OPEN ACCESS Plant Protection, 10 (03) 2026. 431-443 DOI:10.33804/pp.010.03.6017

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Available Online at EScience Press

Plant Protection

ISSN: 2617-1287 (Online), 2617-1279 (Print)

http://esciencepress.net/journals/PP

Research Article

Population Dynamics of Insect Pests across Phenological Growth Stages of Rice in the Forest Belt of Ghana

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ARTICLE INFO

Article history
Received: 9th January, 2026
Revised: 17th April, 2026
Accepted: 20th April, 2026

Keywords
Rice insect pests
Population dynamics
Phenological growth stages
Integrated pest management (IPM)
Forest agroecosystem

ABSTRACT

Rice agroecosystems harbor diverse insect pest communities whose composition and dynamics vary across space, season, and crop growth stages. This study assessed pest species occurrence, dominance, diversity, and indicator species across three rice-growing districts. A total of 35 insect pest species belonging to 17 families and 6 orders were identified from 1,441 specimens collected through sweep net sampling. Juaben exhibited the highest species richness (28 species), followed by Offinso (22) and Atwima Mponua (17), with several species unique to specific locations and 15 species shared across all districts. *Diopsis thoracica* was the most dominant species (16.5-17.5%), followed by *Aspavia armigera*, *Leptocorisa* spp., *Cofana spectra*, and *Cofana unimaculata*, representing key feeding guilds including stem borers, grain suckers, and sap suckers. Guild composition varied spatially, with stem borers dominating in Offinso, while grain and sap suckers were more prominent in Atwima Mponua. Pest abundance was consistently higher in the major season. Diversity indices, including the Shannon–Wiener index, were highest in Juaben, and Bray-Curtis and PERMANOVA analyses revealed significant spatial (p = 0.001) and seasonal differences in pest composition, despite high similarity between seasons (88%). Pest dynamics also varied across crop growth stages, with grasshoppers dominating early stages and grain suckers increasing toward maturity. Indicator species analysis identified eight key species, with *Leptocorisa* spp. strongly associated with later growth stages. In conclusion, spatial heterogeneity, seasonal variation, and crop phenology significantly influence pest community structure, emphasizing the need for location- and stage-specific integrated pest management strategies.

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Introduction

Rice (*Oryza sativa* L.) has become a staple food of increasing importance in Ghana, with per capita consumption estimated at 40 kg/year and rising (Asante et al., 2013; GIPC, 2025). Despite substantial increases in cultivated area in recent years, domestic production remains insufficient to meet demand, making the country a net importer (Abankwa and Tutu, 2021;

Boakye, 2025). This production-consumption gap has prompted intensified efforts to boost local output through both extensification and intensification, supported by the release of improved, consumer-preferred varieties by national breeding programs (Bissah et al, 2022; Ayeh et al., 2025; Issaka et al., 2025).

The expansion and intensification of rice cultivation often leads to shifts in pest pressure and community composition (Behera et al., 2013; Gossner et al., 2016). In Ghana, however, up-to-date information on insect pests associated with rice is limited. Much of the available literature either provides general profiles for West Africa with only sporadic references to Ghana (Umeh et al., 1995; Khan et al., 1991; Nwilene et al., 2009) or dates back several decades (Agyen-Sampong, 1977; Armah, 2001; Nutsuga et al., 2003). During this interval, significant changes have occurred: new varieties have been adopted, production systems have changed and farmers' pest-management practices have shifted (Anang and Amikuzuno, 2015; Gaballah, 2023). Such changes can alter the abundance, diversity, and seasonal dynamics of pest species, potentially leading to unexpected outbreaks or the emergence of new key pests (Bekele, 2018; Gaballah, 2023).

Insect pests inflict substantial yield losses in rice worldwide, with estimates ranging from 25% to 40% in tropical systems (Heinrichs et al., 2017; Saito et al, 2023). Losses are influenced not only by pest identity and abundance but also by the timing of infestation relative to crop phenology. Different growth stages of rice vary in susceptibility to specific pest guilds: seedlings and tillering plants are vulnerable to defoliators and stem borers, whereas reproductive stages are most sensitive to grain-sucking bugs (Pathak and Khan, 1994; Heinrichs and Barrion, 2004). Understanding pest dynamics across phenological stages is therefore fundamental to designing stage-specific monitoring and intervention strategies in integrated pest management (IPM) (Zhou et al., 2024; Abdennour et al., 2025).

In Ghana's semi-deciduous rainforest zone, rice is grown under both rain-fed and irrigated systems, often in lowland valleys within a mosaic of forest and farmland. The pest complexes in these agro-ecologies are poorly documented, and recent anecdotal reports indicate sporadic but damaging pest outbreaks in some rice-producing areas. Without current, location-specific data on pest species composition, abundance, and phenological succession, the development of effective, sustainable IPM recommendations remains hindered.

This study aimed to help address the knowledge gap by determining the suite of insect pests associated with smallholder lowland rice production in the semi-deciduous rainforest belt of Ghana, with particular emphasis on their distribution, abundance, diversity, and succession across key phenological growth stages. By integrating spatial and rice phenological dimensions, this study provides a baseline that can inform the development of responsive management strategies based on current practices.

Materials and Methods

Study location

This study was conducted in three districts: Ayensuso, Namong, and Bonsua in Offinso Municipal; Antwiagyeikrom, Tanodumase, and Mpasatia in Atwima Mponua district; and Juaben, Yaw Nkrumah, and Nobwam in Juaben district (Figure 1). All three locations lie within the semi-deciduous rainforest ecological zone. They experience varying amounts of rainfall but share similar mean temperatures. Mean temperatures ranges between 21ºC and 32ºC, with March and August being the hottest and coldest month respectively. The annual mean rainfall for Offinso is 953.4 - 1,038 mm while that for Atwima Mponua and Juaben are 1,100 - 1800 mm and 1,200 - 1,500 mm respectively (MoFA, 2026).

