

Damage Associated with Lepidoptera Rice Stem Borers in an Integrated Cropping System in Bama, Western Burkina Faso

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Abstract

Lepidoptera stem borers cause significant damage in irrigated rice in Burkina Faso. This study was conducted to monitor the damage associated with these insect pests in an integrated cropping system over two consecutive years, 2020 and 2021. We used a randomized split-plot design in a lattice design. Two rice varieties (FKR64 and Orylux6) were factors and four types of crop management before rice were used. Mineral fertilization (F0, F1, F2, F3) was distributed in secondary plots as the third factor. Weekly entomological assessments were conducted. Dead hearts and white heads were randomly sampled during the vegetative and the reproductive phases of the rice plant, respectively. Pre-immature populations of stem borers were recorded after laboratory dissection of rice tillers showing symptoms of damage. *Chilo* spp. was the most represented stem borer, irrespective of rice variety and type of treatment. Lepidoptera damage was higher in plots with higher NPK and legume than previous crops at 42 days after transplanting. The highest average rate of pre-immature stem borer populations was recorded on the Orylux6 variety. Parasitoids associated with stem borers belonged to four families of the order Hymenoptera. The highest yields were recorded in plots with the FKR 64 * F1 combination.

Keywords

Insects, Dead Hearts, White Heads, Rice

1. Introduction

In Burkina Faso, Lepidoptera stem borers and endophytic Diptera are the main

insect pests of rice [1]. They are prevalent in all rice-growing ecologies and are responsible for significant yield losses of the order of 10% - 15% [2]. These insect pests include the African rice midge, *Orseolia oryzivora* Harris & Gagné (Diptera: Cecidomyiidae), the diopside fly (*Diopsis* spp.) and Lepidoptera insect pests, including several species like *Chilo zacconius* Bleszynski, *Chilo diffusilineus* de Joannis, *Maliarpha separatella* Ragonot and *Sesamia calamistis* Hampson [3]-[8]. Lepidoptera stem borers and diopside fly larvae cause the formation of a characteristic symptom called “dead heart” during the vegetative phase of the rice plant. During the plant’s reproductive phase, these insects are responsible for the formation of the symptom “white head” bearing partially filled or empty spikelets [9] [10]. Damage caused by diopside flies appears earlier than that caused by Lepidoptera [9] [10]. *Maliarpha separatella* larvae feed at the base of the rice plant in the first node of the stem, reducing plant vigour and causing poor grain filling [11] [12]. The number of grains per head and grain weight are reduced [12]. Attacks by *M. separatella* can cause abortion of head flowers [10]. But when infestations of this insect pest are heavy, they can cause the formation of white heads like *Chilo* spp. and *S. calamistis* (Nacro, personal observations).

The economic importance of these insect pests justifies the considerable amount of research devoted to finding appropriate control methods to contain their damage. Research focuses on biological, chemical or cultural control and varietal resistance. Examples include studies on the natural enemies of Lepidoptera stem borers carried out at Bama [13], and on the role of alternative host plants in the survival of these insect pests in western Burkina Faso [6]. [14] worked on the impact of climatic parameters on the relative abundance of Lepidoptera stem borers and on the influence of the rice plant development on the abundance of these insect pests. The efficacy, compatibility and cost-effectiveness of an integrated pest management strategy based on chemical control and varietal resistance against the main insect pests in irrigated rice in Karfiguéla were explored by [15]. The present study was initiated to assess the extent of damage associated with rice Lepidoptera stem borers in an integrated cropping system, which combines three factors: crop management prior to rice transplanting, variety and mineral fertilizer. This study aims at assessing the damage caused by rice Lepidoptera stem borers and the rate of parasitism associated with them in an integrated production system, in order to improve rice productivity.

2. Material and Methods

2.1. Material

2.1.1. Study Site

The study was conducted at Bama agricultural research station (Figure 1) during two consecutive agricultural wet cropping seasons in 2020 and 2021. The climate in the study area is South Sudanian, with an alternating rainy season from May to October and a dry season from November to April. Rainfall frequently exceeds 1000 mm [16].

2.1.2. Biological Material

Field sampling was carried out on damaged tillers of cultivated rice (*Oryza sativa*) varieties Orylux6 and FKR64. The Orylux6 variety has a 100-day cycle and a potential yield of 6.5 t/ha; FKR64 has a 120-day cycle; its potential yield can reach 8 to 10 t/ha [17].

The animal material consisted of the pre-immature stages of arthropods associated with rice.

2.1.3. Field and Laboratory Equipment

Field equipment consisted of:

- Plastic bags for storing damaged plant parts (dead hearts and white heads) to take back to the laboratory for dissection;
- Knives to remove the damaged plant parts;
- Paper tape for labelling;
- Protective equipment (boots);
- Knives and forceps for dissection;
- Mesh pots for rearing immature insect stages (eggs, larvae, pupae).

2.1.4. Data Collection Sheets

Data collection techniques depended on taxonomic group and arthropod development stage. Data were collected throughout the rice development cycle. Data collection sheets were prepared to make observations, take samples, make dissections, incubations/rearing in the field and in the laboratory.

2.2. Methods

2.2.1. Field Sampling Methods for Rice Stem Borer Damage

Sampling consisted in observing the damage caused by rice stem borers. Observations were made from the 28th day after transplanting (DAT) to the 84th DAT with a frequency of 14 days.

Dead hearts were sampled during the vegetative phase of the rice plant, while white heads were sampled during the reproductive phase. These samples were taken randomly from 20 hills per sub-plot.

Pre-immature populations of stem borers were recorded after laboratory dissection of rice tillers showing symptoms of the damage mentioned above. The number of dissections was the same as for visual observations in the field.

2.2.2. Rearing of Pre-Immature Stages of Stem Borers

The rearing of pre-immature stages of stem borers was carried out in the entomology laboratory of the Farako-Ba station, Bobo-Dioulasso. The biological material included chrysalids and larvae of various stages recorded during dissections of damaged tillers. Incubation of these specimens was carried out in flasks containing water-soaked cotton; one individual was placed per flask. Rearing took place under ambient laboratory temperature conditions. Daily observations were made until the complete emergence of either the adults of the rice stem borers, or the adults of their associated parasitoids. The identification of emerged individuals

enabled us to monitor the level of parasitism of pre-immature populations of the insect pests.

2.2.3. Yield Evaluation

At maturity each rice variety was harvested. The rice was harvested by hand, using a sickle and covering an area of 3.5 m². After harvesting, the paddy was sun-dried, threshed, winnowed and weighed, and the moisture content measured and corrected to 14% in order to estimate grain yield.

2.2.4. Identification of Specimens Brought Back from the Field or Emerging from Pre-Immature Populations of Stem Borers

The family identification key by [18] and the insect identification manual, general entomology by [19] were used to identify the various species of stem borers emerged from rice damaged tillers; in addition to these documents, the reference collection of parasitoids associated with rice stem borers compiled by [14] was used for parasitoid identification.

2.2.5. Data Organization and Analysis

The collected data were entered and grouped using Microsoft Excel 2010. The database was then imported into R software version 3.6.0 for various statistical analyses. The data were first tested for normality using the Shapiro-Wilk test. To determine the individual effect of the explanatory variables (variety, previous crops and mineral fertilization) and their interactions on the response variables (arthropods, dead hearts and white heads), the data were then subjected to the Kruskal-Wallis (K-W) test at the 5% significance level. Finally, to determine the combined effects of the factors studied, the data were subjected to a multi-factor analysis of variance at the 5% level. Analyses focused on descriptive statistics (percentages, means and graphical treatments).

