fungicide/bactericide Nordox 56WP (a.i.: copper oxide), at dosages of 5 g and 1 g per kg seeds, respectively, for 48 hours, then drained and incubated for another 48 hours. After the seeds began to germinate, they were sown using the direct seeding tool (*tabela*) with a planting spacing of 30 cm between rows. Plant maintenance was performed following the local recommendation. Weed was controlled mechanically using a hoe. Fungicides and bactericides were applied as needed.

Bio-rational insecticide treatments were applied at the recommended dosages according to the assigned application intervals, namely weekly or once every two weeks, using a battery-operated knapsack sprayer with a 16-L tank capacity operated at a pressure of 40 psi. For the carbofuran treatment, the insecticide was applied twice, with the total recommended dosage of 30 kg/ha divided into two equal applications of 15 kg ha^{-1} each. The first application was made two weeks after plant emergence to control pests during the vegetative stage, and the second application was made eight weeks after plant emergence to control pests during the generative stage. This carbofuran application regime followed the local farmers' practice.

Crop management followed local agronomic recommendations. Fertilizer was applied at rates of 125 kg urea/ha and 375 kg NPK (15:15:15)/ha in two equal splits at two and six weeks after emergence. Weeds were controlled mechanically, while fungicides and

Table 1. Biorational and synthetic insecticides evaluated, their application frequencies, doses, and manufacturers

Active ingredient/Trade name	Application frequency	Dose	Producer
Carbofuran (Furadan 3G)	Once per season	30 kg/ha	
	Once per season	20 kg/ha	PT Bina Guna Kimia
	Once per season	10/kg/ha	
Abamectin (Abacel 18EC)	Twice weekly, once weekly, once every two weeks	1 mL/L	PT Excel Meg Indo
Azadirachtin (Azadirachtin 5EC)	Twice weekly, once weekly, once every two weeks	5 mL/L	CIECHEM
Beauveria bassiana (Bevtek WP)	Twice weekly, once weekly, once every two weeks	5 g/L	Paguyuban Saripati Tani
Metarhizium anisopliae (*Metarhizium* WP)	Twice weekly, once weekly, once every two weeks	5 mL/L	PT Biotek Agri Lestari
Demihipo (Spontan 400 SL)	Twice weekly, once weekly, once every two weeks	2 mL/L	PT Agricon
Untreated control	–	–	–

a.i. = active ingredient.

bactericides were applied only when required. A single application of carbofuran was made two weeks after sowing as part of the standard local crop management practice and was applied uniformly across all plots before differential insecticide treatments commenced.

Pest and Natural Enemy Assessment. The efficacy of the insecticide treatments was evaluated under natural infestations of *N. lugens*, *N. virescens*, and *S. incertulas*. Brown planthopper populations were assessed by counting nymphs and adults on five randomly selected rice hills within each plot.

Adult green leafhoppers and predatory lady beetle (*Coccinella* spp.) were sampled using a sweep net with ten sweeps per plot. *Coccinella* spp. was selected as the representative beneficial arthropod because it was consistently the dominant predator observed throughout the experimental period.

Stem borer infestation was assessed by recording the percentage of rice hills exhibiting dead-heart symptoms. Observations were conducted at 7-day intervals from 21 to 49 days after sowing.

Statistical Analysis. Count data and percentage data were transformed using log(x + 1) and arcsine square-root transformation, respectively, before statistical analysis. Data were analyzed using split-plot analysis of variance (ANOVA), with insecticide treatment and application interval as fixed effects and block as a random effect. When treatment effects were significant, means were separated using Tukey's honestly significant difference (HSD) test at $P \leq 0.05$. Untransformed means are presented in the Results for ease of interpretation.

RESULTS AND DISCUSSION

Brown Planthopper (*N. lugens*). Brown planthopper (BPH) populations were highest during the early vegetative stage (21 and 28 days after sowing) and gradually declined as the crop developed (Table 2). Across all observation dates, all insecticide treatments significantly reduced BPH populations compared with the untreated control, with abamectin consistently producing the lowest pest densities (Table 2).

The rapid suppression achieved by abamectin is consistent with its mode of action as a glutamate-gated chloride channel activator, which disrupts nerve impulse transmission, causing feeding cessation, paralysis, and death shortly after exposure. This rapid activity explains its superior performance during the early stages of crop growth when BPH populations increased rapidly. Similar findings have been reported by Matsukawa et al. (2017), who demonstrated that abamectin provides effective BPH control with minimal phytotoxic effects under rice field conditions.

Although abamectin provided the greatest suppression in BPH populations, the entomopathogenic fungi *B. bassiana* and *M. anisopliae* also significantly suppressed BPH compared with the untreated control and showed efficacy comparable to that of carbofuran and demihipo. Unlike abamectin, fungal entomopathogens infect insects through the cuticle and require time for spore germination, cuticle penetration, and fungal colonization before host mortality occurs. Consequently, their insecticidal activity is generally slower but can provide longer-lasting suppression through horizontal transmission and secondary infection within pest populations (de Faria & Wraight, 2007; Wakil et al., 2024). These characteristics make entomopathogenic fungi suitable components of IPM programs, particularly where long-term suppression rather than immediate knockdown is desired.