The zone is characterized by two cropping seasons, corresponding to the major rainfall period from April to July and the minor rainfall period from September to November. A dry season occurs from December through February. The landscape across these areas is undulating, with streams running through low-lying lands that are used for rice cultivation. The soils across the districts are predominantly forest ochrosols, which are deeply weathered and well-suited for agriculture (MoFA, 2026).

With the exception of Nobwam, which has an irrigation system and cultivates rice year-round, all other areas rely strictly on rainfall, with cultivation limited to two seasons annually (major and minor).

Experimental farms

The trial was conducted on farmer-managed farms across three districts. From each district, three rice-growing communities were selected, and within each community, six farms were chosen, giving a total of 54 farms. Farm selection was based on the rice growth stage at the designated sampling period and the farmers' willingness to participate. Farmers applied their own management practices, which were documented by the research team. Farm sizes ranged from 1 to 5 acres, and most were contiguous with other rice fields. At Nobwam, farmers established nurseries from which seedlings were transplanted 3-5 weeks after sowing. In the other areas, few farmers raise nursery and majority either does direct sowing or broadcasting.

Sampling insect pests

Sampling was carried out during the minor season of 2022 and the major season of 2023. It began at the nursery or seedling stage, depending on the cropping system, starting one week after emergence. Insect collection was conducted once at each rice phenological growth stage: nursery, tillering-stem elongation, booting, flowering, milk, and dough. Each farm was divided into two sections, and an insect sweep net was used to sample rice plants by walking 20 steps, sweeping at every other step. It is acknowledged here that the inherent limitation of the sweep net's inability to sample immature stem borers and soil-dwelling insects limited the scope of the study.

Insect preservation and identification

Insects collected with the sweep net were transferred into a killing bottle until they died. Dead insects, except moths, were preserved in 70% ethanol. Adult moths were placed in labeled envelopes, stored in a refrigerator, and later pinned and dried. Collections were taken to the CSIR-Crops Research Institute Entomology Laboratory, where they were sorted and either pinned and dry-preserved or wet-preserved in 70% ethanol. Preserved specimens were identified using taxonomic keys (Heinrichs and Barrion, 2004).

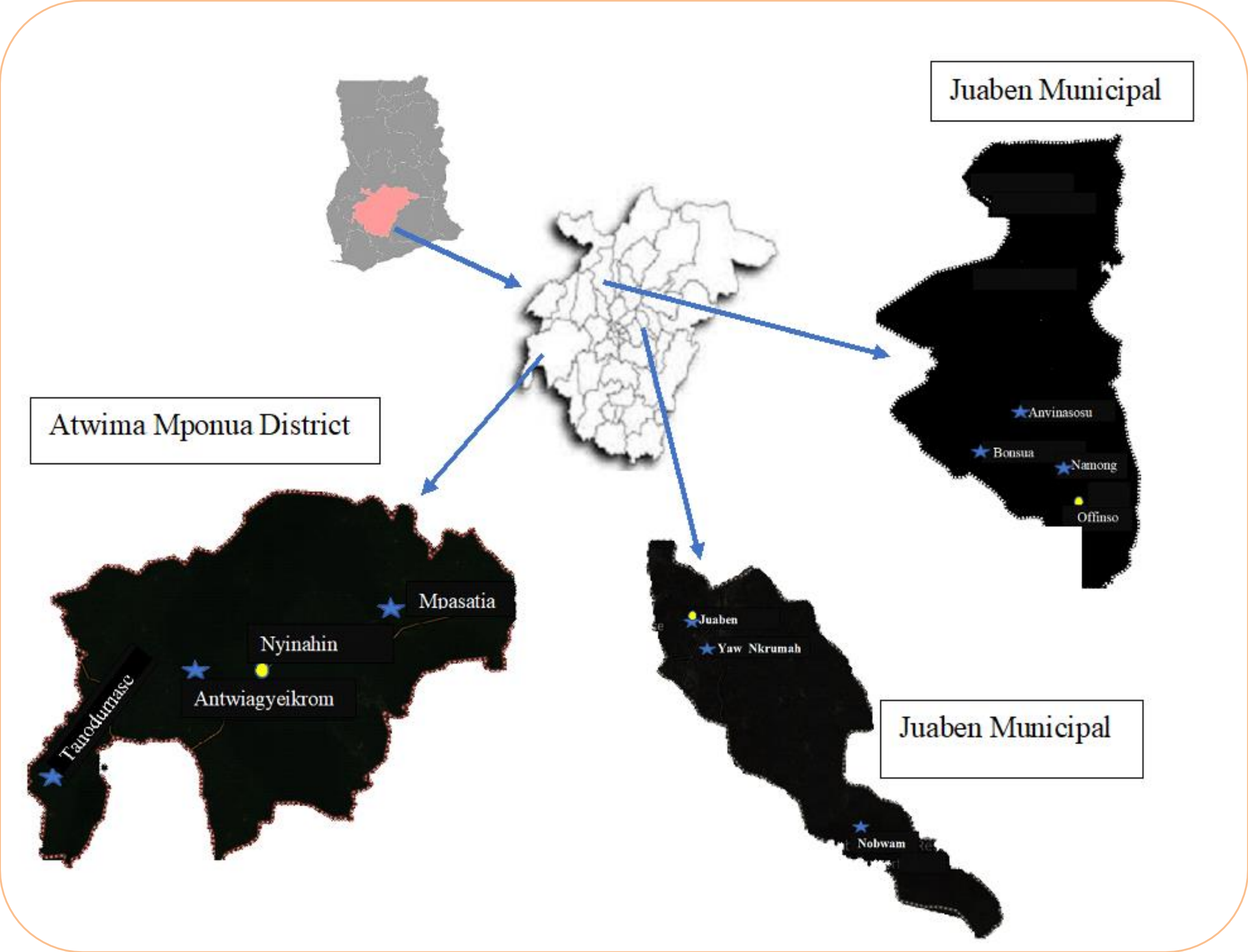

Figure 1. Map of Ghana showing the sampled districts and communities. Source: https://mofa.gov.gh/site/sports/district-directorates/ashanti-region.