3. Results and Discussion

3.1. Results

3.1.1. Importance of Stem Borers Damage

Table 1 presents the results of the analysis of variance (ANOVA) of the factors studied on the formation of dead hearts and white heads during the consecutive wet seasons 2020 and 2021. These results revealed a very highly significant difference between subplots for the factors number of days after transplanting (DAT) and fertilization for the year 2020 with regard to dead hearts and white heads. For the variety factor, a highly significant difference in white heads was observed for the 2020 cropping season. A very highly significant difference for the interaction fertilization * DAT was recorded in the 2021 wet season for dead hearts and finally a very highly significant difference for the interaction fertilization * previous crops * variety * DAT in the 2021 wet season for dead hearts. Significant differences were also recorded between the interactions, previous crops * variety; fertilization * previous crops * DAT for dead hearts in wet seasons 2020 and 2021 and fertilization * previous crops * variety only for dead hearts in 2021. Finally, significant differences

were observed for the interaction fertilization * previous crops for dead hearts in wet seasons 2020 and 2021 and the triple interaction fertilization * cultural previous * variety for dead hearts in 2020.

Table 1. Effect of studied factors on the formation of dead hearts and white heads for the two wet growing seasons in 2020 and 2021 in Bama, Burkina Faso.

Source of variation	Probability			
	Dead hearts		White heads	
	Wet season 2020	Wet season 2021	Wet season 2020	Wet season 2021
Days after transplanting (DAT)	<2.2e-16***	<2.2e-16 ^{ns}	<2.2e-16***	<2.2e-16 ^{ns}
Fertilisation (F)	0.0000005301***	0.0000004647 ^{ns}	0.00000219***	0.000002183 ^{ns}
Previous crops (PC)	0.56 ^{ns}	0.01346 ^{ns}	0.7817 ^{ns}	0.7816 ^{ns}
Variety (Var)	0.09582 ^{ns}	0.02848 ^{ns}	< 2.2e-16***	< 2.2e-16 ^{ns}
Fertilization * DAT	0.0000002578***	0.0000002053***	0.099332 ^{ns}	0.200571 ^{ns}
Fertilization * Previous crops	0.027709*	0.03292*	0.223276 ^{ns}	0.309238 ^{ns}
Fertilization * variety	0.618866 ^{ns}	0.40400 ^{ns}	0.094774 ^{ns}	0.074279 ^{ns}
Previous crops * DAT	0.232099 ^{ns}	0.1808 ^{ns}	0.967134 ^{ns}	0.9491 ^{ns}
Previous crops * variety	0.005838**	0.008338**	0.828442 ^{ns}	0.4769 ^{ns}
Variety * DAT	0.937446 ^{ns}	0.8179 ^{ns}	< 2.2e-16***	2.2e-16***
Fertilization * Previous crops * DAT	0.003449**	0.004529**	0.856206 ^{ns}	0.914661 ^{ns}
Fertilization * Variety * DAT	0.562537 ^{ns}	0.58833 ^{ns}	0.132254 ^{ns}	0.2538978 ^{ns}
Fertilization * Previous crops * Variety	0.015039*	0.004407**	0.191788 ^{ns}	0.195982 ^{ns}
Previous crops * Variety * DAT	0.179359 ^{ns}	0.224826 ^{ns}	0.744458 ^{ns}	0.6291 ^{ns}
Fertilization * Previous crops * Variety * DAT	0.170603 ^{ns}	0.00000005838***	0.626079 ^{ns}	0.6553115 ^{ns}

***: very highly significant; **: highly significant; *: significant; ns: non significant.

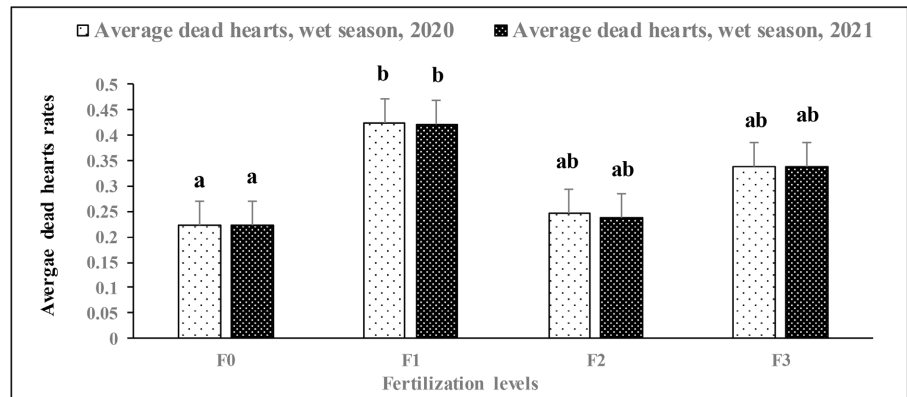
3.1.2. Effect of Rice Mineral Fertilization Level on Dead Heart Formation

Figure 1 illustrates the impact of mineral fertilization level on average dead heart rates observed on rice over two consecutive cropping seasons. The results of the ANOVA revealed a significant difference between the four fertilization levels at the 5% probability threshold in relation to the average rates of dead hearts recorded, even though no significant difference between the two crops seasons was observed. There was a significant difference between the F0 and F1 fertilization levels whatever the growing season.

3.1.3. Combined Effect of Mineral Fertilization and Number of Days after Transplanting on Dead Heart Formation

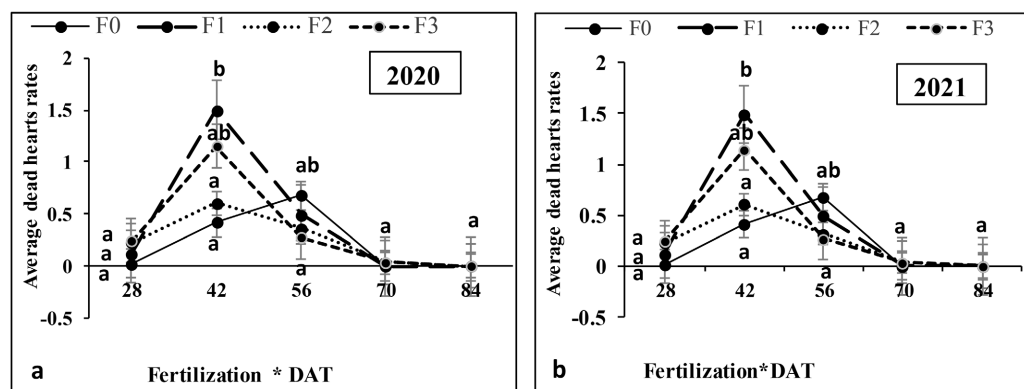
The combined effect of mineral fertilization and number of days after transplanting on dead heart formation over the two growing seasons is illustrated in **Figure 2**. Average dead heart rates first increased from 28 to 42 days after transplanting, before decreasing from 42 to 84 days after transplanting for the two growing seasons. The results of the ANOVA on average dead heart rates revealed significant differences between the four levels of fertilization for the two growing seasons. The highest average dead heart rates were recorded at 42 DAT in all subplots. Plots receiving F1 fertilization had the highest average dead heart rates (1.50%) over the

two growing seasons. This was followed by F3 (1.15%), F2 (0.60%) and F0 (0.40%).



F0: Control with no fertilization; F1: NPK (200 kg/ha) + USG (72 kg/ha); F2: NPK (100 kg/ha) + simple urea (100 kg/ha); F3: NPK (200 kg/ha) + simple urea (150 kg/ha). Figures followed by the same letter are not significantly different from each other at the 5% probability level.

Figure 1. Effect of mineral fertilization on the average dead heart rate for the 2020 and 2021 crops seasons.



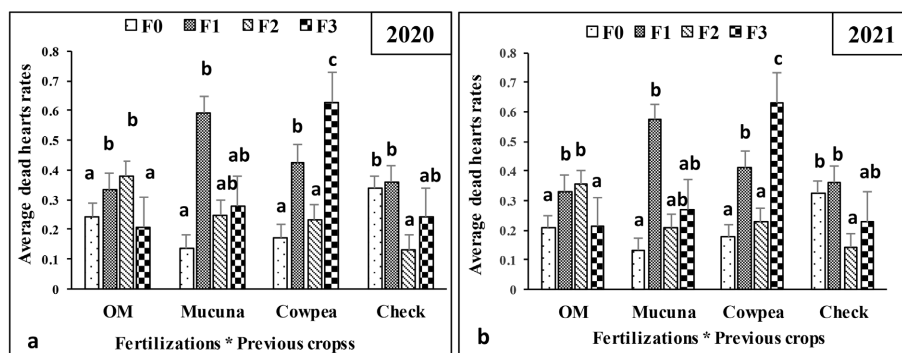
(a) Combined effect of mineral fertilization and number of days after transplanting on dead heart formation for the 2020; (b) Combined effect of mineral fertilization and number of days after transplanting on dead heart formation for the 2020 and 2021 seasons. F0: Control without fertilization; F1: NPK (200 kg/ha) + USG (72 kg/ha); F2: NPK (100 kg/ha) + simple urea (100 kg/ha); F3: NPK (200 kg/ha) + simple urea (150 kg/ha). Figures followed by the same letter are not significantly different from each other at the 5% probability level.