The effectiveness of azadirachtin was intermediate between that of abamectin and the fungal insecticides. This result is consistent with the known

Table 2. Effect of insecticide treatments on the population of the brown planthopper (*N. lugens*) per hill (mean ± SE)

Treatment	21 DAS	28 DAS	35 DAS	42 DAS	49 DAS
Carbofuran	25.33 ± 2.45 d	15.67 ± 2.78 d	3.33 ± 0.34 b	1.33 ± 0.33 a	1.67 ± 0.30 a
Abamectin	5.00 ± 0.68 a	2.67 ± 0.34 a	1.33 ± 0.34 a	0.67 ± 0.34 a	2.00 ± 0.59 a
Demihipo	15.00 ± 1.56 b	6.33 ± 0.34 b	2.00 ± 0.59 b	0.67 ± 0.34 a	2.00 ± 0.59 a
Azadirachtin	20.00 ± 1.18 c	5.00 ± 0.59 b	2.00 ± 0.59 b	0.67 ± 0.34 a	3.33 ± 0.34 b
Beauveria bassiana	19.67 ± 0.90 c	5.67 ± 0.34 b	2.00 ± 0.59 b	2.33 ± 0.34 b	2.33 ± 0.34 a
Metarhizium anisopliae	11.00 ± 1.18 b	2.67 ± 0.68 a	2.00 ± 0.59 b	0.67 ± 0.34 a	1.00 ± 0.59 a
Control	28.67 ± 2.23 d	16.33 ± 0.59 c	12.33 ± 0.68 c	7.67 ± 0.68 c	7.67 ± 0.90 c

Means within a column followed by different letters are significantly different according to Tukey's test ($P \leq 0.05$). DAS = Days after sowing; SE = Standard error.

biological activity of azadirachtin, which primarily acts as an antifeedant, insect growth regulator, and oviposition deterrent rather than as a fast-acting contact poison. Consequently, population reduction is generally more gradual than with neurotoxic insecticides but may contribute to sustained suppression by reducing feeding activity and reproductive capacity. Overall, the results demonstrate that insecticides with contrasting modes of action can provide effective BPH suppression, although they differ substantially in the speed and persistence of their insecticidal activity.

Green Leafhopper (*N. virescens*). Green leafhopper (GLH) populations were significantly lower in all insecticide treatments than in the untreated control throughout the observation period (Table 3). Overall, carbofuran, abamectin, and demihipo provided the greatest suppression in GLH populations, with complete suppression recorded in carbofuran- and demihipo-treated plots at 49 days after sowing (DAS). In contrast, azadirachtin and the entomopathogenic fungi *B. bassiana* and *M. anisopliae* produced a slower but sustained decline in GLH abundance.

The superior performance of abamectin, carbofuran, and demihipo can be attributed to their rapid neurotoxic action, which causes feeding cessation and mortality shortly after exposure. Such rapid suppression is particularly important for GLH management because this species is the principal vector of Rice tungro virus (RTV), and reducing vector populations early in the crop cycle can substantially decrease the risk of virus transmission. Therefore, rapid reduction of GLH populations is often more critical than prolonged residual activity when preventing tungro epidemics.

In contrast, the comparatively slower action of *B. bassiana*, *M. anisopliae*, and azadirachtin reflects their different modes of action. Entomopathogenic fungi require successful attachment, germination, cuticle penetration, and internal colonization before causing insect mortality, whereas azadirachtin primarily interferes with feeding behavior, molting, and reproduction. Consequently, these products generally provide gradual population suppression rather than immediate knockdown. Similar performance has been reported for microbial and botanical insecticides against rice hoppers under field conditions (Tang et al., 2019; Bamisile et al., 2021; Irsad et al., 2023).

Although fungal and botanical insecticides acted more slowly than synthetic products, they maintained GLH populations well below those observed in the untreated control throughout the study. Their relatively selective activity and lower toxicity to beneficial arthropods make these products valuable components of IPM programs, particularly where long-term ecological sustainability is prioritized over immediate pest elimination. Therefore, the present results indicate that biorational insecticides can contribute substantially to GLH management while minimizing adverse effects on the rice agroecosystem.

Yellow Stem Borer (*S. incertulas*). All insecticide treatments significantly reduced dead-heart incidence compared with the untreated control at almost every observation date, except for *M. anisopliae* at 21 DAS (Table 4). Stem borer damage generally increased as the crop developed, reflecting the progressive establishment of larval infestations during the growing season. Among the evaluated products, abamectin and azadirachtin consistently produced the lowest dead-heart incidence, whereas *B. bassiana* and demihipo exhibited comparable levels of suppression throughout the observation period. Carbofuran effectively suppressed stem borer damage during the early crop stages; however, its efficacy gradually declined after 35 DAS, resulting in increased dead-heart incidence

Table 3. Effect of insecticide treatments on the population of the green leafhopper (*N. virescens*) per 10 sweep-net samples (mean ± SE)

Treatment	21 DAS	28 DAS	35 DAS	42 DAS	49 DAS
Carbofuran	1.67 ± 0.34 a	1.33 ± 0.34 ab	1.00 ± 0.59 a	0.67 ± 0.34 a	0.00 ± 0.00 a
Abamectin	1.67 ± 0.34 a	0.67 ± 0.34 a	1.00 ± 0.59 a	0.67 ± 0.34 a	0.33 ± 0.33 a
Demihipo	1.00 ± 0.59 a	0.67 ± 0.34 a	0.67 ± 0.34 a	0.33 ± 0.33 a	0.00 ± 0.00 a
Azadirachtin	2.33 ± 0.68 b	1.67 ± 0.34 b	1.67 ± 0.34 ab	1.33 ± 0.33 b	0.33 ± 0.33 a
Beauveria bassiana	0.33 ± 0.33 a	1.33 ± 0.34 ab	2.00 ± 0.59 b	1.67 ± 0.33 b	0.67 ± 0.34 a
Metarhizium anisopliae	1.33 ± 0.90 a	0.67 ± 0.34 a	1.00 ± 0.59 ab	1.33 ± 0.33 b	0.67 ± 0.67 a
Control	2.67 ± 0.44 b	3.00 ± 0.51 c	3.67 ± 0.34 c	3.33 ± 0.34 c	3.67 ± 0.34 b

Means within a column followed by different letters are significantly different according to Tukey's test ($P \leq 0.05$). DAS = Days after sowing; SE = Standard error.

toward the end of the experiment.

The consistently low damage observed in abamectin-treated plots is likely associated with its strong contact and ingestion activity against newly hatched larvae before they successfully penetrate rice stems. Because stem borer larvae become protected once inside plant tissues, insecticides capable of rapidly affecting neonate larvae are generally more effective than products acting after stem penetration. This mechanism probably contributed to the superior performance of abamectin under field conditions.