Data analysis

The analysis carried out on the collected data included relative abundance, diversity indices and community composition and indicator species using the formulae detailed below:

$$\text{Relative Abundance } (\%) = \frac{\mathrm{C}i}{\mathrm{C}t} \times 100$$

Where: C_i = count of species at district, C_t = total count at district

Diversity

Shannon-Wiener Index (H') = - Σ (p_i * ln p_i)

Where: p_i is the proportion of species i

$$\text{Pielou's Evennes (J')} = \frac{\text{H'}}{\ln(\text{S})}$$

Where: H' = Shannon-Wiener diversity index

S = the total number of species

Pest community composition

$$\text{Bray} - \text{Curtis Dissimilarity } (\text{BC}jk) = \frac{(1 - 2\text{Cjk})}{(\text{S}j + \text{S}k)}$$

Where: C_{jk} = The sum of the lesser counts for each species between sites j and k

S_j = Total count of all individuals in site *j*

S_k = Total count of all individuals in site *k*

Dufrêne and Legendre indictor value (IndVal) (Dufrêne and Legendre, 1997):

$$\text{IndVal}_{ij} = 100\, A_{ij}\, B_{ij}.$$

For each species *i* in group *j*, specificity is defined as:

$$A_{ij} = N_{ij} / N_i$$

Where N_{ij} is the mean number of individuals of species *i* across plant growth stages in group *j*, and N_i is the sum of the mean numbers of individuals of species *i* over all groups.

Fidelity is defined as:

$$Bij = \frac{Nsitesij}{Nsitesj}$$

Where *Ngrowth stages*$_{ij}$ is the number of growth stages in group *j* where species *i* is present, and *Ngrowth stages*$_j$ is the total number of growth stages in group *j*.

Permutational multivariate analysis of variance (PERMANOVA) was used to test the significance of differences in pest structure among the districts and seasons (Heimonen et al., 2013). Statistical analysis was performed using R (version 4.3.1) and graphs drawn with MS Excell 2011 (Microsoft Inc.).

Results

Pest species occurrence and dominance

A total of 35 insect pest species, representing 17 families and 6 orders, were identified from 1,441 specimens collected through sweep net sampling (Table 1). Juaben recorded the highest species richness, with 28 pest species, while Offinso and Atwima Mponua recorded 22 and 17 species, respectively (Figure 2). Five species were unique to Juaben (*Xandathalia* sp*.*, *Lema* sp*.*, *Conocephalus longipenis, Atractomorphas* sp., and *Acrida confusa*), and one species was unique to Offinso (*Trichispa sericea*). Fifteen species were common across all locations, including *Aspavia armigera, Chaetocnema* sp*., Cofana spectra, Cofana unimaculata, Conocephalus maculata, Dicladispa* sp., *Diopsis thoracica, Euscyrtus* sp*., Leptocorisa* sp., *Nezara viridula, Oxya hyla, Paratettix* sp*., Poophilus* sp*., Tenebrio* sp., and *Zonocerus variegatus*.

Diopsis thoracica was the dominant pest species, accounting for 16.5-17.5% of all captured insects (Figure 2). The five most abundant species, in decreasing order, were *D. thoracica*, *A. armigera*, *Leptocorisa* sp., *C. spectra*, and *C. unimaculata*. These species represent three feeding guilds which comprise stem borers, grain suckers, and sap suckers. Relative abundance by feeding guild showed that leafhoppers dominated in Offinso and Atwima Mponua.

The abundance of the five categorized guilds, comprising sap suckers, stem borers, leaf defoliating beetles, defoliating grasshoppers and grain suckers varied across the districts. On the other hand, stem borers were the dominant guild in Offinso, grain suckers and stem borers dominated the Atwima Mponua pest guilds. Offinso showed even dominance for stem borers, grain and sap suckers. All the pest guilds were more abundant in the major season compared to the minor season (Figure 3).

The Shannon-Wiener index (H') and the other diversity indicators were highest at Juaben, followed by Offinso, and lowest at Atwima Mponua (Table 2). Pairwise comparisons of species diversity, based on the Bray-Curtis dissimilarity index coupled with PERMANOVA results showed significant differences in pest composition among the three districts (Table 3). It shows the districts share 48-64% pest composition and the differences between them were significant (pseudo-F = 6.84, R^2 = 0.42, *p* = 0.001). The greatest dissimilarity (0.52) occurred between Atwima Mponua and Juaben. This pattern reflects the contrasting species richness (19 against 35 species, Table 2) and dominance structures between these locations.

Bray-Curtis dissimilarity analysis also revealed that pest community composition was similar between major and minor seasons, with an overall dissimilarity index of 0.124, indicating 88% similarity in species composition

(Table 3). Despite the low dissimilarity value of 0.13, PERMANOVA confirmed that seasonal differences were statistically significant (pseudo-F = 8.94, R^2 = 0.18, p = 0.001). This shows that while the same species assemblage occurs in both seasons, their relative abundance differs.

Table 1. Identified insect pest species.