Figure 2. Combined effect of mineral fertilization and number of days after transplanting on dead heart formation for the 2020 and 2021 seasons.

3.1.4. Combined Effect of Mineral Fertilization and Previous Crops on Dead Heart Formation

The results of the ANOVA on the combined effect of mineral fertilization and previous crops on dead heart formation over the two consecutive growing seasons are shown in **Figure 3**. The average rate of dead hearts varied from one combination to another, with the highest rates recorded in plots with cowpea and Mucuna as previous crops, while the lowest average rates were recorded in plots with Control and Organic matter as previous crops. The highest average rate of dead hearts was recorded in the cowpea * F3 plots (0.63% and 0.63%), followed by the Mucuna *

F1 plots (0.59% and 0.57%) over the two cropping seasons. Damage was low in the Control * F2 (0.13% and 0.14%) and Mucuna * F0 (0.13% and 0.14%) plots.

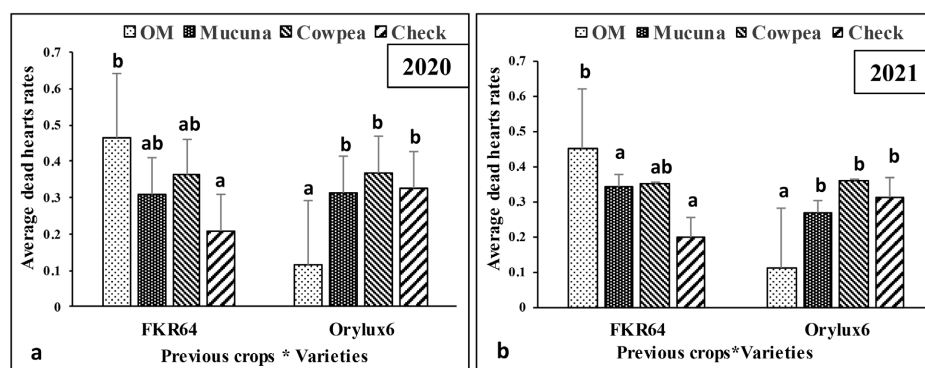


(a) Combined effect of mineral fertilization and previous crops on dead heart formation over the growing seasons 2020; (b) Combined effect of mineral fertilization and previous crops on dead heart formation over the growing seasons 2021. F0: Control without fertilization; F1: NPK (200 kg/ha) + USG (72 kg/ha); F2: NPK (100 kg/ha) + simple urea (100 kg/ha); F3: NPK (200 kg/ha) + simple urea (150 kg/ha); OM: Organic matter. Figures followed by the same letter are not significantly different from each other at the 5% probability level.

Figure 3. Combined effect of mineral fertilization and previous crops on dead heart formation over the two growing seasons.

3.1.5. Combined Effect of Previous Crops and Variety on Dead Heart Formation

Figure 4 shows the combined effect of previous crops and variety on dead heart formation. The ANOVA revealed a significant difference in the average rate of dead hearts for the previous crops * variety interactions. There were no significant differences in average dead heart rates for Mucuna, Cowpea, Control and the two varieties, except with organic matter, where average rates were 0.46% and 0.45% (variety FKR 64) and 0.12% and 0.11% (variety Orylux6) over the two consecutive cropping seasons.



(a) Combined effect of previous crops and variety on dead heart formation in 2020; (b) Combined effect of previous crops and variety on dead heart formation in 2021. OM: Organic matter. Figures followed by the same letter are not significantly different from each other at the 5% probability level.

Figure 4. Combined effect of previous crops and variety on dead heart formation in 2020 and 2021.

3.1.6. Combined Effect of Fertilization, Previous Crops and Number of Days after Transplanting on Dead Heart Formation

The results of the combined effect of fertilization * previous crops * days after transplanting on dead heart formation are presented in **Table 2**. ANOVA revealed a significant difference between treatments at the 5% threshold over the two growing seasons. Damage recorded was low at 28 DAT; some damage was observed with the F1 combination: NPK (200 kg/ha) + USG (72 kg/ha); it then increased at 42 DAT (0.86% over the two cropping seasons) and 56th DAT (0.82% over the two cropping seasons), then became rare at 70th and 84th DAT. No damage was recorded on the 28th DAT with the Mucuna * F0 * F1 * combination; the highest average rate of dead hearts (2.46%) was recorded on the 42nd DAT with the Mucuna * F1 combination, followed by the Cowpea * F3 combination (2.35%) over the two growing seasons. On the other hand, the lowest average rate of dead hearts was observed at 28 DAT (0.06% over the two growing seasons) with the Mucuna * F3 combination at 70 DAT (0.06% over the 2020 wet season and 0.07% over the 2021 wet season).

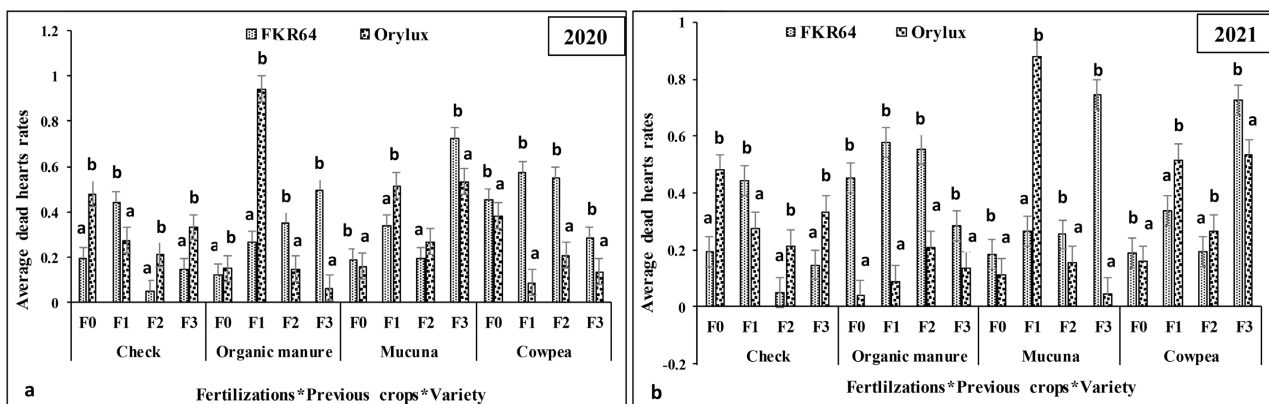
Table 2. Combined effect of mineral fertilization, previous crops and number of days after transplanting on the formation of dead hearts in 2020 and 2021.