Azadirachtin also provided effective suppression despite its slower mode of action. Rather than causing rapid mortality, azadirachtin functions primarily as an oviposition deterrent, feeding inhibitor, and insect growth regulator, thereby reducing larval establishment and subsequent stem damage. Similar mechanisms have been reported in previous studies evaluating botanical insecticides against rice stem borers (Anggraeni et al., 2023). In comparison, the efficacy of *B. bassiana* and *M. anisopliae* depends on successful fungal infection, a process that is influenced by environmental conditions such as temperature and relative humidity. Consequently, their performance may be more variable under field conditions than that of conventional insecticides. The effectiveness of *B. bassiana* and *M. anisopliae* observed in the present study is consistent with previous reports demonstrating their pathogenicity against *S. incertulas* under experimental conditions (Thalib et al., 2014).

An interesting finding of the present study was the gradual decline in carbofuran efficacy during the later stages of crop growth. Because carbofuran was applied to the soil early in the season, its residual activity likely decreased over time, reducing protection against successive generations of stem borers. This observation highlights the importance of considering insecticide persistence and pest phenology when selecting management strategies for stem borers.

Overall, the results demonstrate that both microbial and botanical insecticides effectively reduced stem borer damage under field conditions. Although their modes of action differ from those of conventional insecticides, they achieved levels of protection comparable to synthetic standards while offering the additional advantage of greater compatibility with biological control agents. The comparable efficacy observed in the present study indicates that selected biorational insecticides can substantially reduce reliance on conventional synthetic insecticides that have long been used for rice pest management (Rahaman & Stout, 2019; Harika & Deole, 2023). Collectively, these findings support the integration of biorational insecticides into IPM programs for sustainable management of rice stem borers (Bamisile et al., 2021; Anggraeni et al., 2023).

Interaction between Insecticide Treatment and Application Interval. The interaction between insecticide treatment and application interval significantly influenced the populations of *N. lugens*, *N. virescens*, and the incidence of dead-heart symptoms caused by *S. incertulas* (Figures 1–3). In general, pest populations and stem borer damage declined as the application rate or spray frequency increased. However, the magnitude of the response varied among insecticides because of differences in their modes of action and residual persistence.

For brown planthopper, carbofuran, *B. bassiana*, and *M. anisopliae* exhibited clear responses to increasing application rates or spray frequencies, whereas the efficacy of abamectin, demihipo, and azadirachtin did not differ significantly between once- and twice-weekly applications. This finding indicates that applying these insecticides more than once per week provides little additional benefit under the pest

Table 4. Effect of insecticide treatments on dead-heart incidence (%) caused by the yellow stem borer (*S. incertulas*) (mean ± SE)

Treatment	21 DAS	28 DAS	35 DAS	42 DAS	49 DAS
Carbofuran	1.33 ± 0.33 b	1.33 ± 0.34 b	1.00 ± 0.59 a	5.67 ± 0.68 b	5.00 ± 0.59 c
Abamectin	0.00 ± 0.00 a	0.00 ± 0.00 a	0.67 ± 0.67 a	1.67 ± 0.59 a	2.33 ± 0.34 a
Demihipo	0.00 ± 0.00 a	3.67 ± 0.68 d	4.00 ± 0.59 b	4.33 ± 0.90 b	4.33 ± 0.34 b
Azadirachtin	0.00 ± 0.00 a	0.00 ± 0.00 a	0.33 ± 0.33 a	1.00 ± 0.58 a	1.33 ± 0.68 a
Beauveria bassiana	0.67 ± 0.14 a	3.33 ± 0.34 d	5.33 ± 0.68 b	5.67 ± 0.67 b	4.67 ± 0.68 b
Metarhizium anisopliae	1.67 ± 0.34 bc	2.33 ± 0.41 c	4.00 ± 0.59 b	4.67 ± 0.89 b	4.67 ± 0.34 b
Control	2.33 ± 0.68 c	4.33 ± 0.34 e	6.67 ± 0.67 d	6.33 ± 0.34 c	6.67 ± 0.68 d

Means within a column followed by different letters are significantly different according to Tukey's test ($P \leq 0.05$). DAS = Days after sowing; SE = Standard error.

pressure encountered in the present study. Instead, a weekly application appears sufficient to maintain BPH populations at low levels throughout the cropping period.

A similar trend was observed for green leafhopper. Although higher application rates or more frequent sprays generally resulted in lower GLH populations, weekly applications of most insecticides achieved control comparable to twice-weekly applications. This suggests that increasing spray frequency beyond one application per week is unlikely to produce substantial improvements in vector suppression, while it would inevitably increase production costs and labor requirements.

For the rice yellow stem borer, dead-heart incidence also declined with increasing application intensity. Nevertheless, the response differed among insecticides. Abamectin, demihipo, and azadirachtin maintained similarly low levels of stem borer damage under both weekly and twice-weekly applications, whereas *B. bassiana*, *M. anisopliae*, and carbofuran responded more positively to increased application intensity. These differences are likely associated with their contrasting modes of action. Entomopathogenic fungi require sufficient inoculum density and favorable environmental conditions for successful infection, whereas residual activity of soil-applied carbofuran gradually decreases during crop development.