Sr. No.	Species Name	Order	Family	Common Name / Pest Type
1	*Acrida confusa*	Orthoptera	Acrididae	Defoliator (Grasshopper/cricket)
2	*Acrida bicolor*	Orthoptera	Acrididae	Defoliator (Grasshopper/cricket)
3	*Aiolopus* sp.	Orthoptera	Acrididae	Grasshopper/cricket
4	*Aspavia armigera*	Hemiptera	Pentatomidae	Grain sucker
5	*Atractomorpha acutipennis*	Orthoptera	Pyrgomorphidae	Defoliator (Grasshopper/cricket)
6	*Atractomorpha* sp.	Orthoptera	Pyrgomorphidae	Defoliator (Grasshopper/cricket)
7	*Aulacophora Africana*	Coleoptera	Chrysomelidae	Leaf beetle
8	*Chaetocnema* sp.	Coleoptera	Chrysomelidae	Leaf beetle
9	*Chilo zacchonius*	Lepidoptera	Crambidae	Stem borer
10	*Chnootriba similis*	Coleoptera	Coccinellidae	Leaf beetle
11	*Cofana spectra*	Hemiptera	Cicadellidae	Sap sucker
12	*Cofana unimaculata*	Hemiptera	Cicadellidae	Sap sucker
13	*Conocephalus longipenis*	Orthoptera	Tettigoniidae	Defoliator (Grasshopper/cricket)
14	*Conocephalus maculate*	Orthoptera	Tettigoniidae	Defoliator (Grasshopper/cricket)
15	*Dicladispa* sp.	Coleoptera	Chrysomelidae	Leaf beetle
16	*Diopsis thoracica*	Diptera	Diopsidae	Stem borer
17	*Euscyrtus* sp.	Orthoptera	Gryllidae	Defoliator (Grasshopper/cricket)
18	*Lema* sp.	Coleoptera	Chrysomelidae	Leaf beetle
19	*Leptocorisa* sp.	Hemiptera	Alydidae	Grain sucker
20	*Locris* sp.	Hemiptera	Cercopidae	Sap sucker
21	*Maliarpha separatella*	Lepidoptera	Pyralidae	Stem borer
22	*Nephotettix viriscens*	Hemiptera	Cicadellidae	Sap sucker
23	*Nezara viridula*	Hemiptera	Pentatomidae	Sap sucker
24	*Nymphula* sp.	Lepidoptera	Crambidae	Leaf defoliator
25	*Oebalus pungnax*	Hemiptera	Pentatomidae	Grain sucker
26	*Oxya hyla*	Orthoptera	Acrididae	Defoliator (Grasshopper/cricket)
27	*Paratettix* sp.	Orthoptera	Tetrigidae	Defoliator (Grasshopper/cricket)
28	*Poophilus* sp.	Hemiptera	Aphrophoridae	Sap sucker
29	*Pyrgomorpha cognata*	Orthoptera	Pyrgomorphidae	Defoliator (Grasshopper/cricket)
30	*Riptortus* sp.	Hemiptera	Alydidae	Grain sucker
31	*Tenebrio* sp.	Coleoptera	Tenebrionidae	Grain feeder
32	*Scirpophaga* sp.	Lepidoptera	Crambidae	Stem borer
33	*Trichispa sericea*	Coleoptera	Chrysomelidae	Leaf beetle
34	*Xanthadalia* sp.	Coleoptera	Coccinellidae	Leaf beetle
35	*Zonocerus variegatus*	Orthoptera	Pyrgomorphidae	Defoliator (Grasshopper/cricket)

Table 2. Diversity indices of insect pests across three districts

Diversity Index	Offinso	Atwima Mponua	Juaben
Species Richness (S)	24	19	35
Shannon-Wiener (H')	2.68	2.41	3.16
Simpson's Index (1-D)	0.91	0.88	0.95
Pielou's Evenness (J')	0.84	0.82	0.89