Source of variation		Average dead hearts rates					
Previous crops	Fertilizations	28 DAT		42 DAT		56 DAT	
		2020	2021	2020	2021	2020	2021
Check	F0	-	-	0.86 ^{ab}	0.86 ^{ab}	0.82 ^b	0.82 ^b
	F1	0.13 ^b	0.14 ^b	1.28 ^d	1.29 ^d	0.36 ^{ab}	0.36 ^{ab}
	F2	-	-	0.43 ^{ab}	0.43 ^{ab}	0.22 ^{ab}	0.23 ^{ab}
	F3	0.15 ^b	0.16 ^b	0.57 ^{ab}	0.58 ^{ab}	0.46 ^{ab}	0.47 ^{ab}
Organic manure	F0	0.09 ^a	0.09 ^a	0.46 ^{ab}	0.47 ^{ab}	0.66 ^{ab}	0.67 ^{ab}
	F1	0.19 ^{bc}	0.20 ^a	1.13 ^{bc}	1.14 ^{bc}	0.32 ^{ab}	0.32 ^{ab}
	F2	0.59 ^d	0.60 ^d	0.88 ^{ab}	0.88 ^{ab}	0.41 ^{ab}	0.42 ^{ab}
	F3	0.49 ^d	0.43 ^d	0.04 ^a	0.49 ^a	0.04 ^a	0.05 ^a
Mucuna	F0	-	-	0.33 ^{ab}	0.33 ^{ab}	0.34 ^{ab}	0.35 ^{ab}
	F1	-	-	2.46 ^d	2.46 ^d	0.39 ^{ab}	0.40 ^{ab}
	F2	0.13 ^b	0.14 ^b	0.51 ^{ab}	0.52 ^{ab}	0.40 ^{ab}	0.24 ^{ab}
	F3	0.06 ^a	0.06 ^a	1.17 ^{bc}	1.17 ^{bc}	0.09 ^a	0.09
Cowpea	F0	-	-	-	-	0.86 ^b	0.87 ^b
	F1	0.14 ^b	0.14 ^b	1.09 ^{abc}	1.10 ^{abc}	0.89 ^b	0.90 ^b
	F2	0.17 ^b	0.18 ^b	0.59 ^{ab}	0.60 ^{ab}	0.38 ^{ab}	0.38 ^{ab}
	F3	0.31 ^c	0.32 ^c	2.35 ^d	2.35 ^d	0.47 ^{ab}	0.47 ^{ab}

F0: Control without fertilization; F1: NPK (200 kg/ha) + USG (72 kg/ha); F2: NPK (100 kg/ha) + Simple urea (100 kg/ha); F3: NPK (200 kg/ha) + Simple urea (150 kg/ha). Numbers followed by the same letter are not significantly different from each other at the 5% probability level.

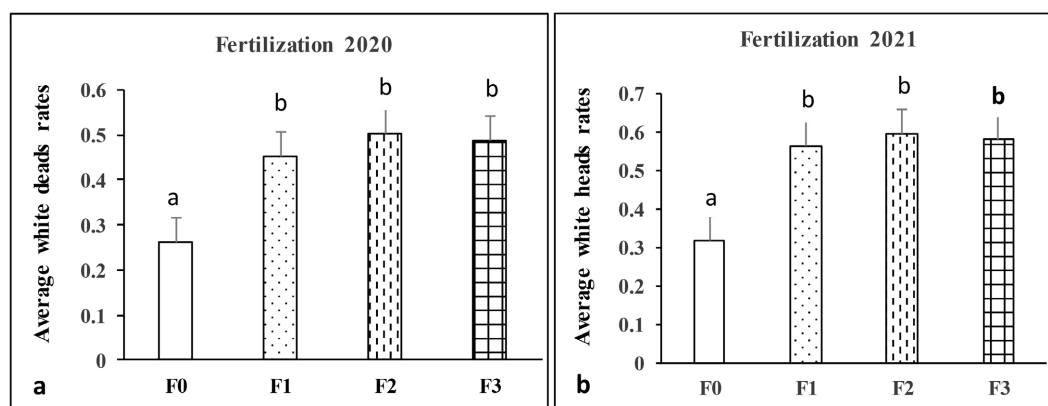
3.1.7. Combined Effect of Fertilization, Previous Crops and Variety on Dead Heart Formation

Figure 5 shows the results of the ANOVA on the combined effect of fertilization * previous crops * variety on dead heart formation over the two consecutive cropping seasons. A significant difference between treatments at the 5% threshold was found over the two growing seasons. The highest average rates of dead hearts (0.94% in 2020 and 0.87% in 2021) were recorded with the Orylux6 * organic matter * F1 combination, followed by the FKR64 * Mucuna * F3 combination with an average rate of 0.72% in 2020 and 0.74% in 2021. The lowest average dead heart rates were recorded with the Orylux6 * Cowpea * F1 and FKR64 * Control * F2 combinations, each recording 0.04% in 2020, and the Orylux6 * Organic manure * F0 0.04% in 2021.



(a) Combined effect of fertilization, previous crops and variety on dead heart damage in 2020; (b) Combined effect of fertilization, previous crops and variety on dead heart damage in 2021. F0: Control with no fertilization; F1: NPK (200 kg/ha) + USG (72 kg/ha); F2: NPK (100 kg/ha) + simple urea (100 kg/ha); F3: NPK (200 kg/ha) + simple urea (150 kg/ha). Figures followed by the same letter are not significantly different from each other at the 5% probability level.

Figure 5. Combined effect of fertilization, previous crops and variety on dead heart damage in 2020 and 2021.



(a) Effect of mineral fertilization on white head formation for 2020; (b) Effect of mineral fertilization on white head formation for 2021. F0: Control with no fertilization; F1: NPK (200 kg/ha) + USG (72 kg/ha); F2: NPK (100 kg/ha) + simple urea (100 kg/ha); F3: NPK (200 kg/ha) + simple urea (150 kg/ha). Figures followed by the same letter are not significantly different from each other at the 5% probability level.

Figure 6. Effect of mineral fertilization on white head formation for both 2020 and 2021.

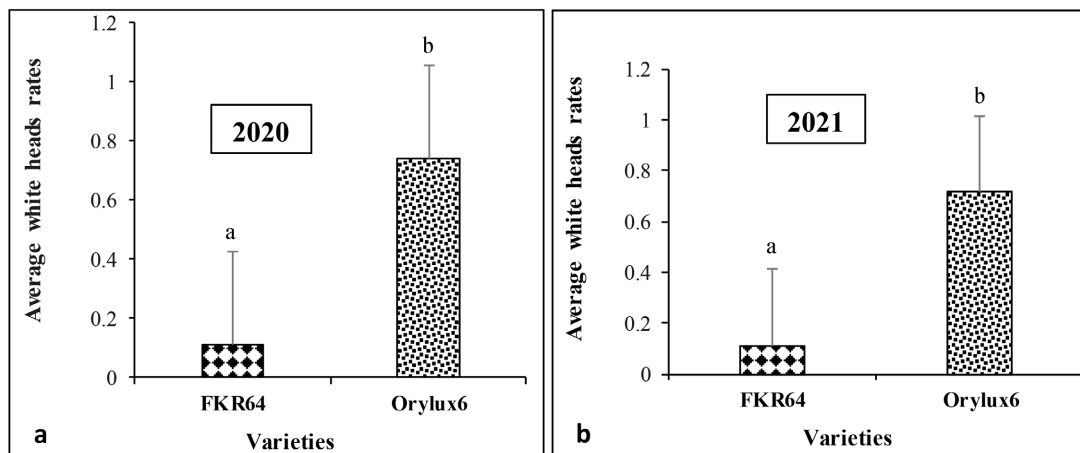
3.1.8. Effect of Factors Studied on White Head Formation

1) Effect of mineral fertilization on white head formation

Figure 6 illustrates the effect of fertilization levels on the average white head rate over two consecutive cropping seasons. ANOVA revealed a significant difference between treatments at 5% level. The lowest average white head rates (0.26% in 2020 and 0.31% in 2021) were recorded in plots that received no fertilization (F0); plots that received F1, F2 and F3 fertilization recorded the highest average white head rates of 0.45%, 0.50% and 0.48% respectively for the 2020 wet season and 0.56%, 0.59% and 0.46% respectively for the 2021 wet season.

2) Effect of rice variety on white head production

Figure 7 shows the effect of rice variety on white head formation. The results of the ANOVA revealed a significant difference between varieties at 5% threshold. Average white head rates were higher (0.76% in 2020) and 0.71% in 2021 with the Orylux6 variety. The FKR64 variety recorded 0.10% in 2020 and 0.11% in 2021.