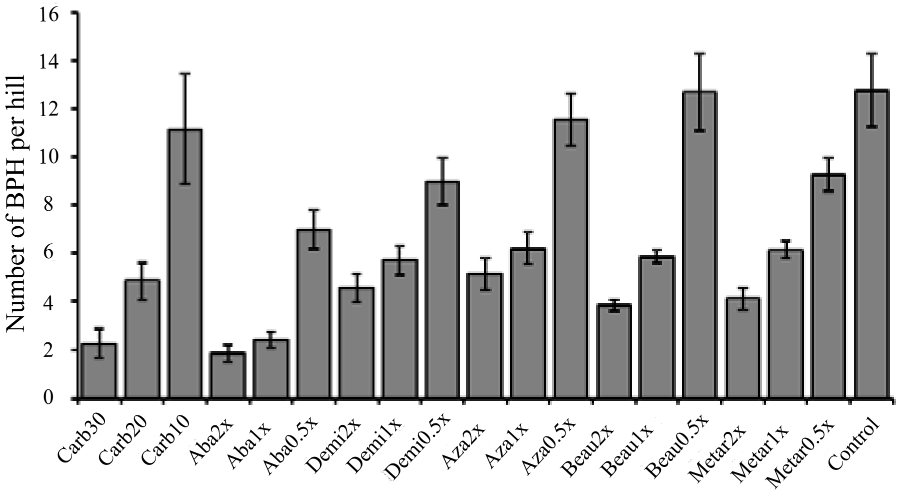

Figure 1. Interaction effect between insecticides and their application frequency on the number of rice brown planthoppers. Carb = Carbofuran; Aba = Abamectin; Demi = Demihipo; Aza = Azadirachtin; Beau = *Beauveria*; Metar = *Metarhizium*. 30 = 30 kg/ha; 20 = 20 kg/ha; 10 = 10 kg/ha; 2x = Twice/week; 1x = Once/week; 0.5x = Once/2 weeks. Bars = Standard error.

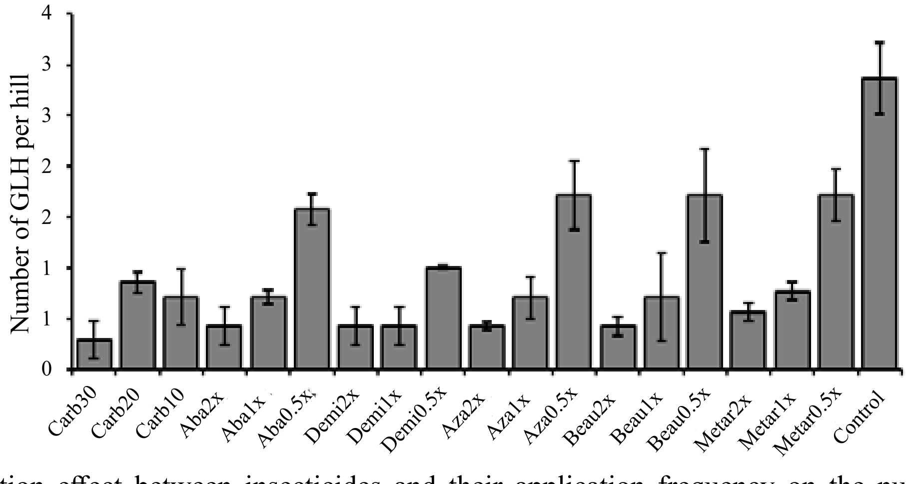

Figure 2. Interaction effect between insecticides and their application frequency on the number of rice rice green leafhopper (per 10 sweeps). Carb = Carbofuran; Aba = Abamectin; Demi = Demihipo; Aza = Azadirachtin; Beau = *Beauveria*; Metar = *Metarhizium*. 30 = 30 kg/ha; 20 = 20 kg/ha; 10 = 10 kg/ha; 2x = Twice/week; 1x = Once/week; 0.5x = Once/2 weeks. Bars = Standard error.

The interaction analysis further demonstrated that reducing application frequency to once every two weeks generally resulted in poorer pest suppression, particularly for BPH and stem borer. Under this schedule, several treatments produced pest populations or damage levels approaching those observed in the untreated control, indicating that the residual activity of the tested insecticides was insufficient to provide prolonged protection over a two-week interval.

The observed interaction between insecticide treatment and application interval agrees with findings reported by Subagja et al. (2023), who demonstrated that application interval significantly influenced the efficacy of chlorantraniliprole against *Spodoptera frugiperda*.

From an IPM perspective, the present findings indicate that weekly application represents the most appropriate compromise between efficacy and input efficiency. Increasing application frequency beyond once per week did not consistently improve pest suppression, whereas extending the interval to two weeks reduced control effectiveness for several treatments. Similar conclusions were reported by Nasruddin et al. (2020), who found that weekly insecticide applications provided control of *Bemisia tabaci* comparable to more frequent spraying while substantially reducing insecticide inputs. Collectively, these results suggest that optimizing application intervals may improve the economic and environmental sustainability of rice pest management without compromising control efficacy.

As illustrated in Figure 4, the three major rice pests exhibited distinct seasonal population dynamics throughout the cropping period. *Nilaparvata lugens* populations peaked during the early vegetative stage (21–28 DAS) and subsequently declined after tillering, whereas *N. virescens* populations remained relatively low and stable throughout the season. In contrast, damage caused by *S. incertulas* increased progressively with crop development, reaching its highest level at 49 DAS. These contrasting population trends largely reflect differences in the biology and feeding habits of the three pest species. Brown planthoppers preferentially colonize young rice plants with actively growing tissues, while stem borer damage accumulates over time as successive larval infestations develop within rice stems. The relatively stable GLH population suggests that vector abundance remained below outbreak levels throughout the study period. Collectively, these seasonal patterns indicate that pest management strategies should be synchronized with crop phenology. Early intervention is particularly important for planthoppers to prevent rapid population buildup and virus transmission, whereas continued protection during the later vegetative and early reproductive stages is required to minimize stem borer damage. Similar temporal patterns have been reported in rice ecosystems by Raju et al. (2021) and Sreelatha et al. (2022), supporting the importance of pest-specific intervention timing within IPM programs.

Effects of Biorational Insecticides on Natural Enemies. The compatibility of insecticides with beneficial arthropods is an essential consideration in IPM, as effective pest suppression should be achieved without disrupting naturally occurring biological control. In the present study, populations of *Coccinella* spp., the dominant predator and representative beneficial arthropod observed throughout the experiment, differed significantly among insecticide treatments (Figure 5).