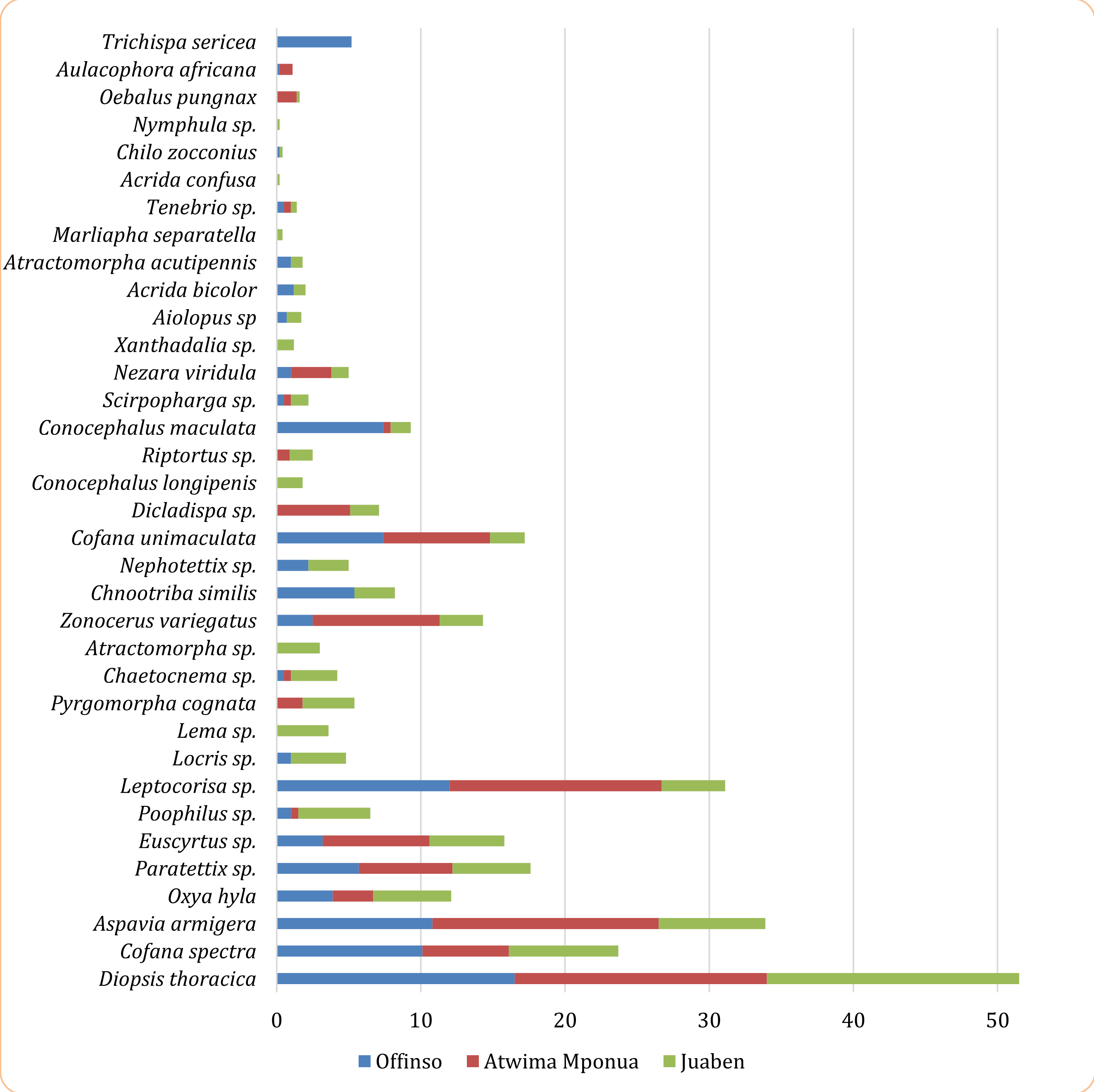

Figure 2. Relative abundance of insect pests on rice across three districts

Table 3. Bray-Curtis Dissimilarity and PERMANOVA results of insect pests of rice across three districts in two different seasons.

Districts Compared	Dissimilarity Index	Pseudo-F	R^2	*p*-value
Offinso/Atwima Mponua	0.36	3.4	0.23	0.014
Offinso /Juaben	0.41	4.78	0.32	0.002
Atwima Mponua/ Juaben	0.52	6.12	0.38	0.001
Major/minor	0.13	8.94	0.18	0.001

Dissimilarity index scale: 0 = identical, 1 = completely different.

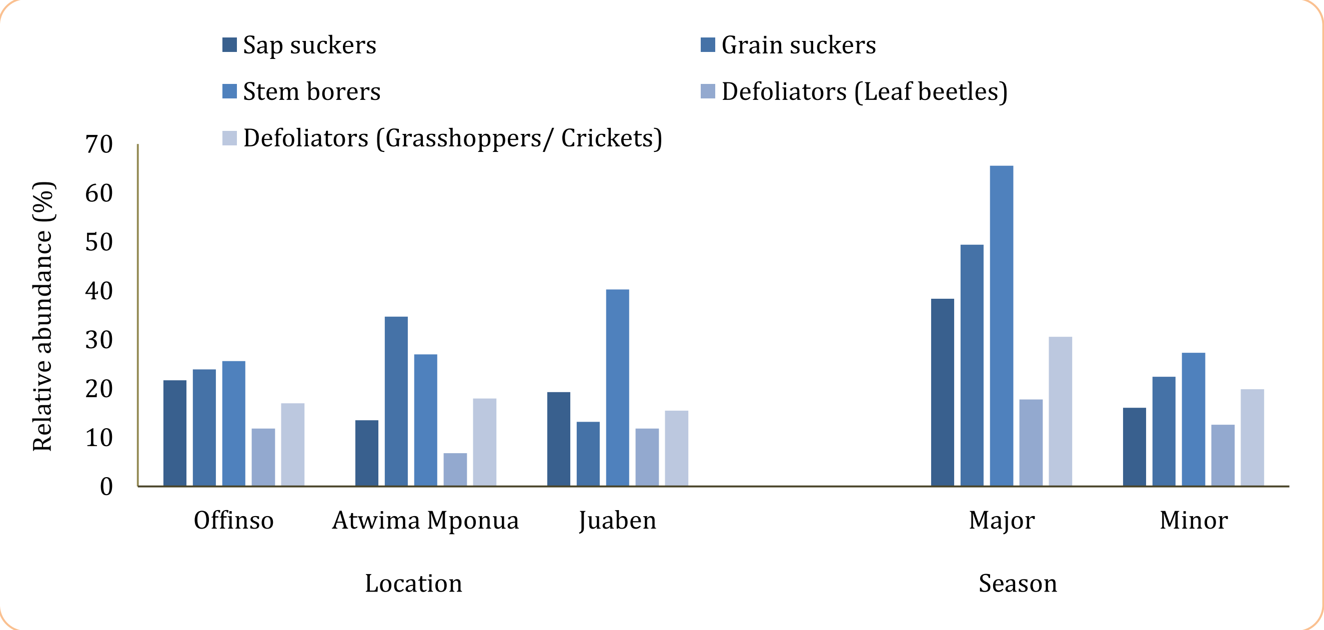

Figure 3. Relative abundance of pest groups by feeding guild across three districts over two seasons.

At the seedling stage, only a few species were recorded, primarily stem borers (*D. thoracica*), sap suckers, and grasshoppers (Figure 4 and 5). Grasshoppers were dominant during the tillering and booting stages but declined sharply thereafter. Stem borers, sap suckers, and grain suckers were all abundant at tillering and booting, with their proportions gradually decreasing beyond these stages. The booting stage showed a more balanced representation of feeding guilds. From booting onward, there was a rapid increase in grain suckers. During the milk to dough stages, the proportions of all guilds declined, except for grain suckers, which continued to increase.

Dufrêne-Legendre indicator species analysis identified 8 potential indicator species across the six rice growth stages (Table 4). *Leptocorisa* sp. was the strongest indicator, with IndVal increasing from 31.0% at flowering (p = 0.016) to 52.0% at dough stage (p = 0.001). *C. spectra* was a significant indicator of the tillering stage (IndVal = 42.0%, p = 0.008), while *Diopsis thoracica* showed moderate indicator value for the nursery stage (IndVal = 39.8%, p = 0.012). Three leaf beetle species (*Lema* sp., *Chnootriba similis*, and *Trichispa sericea*) were significant indicators of the tillering stage (IndVal = 25.5-29.1%, p < 0.05).