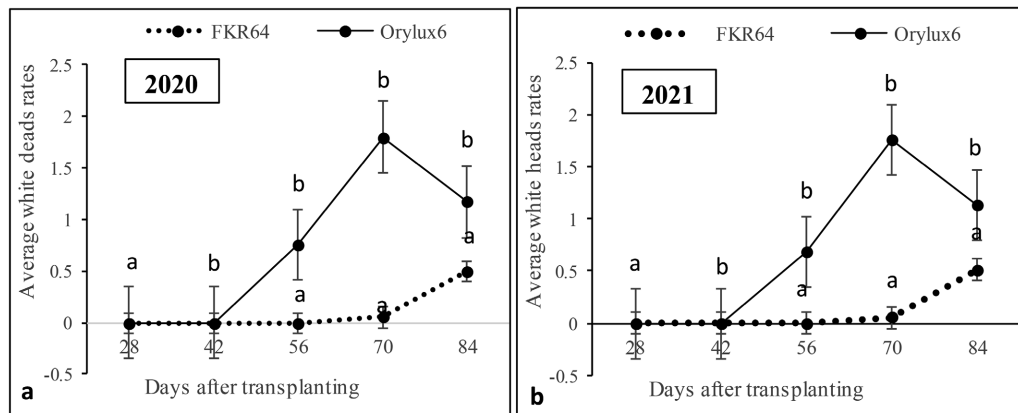


(a) Effect of variety on white head formation in 2020 and 2021; (b) Effect of variety on white head formation in 2020 and 2021. Figures followed by the same letter are not significantly different from each other at 5% probability level.

Figure 7. Effect of variety on white head formation in 2020 and 2021.

3) Combined effect of variety and number of days after transplanting on white head formation for both seasons

Figure 8 illustrates the effect of varieties on the evolution of the average rate of white heads. The results of the ANOVA showed a significant difference between varieties over the two growing seasons. The average white head rate increased from 42 to 70 DAT for the Orylux6 variety, before decreasing after 70 days. This curve followed the same trend for the two consecutive growing seasons. On the other hand, for the FKR64 variety, the first white heads were observed at 42 DAT; they increased slightly between 42 and 70 DAT, before rising again slightly at the end of the plant cycle (between 70 and 84 DAT). The highest average rate of white heads was recorded at 70 DAT for the variety Orylux6 (1.80% in 2020 and 1.75% in 2021) and at 84 DAT for the variety FKR64 (1.16% in 2020 and 1.13% in 2021).



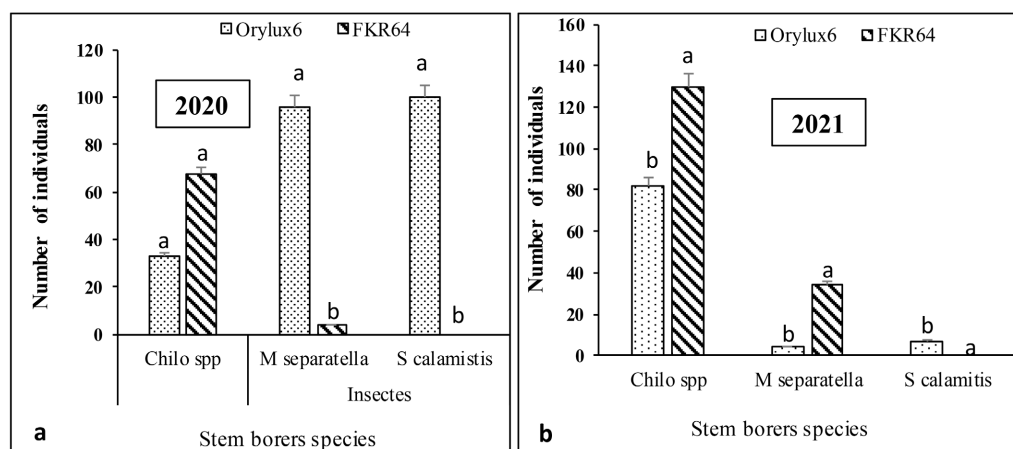
(a) Combined effect of variety and number of days after transplanting on white head formation in 2020; (b) Combined effect of variety and number of days after transplanting on white head formation in 2021. Numbers followed by the same letter are not significantly different from each other at the 5% probability level.

Figure 8. Combined effect of variety and number of days after transplanting on white head formation.

3.1.9. Evolution of Pre-Immature Populations of Rice Stem Borers

1) Evolution of pre-immature populations of rice stem borers as a function of variety

Figure 9 illustrates the evolution of the number of individuals in the pre-immature populations of rice stem borers as a function of the varieties used. In the 2020 wet season, the FKR64 variety recorded 67.38 individuals of *Chilo* spp. and 130 in 2021, compared with 32.6 individuals in 2020 and 82 in 2021 for Orylux6. As for *M. separatella*, 96.15 individuals in 2020 and 04 in 2021 were hosted by Orylux6, compared with 3.85 individuals in 2020 and 34 in 2021 for FKR 64. Finally, 100 individuals of *S. calamistis* in 2020 and 07 in 2021 were found on Orylux6. During the 2021 wet cropping season, the *Chilo* spp. population was more abundant during the vegetative phase than during the reproductive one.



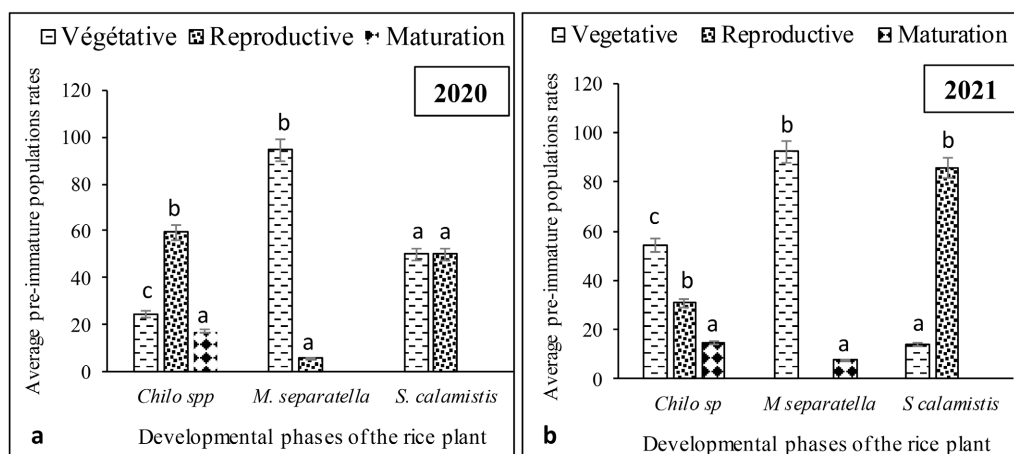
(a) Variation in pre-immature populations of rice stem borers by variety in 2020; (b) Variation in pre-immature populations of rice stem borers by variety in 2021. Figures followed by the same letter are not significantly different from each other at the 5% probability level.

Figure 9. Variation in pre-immature populations of rice stem borers by variety.

2) Relative importance of pre-immature populations of rice stem borers as a function of rice plant development phases

Figure 10 illustrates the results on the evolution of pre-immature populations of rice stem borers insects as a function of rice plant development phases.

Chilo spp. was the species recorded throughout the rice development cycle. An average rate of 24% of *Chilo* spp. populations was recorded during the vegetative phase, 59.29% during the reproductive phase and 17.25% during the maturation phase of the rice plant in 2020; 54% pre-immature population were recorded during the vegetative phase of the plant, 31% pre-immature population at rice reproduction and 15% pre-immature population at plant maturation in 2021. A percentage of 94% of *M. separatella* was observed during the vegetative phase and 5.55% during the reproductive phase in 2020. In the 2021 growing season, 92% of the pre-immature population of *M. separatella* was recorded during the vegetative phase, compared with 8% during the maturation phase of the rice plant. *Sesamia calamistis* showed the lowest average pre-immature population rate. This species was not recorded during the rice plant maturation phase in 2020 (50% of its population was recorded during the vegetative phase and 50% during the reproductive phase). In 2021, 14% of the pre-immature population was recorded during the vegetative phase and 86% during the reproductive phase of the plant. No individuals of this species were recorded during the rice maturation phase in any of the two consecutive growing seasons.