The abundance of *Coccinella* spp. in plots treated with azadirachtin, *B. bassiana*, *M. anisopliae*,

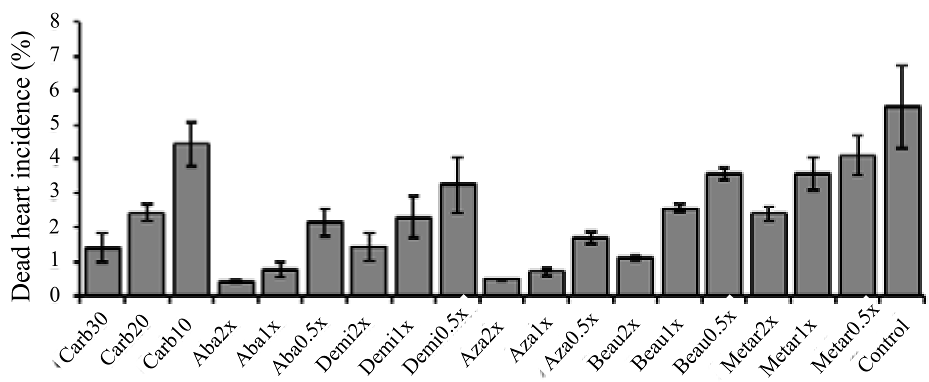

Figure 3. Interaction effect between insecticides and their application frequency on the the percentage of hills damaged by the yellow stem borer (dead heart). Carb = Carbofuran; Aba = Abamectin; Demi = Demihipo; Aza = Azadirachtin; Beau = *Beauveria*; Metar = *Metarhizium*. 30 = 30 kg/ha; 20 = 20 kg/ha; 10 = 10 kg/ha; 2x = Twice/week; 1x = Once/week; 0.5x = Once/2 weeks. Bars = Standard error.

and carbofuran did not differ significantly from that in the untreated control. Average predator populations ranged from 2.45 to 3.81 individuals per sampling unit, indicating that these treatments were generally compatible with the dominant predator community under field conditions. In contrast, significantly lower predator populations were recorded in plots treated with abamectin and demihipo, suggesting greater non-target effects of these insecticides. Although only *Coccinella* spp. was quantified in this study, this predator is widely recognized as an important component of biological control in rice ecosystems. Therefore, its conservation may reflect the broader compatibility of biorational insecticides with beneficial arthropod communities. Conservation of natural enemies is a key component of sustainable rice pest management, and ecological approaches have been shown to maintain predator populations while suppressing pest outbreaks in rice ecosystems (Usyati et al., 2020).

The higher predator abundance observed in fungal and botanical insecticide treatments can be explained by their relatively selective modes of action. Entomopathogenic fungi infect susceptible insect hosts through direct contact and generally exhibit a narrower host range than broad-spectrum neurotoxic insecticides. Likewise, azadirachtin primarily affects feeding behavior, development, and reproduction of target herbivorous insects while exhibiting comparatively low acute toxicity to many predatory arthropods. Consequently, these biorational insecticides are generally considered more compatible with biological control agents and better suited for integration into IPM programs.

Interestingly, carbofuran-treated plots also maintained predator populations comparable to those of the untreated control despite effectively suppressing the target pests. This result is likely associated with the method of application. Because carbofuran was applied to the soil during the early stages of crop growth, direct exposure of above-ground predators was probably limited, thereby reducing non-target mortality. Similar observations have been reported by

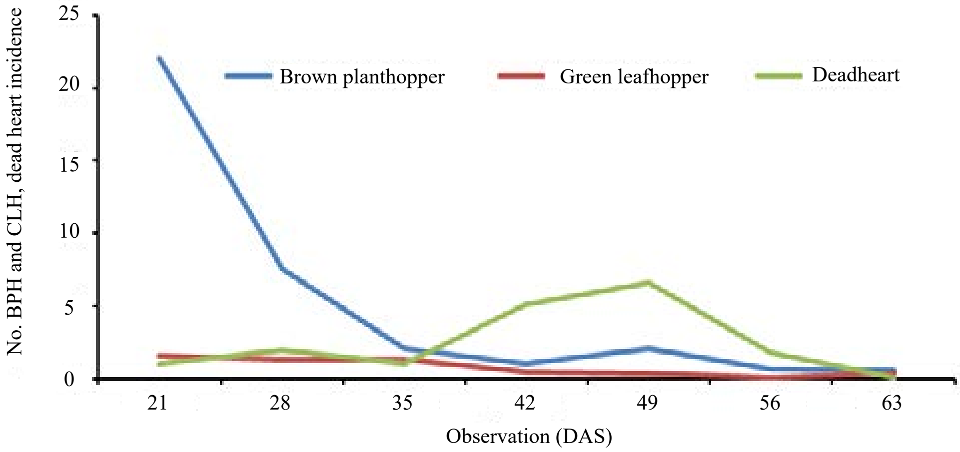

Figure 4. Seasonal population dynamics of the brown planthopper (*N. lugens*), green leafhopper (*N. virescens*), and dead-heart incidence caused by the yellow stem borer (*S. incertulas*) during the rice growing season. DAS = days after sowing.

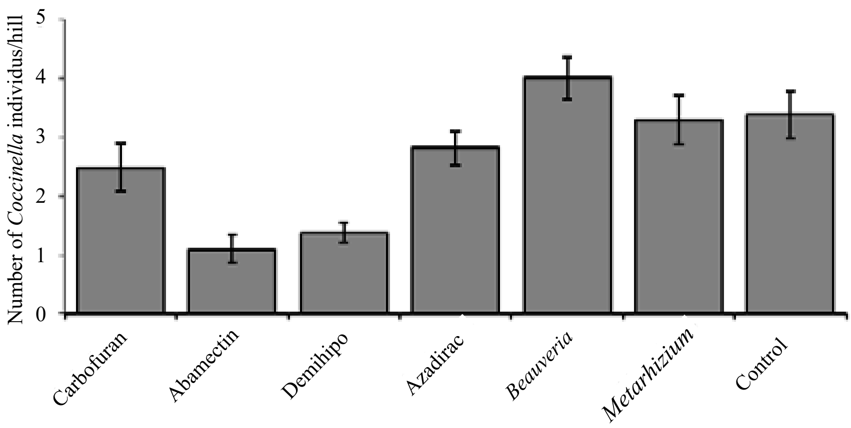

Figure 5. Mean (± SE) abundance of the predatory lady beetle, *Coccinella* spp., per rice hill under different insecticide treatments.