Table 4: Dufrene-Legendre indicator species analysis

Stage	Indicator Species	IndVal (%)	Significance
Nursery	*Diopsis thoracica*	46.2	p < 0.05
Tillering	*Cofana spectra*	52.8	p < 0.01
	Lema sp.	42.9	p < 0.05
	Chnootriba similis	40.2	p < 0.05
Booting	*Aspavia armigera*	34.7	p < 0.05
	Conocephalus maculata	30.1	p < 0.05
Flowering	*Leptocorisa sp.*	41.2	p < 0.01
	Aspavia armigera	38.6	p < 0.05
Milk	*Leptocorisa sp.*	55.6	p < 0.001
	Aspavia armigera	46.2	p < 0.01
Dough	*Leptocorisa sp.*	66.7	p < 0.001

α = 0.05.

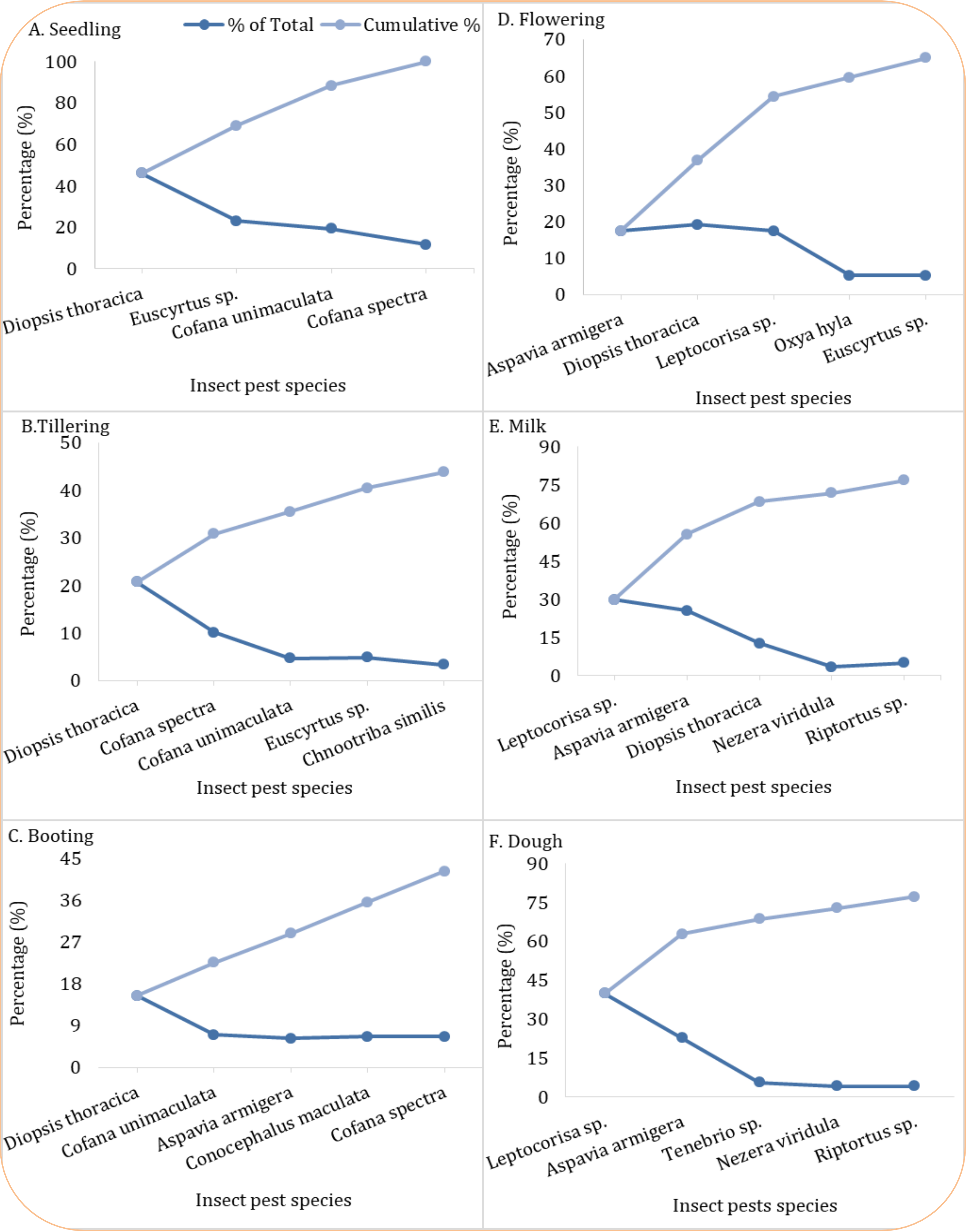

Figure 4. Five most abundant pest species at the different phenological growth stages of rice.