(a) Variation in pre-immature stem borer populations according to rice plant development phases in 2020; (b) Variation in pre-immature stem borer populations according to rice plant development phases in 2021. Figures followed by the same letter are not significantly different from each other at the 5% probability level.

Figure 10. Variation in pre-immature stem borer populations according to rice plant development phases.

3) Evolution of parasitism affecting pre-immature populations of rice stem borers

Only pre-immature populations of *Chilo* spp. were parasitized (**Table 3**). Larval parasitism of *Chilo* spp. was observed during the vegetative (14.28%) and reproductive

(5.08%) phases of rice on the Orylux6 variety and during the vegetative phase on the FKR 64 variety (16.66%). The average rate of parasitism was higher during the vegetative phase for both varieties.

Table 3. Variation in the average rate of parasitism affecting pre-immature populations of *Chilo* spp. according to rice variety.

Crops seasons	Varieties	Orylux6	FKR64
Wet season 2020	Vegetative phase	14.28%	16.66%
	Reproductive phase	5.08%	0.00%
Wet season 2021	Vegetative phase	7.40%	33.45%
	Reproductive phase	9.80%	9.84%

3.1.10. Biological Diversity of Parasitoids Associated with *Chilo* spp.

The results in **Table 4** show the different parasitoids that emerged from *Chilo* spp. larvae. All parasitoids belong to the order Hymenoptera. The following families were represented: Ichneumonidae, Braconidae, Chalcididae and Bethyidae.

Table 4. Parasitoids emerged from the larvae of *Chilo* spp.

Family	Genus and species	Number of individuals
Ichneumonidae	<i>Ichneumons</i> spp.	15
Ichneumonidae	<i>Megarhyssa macrurus macrurus</i>	11
Ichneumonidae	<i>Xanthopimpla</i> sp.	7
Chalcididae	<i>Brachymeria ovata</i>	5
Braconidae	<i>Dolichogenidae oryzae</i>	9
Braconidae	<i>Tropobracon antennatus</i>	16
Braconidae	<i>Chelonus texanus</i>	12
Braconidae	<i>Bracon</i> sp.	4
Braconidae	<i>Cotesia sesamiae</i>	8
Bethyidae	<i>Goniozus procerae</i>	6

3.1.11. Yield Estimation

The results of the ANOVA for paddy rice yield are shown in **Table 5**. Fertilization and variety had a very highly significant effect on rice yield in both cropping seasons, 2020 and 2021. The study of the fertilization * variety interaction revealed a significant effect on yield during the same growing seasons.

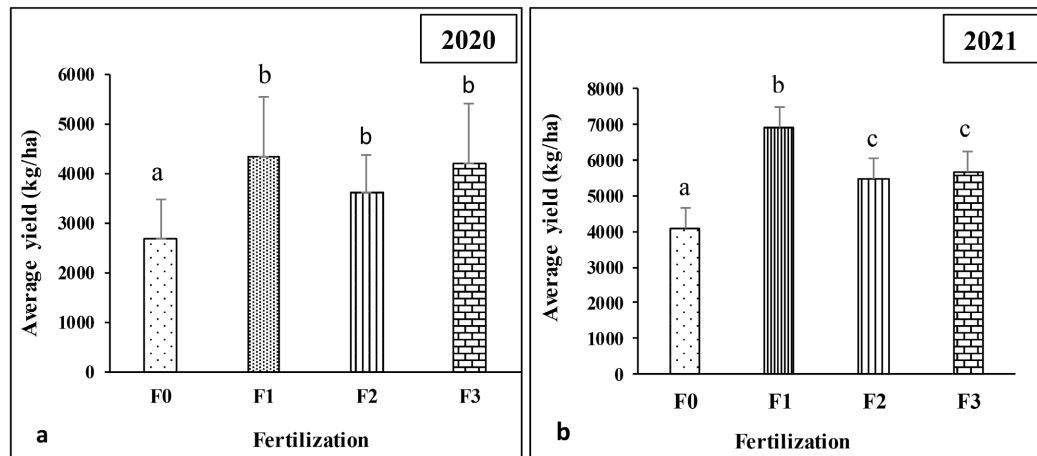
Table 5. Yield analysis results.

Source of variation	Probability	
	Yield 2020	Yield 2021
Fertilization	0.0000001534***	7.61e-13***
Previous crops	0.1434710 ^{ns}	0.136 ^{ns}
Variety	0.0006308***	0.000404***
Fertilization * Previous crops	0.6195088 ^{ns}	0.71873 ^{ns}
Fertilization * variety	0.0144960*	0.3174 ^{ns}
Previous crops * variety	0.9311673 ^{ns}	0.1092365 ^{ns}
Fertilization * Previous crops * Varieties	0.5975340 ^{ns}	0.790779 ^{ns}

***: very highly significant; *: significant; ns: not significant. From **Table 5**, the following variables were examined: the effect of fertilization on yield, the average yield per variety and the combined effect of fertilization * variety on yield for the year 2020.

1) Effect of mineral fertilization on rice paddy yield

Figure 11 illustrates the effect of mineral fertilization levels on yield. The ANOVA revealed a highly significant difference between treatments at the 5% threshold over the growing seasons. The highest average yields (4321 kg/ha in 2020 and 6912 kg/ha) in 2021 were recorded with F1, followed by F3 (4,182 kg/ha in 2020 and 5669 kg/ha) in 2021 and F2 (3613 kg/ha in 2020 and 5,481 kg/ha in 2021). The lowest average yield was recorded for F0 (2683 kg/ha in 2020 and 4058 kg/ha in 2021).



(a) Effect of mineral fertilization on paddy rice yield in 2020; (b) Effect of mineral fertilization on paddy rice yield in 2021. F0: Control with no fertilization; F1: NPK (200 kg/ha) + USG (72 kg/ha); F2: NPK (100 kg/ha) + simple urea (100 kg/ha); F3: NPK (200 kg/ha) + simple urea (150 kg/ha). Figures followed by the same letter are not significantly different from each other at the 5% probability level.

Figure 11. Effect of mineral fertilization on paddy rice yield.

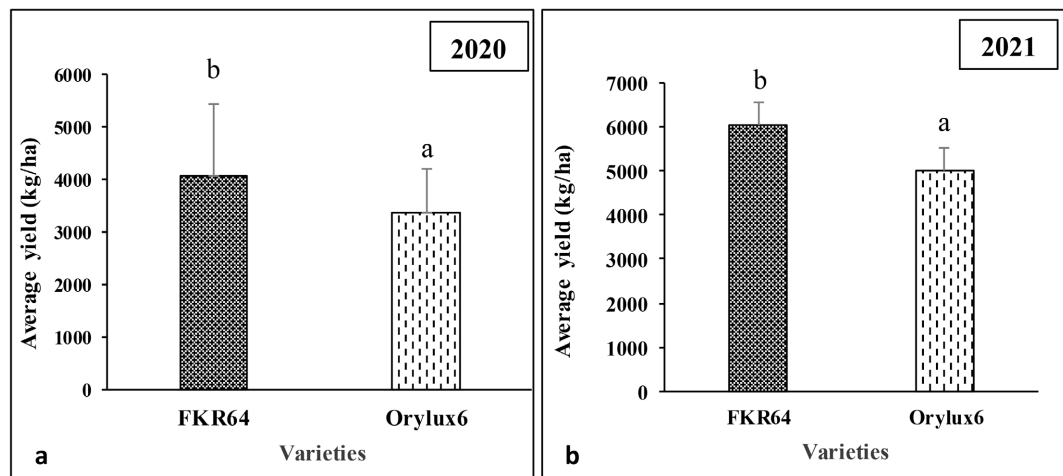
2) Effect of varieties on paddy rice yields

Figure 12 shows the average paddy yield by variety. ANOVA revealed a highly significant difference between treatments at 5% threshold over the two consecutive growing seasons. The highest average yield was recorded with the FKR64 variety, *i.e.* an average of 4043.98 kg/ha in 2020 and 6049.51 kg/ha in 2021, compared with an average of 3356.01 kg/ha in 2020 and 5009.56 kg/ha in 2021 for the Orylux6 variety.