Pham et al. (2008), who demonstrated that soil-applied systemic insecticides may exert lower direct impacts on natural enemies than foliar applications, although indirect ecological effects should still be considered.

In contrast, the reduced abundance of *Coccinella* spp. in abamectin- and demihipo-treated plots may reflect greater contact exposure during foliar spraying and broader insecticidal activity. Although abamectin is widely recognized as a biorational insecticide because of its microbial origin and favorable environmental profile, it can still adversely affect beneficial arthropods immediately following application, particularly when predators are directly exposed to spray deposits. Similar short-term reductions in predator abundance have been reported for abamectin in several agricultural systems (Desneux et al., 2007).

Overall, the present findings demonstrate that effective suppression of the major rice pests can be achieved while conserving beneficial arthropods through the use of selected biorational insecticides. The compatibility of *B. bassiana*, *M. anisopliae*, and azadirachtin with the dominant predator, *Coccinella* spp., together with their satisfactory pest suppression, highlights their suitability for incorporation into rice IPM programs. These findings are consistent with the principles of IPM, which emphasize the integration of selective pest control tactics with the conservation of natural enemies to achieve sustainable pest suppression (Heong et al., 2021; Isman, 2020; Rosell et al., 2008). Such an approach also supports ecological intensification, where agricultural productivity is maintained while reducing reliance on external chemical inputs (Pretty et al., 2018; Ganesan et al., 2025). Nevertheless, validation under different agroecological conditions and across multiple growing seasons is required before broad recommendations can be made for rice production systems in Indonesia. Such studies would also improve understanding of the long-term ecological and economic benefits of integrating biorational insecticides into rice IPM programs.

CONCLUSION

The present study demonstrates that commercially available biorational insecticides, including abamectin, azadirachtin, *B. bassiana*, and *M. anisopliae*, effectively suppressed the major rice pests *N. lugens*, *N. virescens*, and *S. incertulas* under field conditions in South Sulawesi. Although abamectin consistently provided the most rapid and effective pest suppression, the botanical insecticide azadirachtin and the entomopathogenic fungi also achieved satisfactory control while exhibiting greater compatibility with the predatory lady beetle, *Coccinella* spp. Weekly insecticide applications were generally sufficient to maintain effective pest suppression, indicating that increasing application frequency provided little additional benefit under the conditions of this study. These findings demonstrate that optimizing application intervals can improve input efficiency while maintaining effective pest management. Overall, the results support the integration of biorational insecticides into rice Integrated Pest Management (IPM) programs as environmentally compatible alternatives that reduce reliance on conventional synthetic insecticides while conserving beneficial arthropods. Nevertheless, further multi-season and multi-location studies are recommended to validate these findings under a broader range of agroecological conditions before large-scale recommendations are implemented.

ACKNOWLEDGMENTS

The authors sincerely thank the Ministry of Education, Culture, Research, and Technology, Republic of Indonesia, for financially supporting this study.

FUNDING

This study was funded by the Ministry of Education, Culture, Research, and Technology of the Republic of Indonesia through the Penelitian Dosen Pemula research scheme (Contract No. 002/128/LEMLIT/UNISAN-SR/A/VI/2024, dated 20 June 2024), administered by the Institute for Research (Lembaga Penelitian), Universitas Ichsan Sidenreng Rappang.

AUTHORS' CONTRIBUTIONS

JJ and D conceived and designed the study, developed the methodology, conducted the investigation, administered the project, and approved the final manuscript. MS and EE carried out the investigation, curated the data, and approved the final manuscript. ND and AN contributed to the study design, performed the formal data analysis and interpretation, prepared the original manuscript draft, critically revised the manuscript, and approved the final manuscript.

COMPETING INTEREST

The authors declare that they have no competing interests.

REFERENCES

Anggraeni FD, Rahmat B, & Saepudin A. 2023. Pengaruh mating disruption pheromone hexadecenal dan insektisida spinoteram, abamektin, assefat, serta pimetrozin terhadap pertumbuhan dan hasil tanaman padi serta serangan hama penggerek batang padi kuning (*Schirpophaga incertulas* Walker) [The effect of mating disruption pheromone hexadecenal and spinoteram insecticide, abamektin, assefate, and pimetrozin on growht and results of rice plant and yellow rice bender (*Schirpophaga incertulas* Walker)]. *JA-CROPS.* 1(1): 19–25.

Ansari A, Pranesti A, Telaumbanua M, Alam T, Taryono, Wulandari RA, Nugroho BDA, & Supriyanta. 2023. Evaluating the effect of climate change on rice production in Indonesia using multimodelling approach. *Heliyon*. 9(9): e19639. https://doi.org/10.1016/j.heliyon.2023.e19639

Baehaki SE. 2015. Hama penggerek batang padi dan teknologi pengendalian [Rice stem borer and its control techniques]. *Iptek Tanaman Pangan.* 8(1): 1–14. https://repository.pertanian.go.id/server/api/core/bitstreams/8bea6c9c-edd6-4d47-8425-910f0ce6263c/content

Bamisile BS, Akutse KS, Siddiqui JA, & Xu Y. 2021. Model application of entomopathogenic fungi as alternatives to chemical pesticides: Prospects, challenges, and insights for next-generation sustainable agriculture. *Front. Plant Sci.* 12: 741808. https://doi.org/10.3389/fpls.2021.741804

BPS-Statistics Indonesia (BPS). 2023. *Impor Beras Menurut Negara Asal Utama [Imports of Rice by Major Countries of Origin]*. https://www.bps.go.id/id/statistics-table/1/MTA0MyMx/impor-beras-menurut-negara-asal-utama-2017-2023.html. Accessed 15 October 2025.