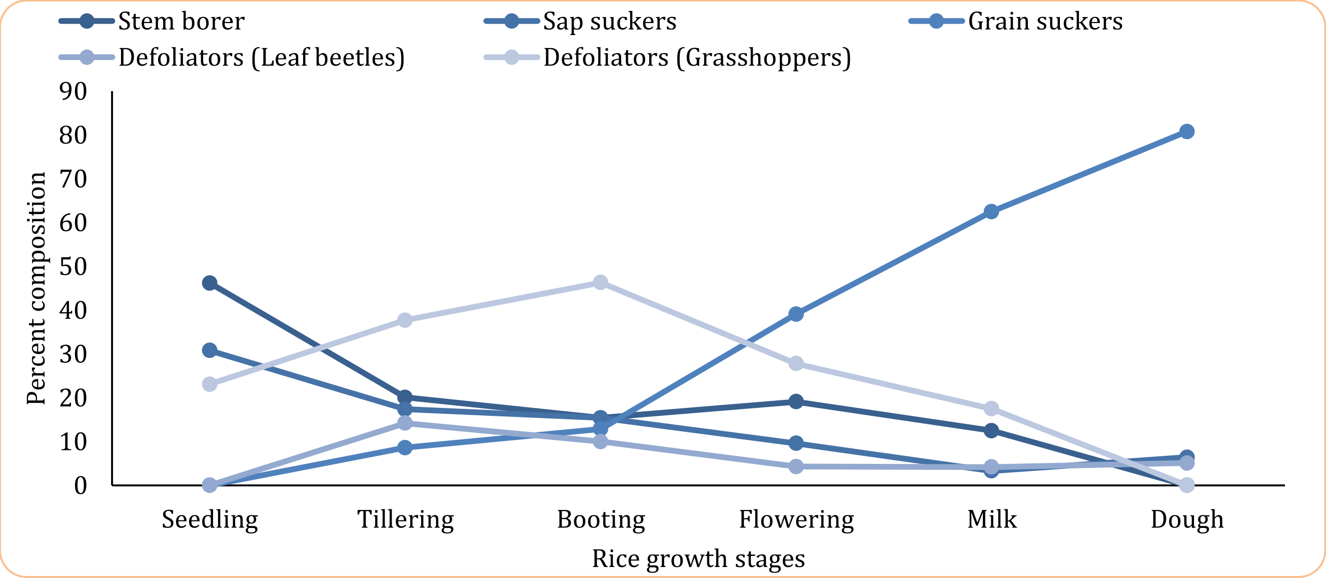

Figure 5. Insect pest feeding guilds abundance at different phenological stages of rice.

Discussion

The results from this study give some perspective of rice pest complex in the current rice agro-landscape in a typical lowland rice production in the semi-deciduous forest belt of Ghana. Given the paucity of recent profile of rice insect pests in Ghana, the findings give important update on rice in Ghana and contribute important baseline information for refining integrated pest management (IPM) strategies under current production systems.

Pest species composition and dominance patterns

The identification of 35 insect pest species across 17 families and 6 orders indicates a complex pest profile in the study area. This output represents one of the most complete rice insect pest inventories for Ghanaian rice ecosystem in recent decades.

D. thoracica emerged as the dominant species, accounting for approximately 16% of total pest abundance. The consistent dominance of this stem borer across districts underscores its importance as a key pest of rice in the forest belt of Ghana. This finding aligns with earlier reports identifying *Diopsis* spp. as major pests in West African lowland rice (Nwilene et al., 2009). It suggests that this stem borer remains a primary pest in Ghana's forest belt despite changes in rice production systems. This pest is notorious under humid conditions that favor larval development and tiller infestation, thereby can cause significant yield loss (Nwilene et al., 2009). Although *D. thoracica* was the dominant species and also among the stem borers, its certainty as the dominant stem borer is inconclusive. The sweep net sampling methodology employed in this study may have underestimated the true abundance of lepidopteran stem borers, which typically require light trapping or destructive sampling of tillers for accurate population assessment (Duman and Mutlu, 2019; Gyawali et al., 2019; Siregar et al., 2024), Previous studies in West Africa have identified *Maliarpha separatella* and *Sesamia calamistis* as equally important stem borer species (Umeh et al., 1995; Nwilene et al., 2009), suggesting that a more comprehensive assessment of the stem borer guild using complementary sampling methods would provide a more complete understanding of this economically important pest complex.

The prominence of *A. armigera*, *Leptocorisa* sp., *C. spectra* and *C. unimaculata* among the most abundant species suggest they should be of prime importance in pest management decisions. Nevertheless, abundance alone does not dictate pest status of the pest. *C. cofana* and *C. unimaculata* and the less abundant leafhopper *Nephotettix viriscens* serve as vectors of the rice yellow mottle virus (RYMV) disease, and also causes hopperburn at high population density (Koudamiloro et al., 2015; Heinrichs et al., 2017). RYMV poses a significant threat to rice production in West Africa, with yield losses ranging from 20% to 100% under severe epidemic conditions (Koudamiloro et al., 2015). Although RYMV distribution in Ghana is currently patchy, the expansion of rice cultivation and intensification of production systems may facilitate the spread of both vector populations and the virus itself, warranting continued surveillance. In this study, only one community in Atwima Mponua showed

RYMV incidence, while another had hopperburn during the minor season in 2022.

Leaf beetle incidence in rice is sporadic but can be very devastating when infestation occurs at early vegetative stages, and their low abundance in the study areas conforms to this (Murphy, 2005; Koudamiloro et al., 2019; Chaiwong and Wong, 2025). Besides leaf defoliation, some of them including *Dicladispa* sp., *Lema* sp., *T. sericea* and *Chaetocnema* sp. are major vectors of RYMV (Koudamiloro et al., 2015).

The observed differences in species richness, diversity and community composition among districts point to moderate to high spatial heterogeneity in rice pest assemblages. Juaben recorded the highest species richness (28 species) and Shannon-Wiener diversity (3.14), while Atwima Mponua exhibited the lowest diversity (2.41) and species richness (17). These differences were statistically validated by PERMANOVA (pseudo-F = 6.84, R^2 = 0.42, p = 0.001) and Bray-Curtis dissimilarity values ranging from 0.36 to 0.52. These observations reflect their contrasting ecological, landscape architecture or cropping system. The increased diversity and species richness observed in Juaben district can be attributed primarily to the influence of Nobwam rice enclave. It has the largest irrigated rice production area within the Ashanti Region (Acheampong and Dartey, 2024). Unlike the other surveyed locations, which rely predominantly on rain-fed cultivation with two cropping cycles annually, Nobwam maintains continuous rice production throughout the year due to functional irrigation infrastructure. This temporal continuity in host availability creates a more stable and predictable habitat for insect pest populations, potentially supporting greater species persistence and reducing localized eliminations that may occur in seasonally interrupted systems (Bottrell and Schoenly, 2012). Similar patterns have been documented in other tropical rice production systems, where continuous cropping facilitates the build-up of diverse pest communities (Heinrichs and Muniappan, 2017; Islam et al., 2012).