3) Combined effect of mineral fertilization and varieties on rice paddy yield

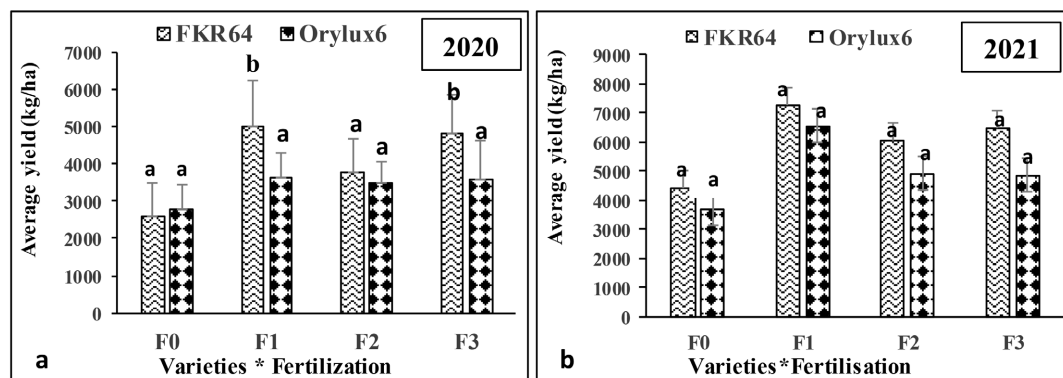
Rice yield was influenced by varieties and mineral fertilization levels. **Figure 13** illustrates the effect of variety and fertilization level on average rice yield. The highest average yield was recorded with F1 fertilization for both FKR 64 (5018 kg/ha) and Orylux6 (3624 kg/ha) in wet season 2020 and (7275 kg/ha) for FKR 64 and 6549.83 kg/ha for Orylux6 in 2021 ; followed in decreasing order of average yield F3 (4796 kg/ha) with FKR 64 and 3568 kg/ha with Orylux6 in 2020, in the wet season 2021, 6464.86 kg/ha with FKR 64 and 4866.12 kg/ha with Orylux6; then F2 (3755 kg/ha) with FKR 64 and 3470 kg/ha with Orylux6 in 2020 and in the 2021 season with F2 (6051.52 kg/ha) for FKR 64 and 4911.09 kg/ha for Orylux6. The

lowest average yields were recorded with F0, *i.e.* 2605 kg/ha with FKR 64 and 2761 kg/ha with Orylux6 in 2020 and in 2021 F0 (4006.66 kg/ha) with FKR 64 and (3711.19 kg/ha) with Orylux6.



(a) Effect of varieties on paddy rice yields in 2020; (b) Effect of varieties on paddy rice yields in 2021. Figures followed by the same letter are not significantly different from each other at the 5% probability level.

Figure 12. Effect of varieties on paddy rice yields.



(a) Combined effect of fertilization and varieties on the average yield of paddy rice in 2020; (b) Combined effect of fertilization and varieties on the average yield of paddy rice in 2021. F0: Control with no fertilization; F1: NPK (200 kg/ha) + USG (72 kg/ha); F2: NPK (100 kg/ha) + simple urea (100 kg/ha); F3: NPK (200 kg/ha) + simple urea (150 kg/ha). Figures followed by the same letter are not significantly different from each other at the 5% probability level.

Figure 13. Combined effect of fertilization and varieties on the average yield of paddy rice.

3.2. Discussion

Damage associated with Lepidoptera rice stem borers was relatively low (with levels often below 2%) over the two consecutive years covered by this study. Infestations increased at the beginning of the rice plant cycle. The highest levels of damage were recorded at 42 DAT for dead hearts during the vegetative phase, and at 70 DAT for white heads during the reproductive phase of the rice plant. The presence of *M. separatella* during the vegetative phase of the rice plant seems to be

associated with the presence of young plants. Our results are in line with those of [20], who showed that *M. separatella* females only lay eggs on plants at the tillering stage of the rice plant. Average dead heart rates were higher in plots that received higher NPK and legume as previous crops, and lower in control plots. In addition, white head rates were higher in plots that received mineral fertilizers and lower in control plots. Chilo species and *S. calamistis* species were more present during the vegetative and reproductive phases of the rice plant, while *M. separatella* species was more recorded during the reproductive phase of the rice plant. Rice Lepidoptera stem borers had a preference for plots that received mineral fertilization. Our results are similar to those reported by [21], who showed that high doses of phosphorus favored the multiplication of Lepidoptera populations. A study of the combined effect of fertilization * previous crops * variety revealed that the highest rate of damage was recorded in the Orylux6 * Organic matter * F1 plots in 2020 and Orylux6 * Mucuna * F1 in 2021, and the lowest rate was recorded in the FKR64 * Control * F2 plots in 2020 and 2021 with the Orylux6 * Organic matter * F0. These results confirm that insect pests have a preference for nutrient-rich plots.

Our results revealed significant variations in abundance levels between species during the development cycle of the rice plant. Chilo species were more representative in terms of numbers of individuals during the vegetative and reproductive phases of the two rice varieties. The permanent presence of *Chilo* spp. may be associated with the fact that the species has two successive generations during the cropping season. Authors of [22] and [23] have shown that the first generation of *Chilo* spp. infests the tillering stage of the rice plant, while the second generation, with a higher number of individuals, attacks the heading and flowering stages. These results, reflecting the relative importance of this genus at Bama, are in line with those of [6], who studied the seasonal abundance of Lepidoptera stem borers in western Burkina Faso, where they reported that *Chilo* spp. was the most abundant dry-season borer at Bama. Our findings also corroborate those of [1] [14] [15] and [24], who reached the same conclusions. *Maliarpha separatella* species was present during the vegetative phase of the FKR64 variety; these results are similar to those of [25]. Although it has been established that *M. separatella* does not cause dead hearts, its presence in the stems reduces the plant's vigor, disrupts its feeding and makes it vulnerable to fungal diseases. The presence of *M. separatella* during the vegetative phase of the plant could be due to the fact that this species attacks young organs, which could justify its abundance during this phase. Our results are in line with those of [18], who showed that the female of *M. separatella* only lays eggs on plants in the tillering stage (15 days after transplanting at the earliest), and that this species becomes rare from heading onwards. The presence of *S. calamistis* was rare in the experiment. This result is similar to that reported by [14], who noted a very low presence of this species in rice plots in Bama.

With regard to parasitoids, the four families listed all belong to the Hymenoptera order, all of which are associated with stem borers, particularly the Chilo genus. These findings could be explained by the fact that *Chilo* spp. is the most abundant

and frequent stem borer in Bama. Our results are lower in terms of parasitoid species abundance than those reported by [14], who listed 15 parasitoid species, and higher than those reported by [16], who listed six parasitoid species, all of them belonging to the Hymenoptera order and associated with *Chilo* spp. This discrepancy could be associated, on the one hand, to the fact that parasitism is as dynamic as the evolution of host insect populations and, on the other, to differences in entomological sampling methods. In fact, our observations were limited to hills showing damage symptoms (“dead hearts” or “white heads”), while previous authors sampled hole hills for dissection in the laboratory. The relative high rate of parasitism during the two wet seasons could be associated with the high rainfall and humidity that favoured egg hatching and the development of stem borers. Authors of [26] have shown that rainfall and altitude influence the absence or presence of parasitoids, and therefore parasitism rate.

Grain yield was influenced by variety, fertilization and fertilization * variety interaction. The results show that the lowest yields were recorded in the control plots, with an average of 2683 Kg/ha in 2020 and 4058.92 Kg/ha in 2021, while the highest yields were observed in the plots that benefited from mineral fertilization, with an average yield of 4321 Kg/ha in 2020 and 6912.41 Kg/ha. Increasing doses of NPK had an effect on yield. This could be explained by the multiple roles played by this nutrient, notably in stimulating root development, tillering, flowering and grain ripening. Our results corroborate those reported by [27], who concluded that the use of high-performance varieties and appropriate doses of mineral nutrients in irrigated lowland rice maximized yield.