Chen CC & Chiu RJ. 1982. Three symptomatologic types of rice virus diseases related to grassy stunt in Taiwan. *Plant Dis*. 66(1):15–18. https://doi.org/10.1094/PD-66-15

Desneux N, Decourtye A, & Delpuech JM. 2007. The sublethal effects of pesticides on beneficial arthropods. *Annu. Rev. Entomol.* 52(1): 81–106. https://doi.org/10.1146/annurev.ento.52.110405.091440

de Faria MR & Wraight SP. 2007. Mycoinsecticides and mycoacaricides: A comprehensive list with worldwide coverage and international classification of formulation types. *Biol. Control*. 43(3): 237–256. https://doi.org/10.1016/j.biocontrol.2007.08.001

Ganesan K, Kumar BA, Soundararajan RP, Suganthy M, Venugopal S, Manivannan V., Sangeetha SV, & Murugan M. 2025. Botanicals for managing insect pests in rice: An eco-friendly strategy for sustainable rice production. *Plant Sci. Today.* 12(1): 1–10. https://doi.org/10.14719/pst.6006

Garrood WT, Zimmer CT, Gorman KJ, Nauen R, Bass C, & Davies TGE. 2016. Field-evolved resistance to imidacloprid and ethiprole in populations of the brown planthopper *Nilaparvata lugens* collected from across South and East Asia. *Pest Manag. Sci*. 72(1): 140–149. https://doi.org/10.1002/ps.3980

Harika R & Deole S. 2023. Evaluation of selected insecticides against brown planthopper and their impact on natural enemies. *Pharma Innov. J.* 12(7): 2570–2573.

Heong KL, Wong L & Delos Reyes, JH. 2015. Addressing planthopper threats to Asian rice farming and food security: Fixing insecticide misuse. In Heong KL, Cheng J, & Escalada MM (Eds.). *Rice Planthoppers*. pp. 65–76. Springer, Dordrecht. https://doi.org/10.1007/978-94-017-9535-7_3

Heong KL, Lu ZX, Chien HV, Escalada M, Settele J, Zhu ZR, & Cheng JA. 2021. Ecological engineering for rice insect pest management: The need to communicate widely, improve farmers' ecological literacy and policy reforms to sustain adoption. *Agronomy*. 11(11): 2208. https://doi.org/10.3390/agronomy11112208

Horgan FG, Romena AM, Bernal CC, Almazán MLP, & Ramal AF. 2021. Stem borers revisited: Host resistance, tolerance, and vulnerability determine levels of field damage from a complex of Asian rice stemborers. *Crop Prot.* 142: 105513. https://doi.org/10.1016/j.cropro.2020.105513

Hutasoit RT, Widiarta IN, Jihad M, Sitorus A, Susilawati, & Puspitasari M. 2025. Biology and demographic statistics of the green leafhopper (*Nephotettix virescens* Distant) as the main vector of tungro virus in tungro-resistant rice varieties. *J. Trop. Plant Pests Dis*. 25(1): 96-105. https://doi.org/10.23960/jhptt.12596-105

Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG). 2024. *Curah Hujan Harian UPT Kabupaten Toraja [Daily rainfall at the UPT of Toraja Regency]*. https://dataonline.bmkg.go.id/data-harian. Accessed 5 December 2024.

International Plant Protection Convention (IPPC). 2022. *Half of the World Eats Rice. Are You One of Them?*. www://ippc.int/resources/to-crops-why-protecting-them-from plant- pests-matter/rice-oryza-sativa/. Accessed 5 October 2025.

Irsad, Shahid M, Haq E, Mohamed A, Rizvi PQ, & Kolanthasamy E . 2023. Entomopathogen-based biopesticides: Insights into unraveling their potential in insect pest management. *Front. in Microbiol*. 14: 1208237. https://doi.org/10.3389/fmicb.2023.1208237

Isman MB. 2020. Botanical insecticides in the twenty-first century—Fulfilling their promise?. *Annu. Rev. Entomol.* 65(1): 233–249. https://doi.org/10.1146/annurev-ento-011019-025010

Khoa DB, Thang BX, Liem NV, Holst N, & Kristensen M. 2018. Variation in susceptibility of eight insecticides in the brown planthopper *Nilaparvata lugens* in three regions of Vietnam, 2015–2017. *PLoS ONE*. 13(10): e0204962. https://doi.org/10.1371/journal.pone.0204962

Matsukawa M, Ito K, Kawakita K, & Tanaka T. 2017. Current status of insecticide susceptibility in the brown planthopper in Cambodia. *J. Pestic Sci*. 42(2): 45–51. https://doi.org/10.1584/jpestics.D16-101

Nasruddin A, Agus IN, Saubil A, Jumardi, Rasyid B, Siriniang A, Nasruddin AD, Firdaus, & Said AE. 2020. Effects of mulch type, plant cultivar, and insecticide use on sweet potato whitefly population in chili pepper. *Scientifica*. 2020(1): 6428426. https://doi.org/10.1155/2020/6428426

Pallavi D, Sharanabasappa, & Girijesh GK. 2017. Crop loss estimation of yellow stem borer *Scirpophaga incertulas* (Walker) damage on paddy. *J. Entomol. Zool. Stud.* 5(6): 635–638. https://www.entomoljournal.com/archives/2017/vol5issue6/PartI/5-5-142-293.pdf

Pham HH, Kim JK, Choi BR, & Song YH. 2008. Effects of root zone applications of some systemic insecticides for control the brown planthopper, *Nilaparvata lugens* (Stål) (Homoptera: Delphacidae). *Korean J. Pestic. Sci.* 12(3): 236–242. https://www.koreascience.kr/article/JAKO200816256327343.pdf