Conversely, the lower diversity and distinct community composition observed in Atwima Mponua may reflect the influence of landscape heterogeneity. The predominance of small, non-contiguous rice fields interspersed within a diversified agricultural matrix in this district likely supports higher natural enemy populations that exert regulatory pressure on pest species (Birkhofer et al., 2018). This aligns with the evidence indicating that landscape complexity can enhance biological control services in agro-ecosystems (Gossner et al., 2016).

At the seasonal level, there were high species similarity among the major and minor seasons (Bray-Curtis dissimilarity = 0.13), which indicates about 88% of the species overlap. The statistically significant seasonal differences (pseudo-F = 8.94, R^2 = 0.18, p = 0.001), indicates that while the same species assemblage occurs in both major and minor seasons, their relative abundances differ markedly. This pattern suggests that seasonal environmental factors exert selective pressures that alter population growth rates within the communities. The higher pest abundance observed during the major season (April-July) compared to the minor season (September-November) can be attributed to several interacting factors. The major season coincides with more consistent and abundant rainfall and high humidity, which creates favourable microclimatic conditions for insect development, including higher humidity and more sustained availability of more suitable host plant tissues (Heinrichs and Barrion, 2004). This is consistent with earlier reports from other West African rice production systems (Umeh et al., 1995; Nwilene et al., 2009).

Rice growth phenology and pest structure

Pest guilds followed a predictable successional displacement based on their feeding behaviour in relation to availability of resources. Stem borers and sap-sucking insects were most abundant during the vegetative stages (nursery through tillering), when succulent tissues and rapidly growing stems provide optimal conditions for colonization and development (Pathak and Khan, 1994; Heinrichs and Barrion, 2004; Heinrichs and Muniappan, 2017). Defoliating grasshoppers and leaf beetles also exhibited peak abundance during early vegetative stages, consistent with their preference for tender foliage (Nwilene et al., 2009).

The booting stage emerged as a critical transition period characterized by relatively balanced representation across all feeding guilds. This stage represents a phenological window where management strategies could be effectively shifted from targeting vegetative-stage pests to reproductive-stage pests. The high evenness observed at booting suggests that this period may represent a vulnerable point in the crop's development, where multiple pest guilds are simultaneously present and could be a critical decision-making stage.

From booting through dough development, grain-sucking bugs progressively dominated the pest community, culminating in their overwhelming dominance (87.5%) at the dough stage. *Leptocorisa* sp. was the primary contributor to this trend, with its relative abundance increasing steadily as grains developed. This pattern conforms to the feeding ecology of grain-sucking bugs, which preferentially feed on developing grains (Sadou et al., 2017). The increasing dominance of grain-sucking bugs during reproductive stages underscores the importance of targeted management during this critical period, as damage to developing grains directly impacts yield and grain quality (Heinrichs and Muniappan, 2017).

The Dufrêne-Legendre indicator species analysis identified several pest species with high potential value as phenological indicators for monitoring and management decision-making. *C. spectra* (IndVal = 52.8%) and *D. thoracica* (IndVal = 48.3%) emerged as potential indicators for the tillering stage, while *Leptocorisa* sp. showed increasing indicator values from flowering (41.2%) through dough (66.7%), reflecting its strong association with reproductive-stage rice. The leaf beetles *Lema* sp., and *C. similis* can serve as possible indicators for the tillering stage (IndVal = 40.2-42.9%). Although leaf beetles were not among the most abundant pests overall, their indicator status suggests that they may serve as useful sentinels for the initiation of management interventions during vegetative stages. The moderate indicator values for *Aspavia armigera* across booting, flowering, and milk stages (IndVal = 34.7-46.2%) indicate that this species may serve as a useful indicator for the transition period between vegetative and reproductive phases.

These indicator species could provide a simplified basis for monitoring programs that could be implemented by farmers and extension agents without requiring comprehensive taxonomic expertise (Birkhofer et al., 2018). Furthermore, the indicator species coupled with rice growth phenology-based pest regime can be incorporated into an IPM strategy.

Conclusion

This study demonstrates that insect pest communities in lowland rice systems in the forest ecology of Ghana are spatially heterogeneous and structured by crop phenology. Potential indicator species for the crop were identified and they could be used as simple monitoring strategy. There is the need for further trial to validate the indicator status of these pests. These propositions can be useful for the development of sustainable IPM strategies suitable for the current rice production practices in the forest belt of Ghana.

Acknowledgements

The authors are grateful to the Director and staff of the Department of Agriculture in Juaben Municipal, Offinso Municipal, and Atwima Mponua district for their support and assistance throughout this study. The authors also sincerely thank the rice farmers who generously made their fields available for this research.

Authors' Contributions

KFA and ASnrKA conceptualized and designed the study, performed data analysis, and drafted the manuscript. ENA, JFA, and WLK contributed to data collection and manuscript editing. PO and DA were responsible for insect collection, preparation, and curation. YJN carried out the final editing of the manuscript.

Research Funding

This study was supported by the project titled "Achieving Rice Sufficiency in Ghana: Development of an Integrated Management Manual for Insect Pests and Diseases for Sustainable Rice Production in Ghana (2022-GHA-01)", funded by the Korea Partnership for Innovation of Agriculture (KOPIA), Ghana Center.

Conflict of Interest

The authors declare no conflict of interest.

Sustainable Development Goals Targeted

SDG 2: Zero Hunger
SDG 12: Responsible Consumption and Production
SDG 15: Life on Land

Policy Addressed

1. Stage-Specific Integrated Pest Management (IPM) Policy
2. Location-Specific Pest Surveillance and Management

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