4. Conclusions

Our work revealed the presence of three genera of stem borers Lepidoptera, in order of importance: *Chilo* spp., *M. separatella* and *S. calamistis*. The *Chilo* genus is the most important, whatever the rice variety and type of treatment. Damage caused by these Lepidoptera was higher in plots receiving higher NPK and legume than previous crops, but lower in control plots. Damage was most severe at 42 days before harvest. The highest average rate of pre-immature populations of *Chilo* spp. was recorded on the Orylux6 variety. The rate of parasitism associated with *Chilo* spp. was high. Parasitoids associated with stem borers belong to four families and 10 species of the order Hymenoptera.

Grain yield was influenced by variety, fertilization and fertilization * variety interaction, and the best yield was recorded in plots with the FKR 64 * F1 combination.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

- [1] Sanou, A.G. (2014) Influence du Système de Riziculture Intensif (SRI) sur les populations

- des principaux insectes ravageurs, et de leurs ennemis naturels sur les périmètres rizicoles de Karfiguèla et de la Vallée du Kou. Master's Thesis, Université de Ouagadougou, 101 p.
- [2] IRRI, Dawe, D., Pandey, S. and Nelson, A. (2010) Emerging Trends and Spatial Patterns of Rice Production. International Rice Research Institute, 35 p.
- [3] Dakouo, D., Nacro, S. and Bacye B. (1991) Mise au point d'un système de lutte rationnelle contre les insectes ravageurs sur les périmètres rizicoles irrigués au Burkina Faso. *Insect Science and Its Application*, **9**, 469-473.
- [4] Nacro, S., Heinrichs, E.A. and Dakouo, D. (1996) Estimation of Rice Yield Losses Due to the African Rice Gall Midge, *Orseolia oryzivora* harris and Gagne. *International Journal of Pest Management*, **42**, 331-334.
<https://doi.org/10.1080/09670879609372016>
- [5] Tankoano, H. (2005) Impact de la date de repiquage du riz sur la Cécidomyie africaine du riz, *Orseolia oryzivora* H. & G. et son cortège parasitaire sur la plaine rizicole de Boulbi. Mémoire d'Ingénieur du Développement Rural, Institut du Développement Rural, Université Polytechnique de Bobo-Dioulasso, 103 p.
- [6] Ba, N.M., Dakouo, D., Nacro, S. and Karamage, F. (2008) Seasonal Abundance of Lepidopteran Stem-borers and Diopsid Flies in Irrigated Fields of Cultivated (*Oryza sativa*) and Wild Rice (*Oryza longistaminata*) in Western Burkina Faso. *International Journal of Tropical Insect Science*, **28**, 30-36.
<https://doi.org/10.1017/s1742758408930435>
- [7] Nacro, S. (2011) Principaux insectes nuisibles au riz et leur gestion. Module de Formation, INERA, 60 p.
- [8] Ouattara, D., Dakouo D. and Nacro S. (2016) La lutte intégrée contre les principaux insectes ravageurs en riziculture irriguée à Karfiguèla. *Science et Technique*, No. 2, 7-24.
- [9] Polaszek, A. and Delvare, G. (2010) Les foreurs des tiges de céréales en Afrique: Importance économique, systématique, ennemis naturels et méthodes de lutte. CTA et CIRAD, Editions Quae, 534 p.
- [10] Nwilene, F.E., Nwanze, K.F. and Okhidievbie O. (2006) African Rice Gall Midge: Biology, Ecology and Control. Field Guide and Technical Manual. Africa Rice Centre, 18 p.
- [11] Heinrichs, E.A. and Barrion A.T. (2004) Rice Feeding Insects and Selected Natural Enemies West Africa: Biology, Ecology and Identification. International Rice Research Institute and WARDA-The Africa Rice Centre, 247 p.
- [12] Williams, C.T., Harris, K.M., Ukwungwu, N.M., Nacro, S., Dakouo, D., Nwilene, E.F., Singh, B.N. and Okhidievbie, O. (2002) African Rice Gall Midge; Research Guide. West Africa Rice Development and CAB International, 28 p.
- [13] Ba, N.M. (2003) Cycle annuel de la Cécidomyie africaine du riz, *Orseolia oryzivora* Harris et Gagné (Diptera: Cecidomyiidae) en relation avec ses plantes hôtes ses parasitoïdes et certaines pratiques culturales au sud-Ouest du Burkina Faso. Thèse en Science Biologiques Appliquées, Université de Ouagadougou, 121 p.
- [14] Souobou, M. (2014) Ennemis naturels associés aux insectes foreurs de tige du riz à la Vallée du Kou, Burkina Faso. Mémoire de fin d'Études, Centre Agricole Polyvalent de Matourkou, 92 p.
- [15] Dabiré, S.F. (2021) Ecologie des insectes lépidoptères foreurs de tige du riz dans l'Ouest du Burkina Faso. Mémoire de Fin de Cycle, Université Nazi Boni, 71 p.
- [16] Guinko, S. (1984) Végétation de la Haute Volta. Thèse de Doctorat des Sciences Naturelles, Université de Bordeaux III, 394 p.

- [17] INERA (2018) Document préparatoire du plan stratégique du CNRST. Programme riz et Riziculture, Station de Farakô-Bâ, 46 p.
- [18] Delvare, G. and Aberleng, P. (1989) Les insectes d'Afrique et d'Amérique Tropicale. Clé pour la reconnaissance des familles. PRIFAS-CIRAD, GERDAT, 302 p.
- [19] Ouattara D. (2011) Manuel d'identification des insectes, entomologie générale. INERA Farakô-Bâ, 111 p.
- [20] Wopereis, M.C.S. (2008) Connaissance de la plante de riz: Les foreurs de tiges. Curriculum APRA-GIR: Manuel technique. 109-115.
- [21] Karamage, F.X. (2001) Etude de l'influence de la fertilisation phosphatée sur les attaques de la cécidomyie africaine du riz, ses parasitoïdes et les foreurs de tige en riziculture irriguée. Mémoire d'Ingénieur du Développement Rural, Université Polytechnique de Bobo-Dioulasso, 95 p.
- [22] Odjo, T.A. (1984) Contribution à l'étude de la biologie et de l'écologie de *Sesamia calamitis* Hampson (Lepidoptera: Noctuidae) en Côte d'Ivoire centrale. Thèse en Science Biologiques Animales, Université de Paris-Sud, 115 p.
- [23] Hamadou, A. (1992) Evolution naturelle de la population de *Sesamia calamitis* Hampson (Lepidoptera: Noctuidae) au Mali. Revue Scientifique: Nuisible-Pest Pragas, N°001/Institut du Sahel Bamako, 28-41.
- [24] Sama, K. (2011) Effet des périodes de repiquage sur les populations, le parasitisme et les dégâts des lépidoptères foreurs de tige du riz sur le périmètre rizicole irrigué de la vallée du Kou, Burkina Faso. Mémoire de Fin de Cycle, Université Polytechnique de Bobo-Dioulasso, 82 p.
- [25] Ouattara, D. (2014) Effet des dates de repiquage et des zones sur les populations, le parasitisme et les attaques des foreurs de tiges du riz sur le périmètre rizicole de la Vallée du Kou. Mémoire de Fin d'Étude, Université de Ouagadougou, 70 p.
- [26] Mailafiya, D.M., Le Ru, B.P., Kairu, E.W., Calatayud, P. and Dupas, S. (2010) Factors Affecting Stem Borer Parasitoid Species Diversity and Parasitism in Cultivated and Natural Habitats. *Environmental Entomology*, **39**, 57-67.
<https://doi.org/10.1603/en09196>
- [27] Sanogo, S., Camara, M., Zouzou, M., Keli, Z., Messoum, F.G. and Sekou, A. (2010) Effet de la fertilisation minérale sur des variétés améliorées de riz en condition irriguée à Gagnoa, Côte d'Ivoire. *Journal of Applied Biosciences*, **35**, 2235-2243.