Pretty J, Benton TG, Bharucha ZP, Dicks LV, Flora CB, Godfray HCJ, Goulson D, Hartley S, Lampkin N, Morris C, Pierzynski G, Prasad PVV, Reganold J, Rockström J, Smith P, Thorne P, & Wratten S. 2018. Global assessment of agricultural system redesign for sustainable intensification. *Nat. Sustain.* 1(8): 441–446. https://doi.org/10.1038/s41893-018-0114-0

Center for Agricultural Data and Information System. 2023. *Statistik Konsumsi Pangan 2023 [Statistics of Food Consumption 2023]*. Sekretariat Jenderal Kementerian Pertanian. https://satudata.pertanian.go.id/assets/docs/publikasi/Buku_Statsitik_Konsumsi_Pangan_2023.pdf. Accessed 2 November 2025.

Rahaman MM & Stout MJ. 2019. Comparative efficacies of next-generation insecticides against yellow stem borer and their effects on natural enemies in rice ecosystem. *Rice Sci.* 26(3): 157−166. http://dx.doi.org/10.1016/j.rsci.2019.04.002

Raju SVS, Sharma KR, Babu SR, & Mohanta PR. 2021. Population dynamics of insect pests in the rice ecosystem. *Indian J. Entomol.* 83(1): 39–42. https://doi.org/10.5958/0974-8172.2020.00232.1

Rosell G, Quero C, Coll J, & Geurrero A. 2008. Biorational insecticides in pest management. *J. Pestic. Sci.* 33(2): 103–121. https://doi.org/10.1584/jpestics.R08-01

Sofyan DA, Koesmaryono Y, & Hidayati R. 2019. Analisis pengaruh faktor cuaca terhadap dinamika populasi wereng batang coklat (Nilaparvata lugens Stål) yang tertangkap lampu perangkap [Analysis of the effect of weather on population dynamics of brown planthopper (*Nilaparvata lugen*s Stål)]. *Jurnal Entomologi Indonesia*. 16(1): 1–8. https://doi.org/10.5994/jei.16.1.1

Sreelatha E, Prasoona US, Shailaja B, & Rajan SJ. 2022. Study on seasonal incidence of insect pests in rice (*Oryza sativa* L.) ecological engineering field. *Biol. Forum.* 14(2a): 44–49.

Subagja RA, Agustiani T, Hidayati LN, Yudi J, Deden, & Dukat. 2023. Effect of concentration and application interval of Chlorantraniliprole active ingredient insecticide on attack intensity of *Spodoptera frugiperda* J.E Smith (Lepidoptera: Noctuidae) and yield of sweet corn (*Zea mays saccaharata* Sturt) plants. *Eduvest*. 3(9): 1650–1659.

Subedi S, Bohara AK, Thapa S, & Timilsena K. 2024. Safeguarding rice crops in Nepal: Unveiling strategies against the yellow stem borer (*Scirpophaga incertulas*). *Discov Agric*. 2(1): 64. https://doi.org/10.1007/s44279-024-00065-8

Tang J, Liu X, Ding Y, Jiang W, & Xie J. 2019. Evaluation of *Metarhizium anisopliae* for rice planthopper control and its synergy with selected insecticides. *Crop Prot*. 121: 132–138. https://doi.org/10.1016/j.cropro.2019.04.002

Thalib R, Fernando R, Khodijah, Meidalima D, & Herlinda S. 2014. Patogenisitas isolat *Beauveria bassiana* dan *Metarhizium anisopliae* asal tanah lebak dan pasang surut Sumatera Selatan untuk agens hayati *Scirpophaga incertulas* [Pathogeicity of *Beauveria bassiana* and *Metarhizium anisopliae* isolates from fresh swamp and tidal lowland, South Sumatra for *Scirpophaga incertulas* biological agents]. *J. Trop. Plant Pests Dis*. 13(1): 10–18. https://doi.org/10.23960/j.hptt.11310-18

Thresh JM. 1989. Insect-borne viruses of rice and the green revolution. *Trop. Pest Manag*. 35(3): 264–272. https://doi.org/10.1080/09670878909371378

Usyati N, Kurniawati N, & Rumasa O. 2020. Impact of ecological engineering on the type and population of pests, natural enemies, and yield of the rice. *J. Trop. Plant Pests Dis.* 20(2): 140–149. https://doi.org/10.23960/jhptt.220140-149

Wakil W, Boukouvala MC, Kavallieratos NG, Riasat T, Ghazanfar MU, & Avery PB. 2024. Acaricidal efficacy of abamectin against *Tetranychus urticae* populations when combined with entomopathogenic fungi. *Horticulturae*. 10(10): 1019. https://doi.org/10.3390/horticulturae10101019

Wang P, Liu J, Lyu Y, Huang Z, Zhang X, Sun B, Li P, Jing X, Li H, & Zhang C. 2022. A review of vector-borne rice viruses. *Viruses*. 14(10): 2258. https://doi.org/10.3390/v14102258

Widiarta IN, Kusdiaman D, Siwi SS, & Hasanuddin A. 2004. Varian efikasi penularan tungro oleh koloni-koloni wereng hijau *Nephotettix virescens* Distant [Variation in the efficiency of tungro transmission by colonies of the green leafhopper, *Nephotettix virescens* Distant]. *Jurnal Entomologi Indonesia*. 1(1): 50–58. https://doi.org/10.5994/jei.1.1.50

Wu SF, Zheng B, Zheng C, Mu XC, Zhang Y, Hu J, Zhang S, Gao CF, & Shen JL. 2018. The evolution of insecticide resistance in the brown planthopper (*Nilaparvata lugens* Stål) of China in the period 2012–2016. *Sci. Rep*. 8(1): 4586. https://doi.org/10.1038/s41598-018-22906-5