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Efficacy of Neem (*Azadirachta indica*) Biopesticides Against Stem Borer (*Busseola fusca*) Infestation in Sorghum (*Sorghum bicolor* L.) Varieties in the Sudan Savanna, Nigeria

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ABSTRACT

The study evaluated the efficacy of neem-based biopesticides against stem borer (*Busseola fusca*) infestation in sorghum varieties (SAMSORG-3, SAMSORG-6, and SAMSORG-40) under Sudan Savanna conditions of Nigeria during the 2017 rainy season. A split-plot design with three replications was employed. Neem seed formulations (aqueous extract, oil, and powder) were applied weekly for six weeks, while Carbofuran served as a synthetic control. Results indicated significant differences among treatments ($p < 0.05$). SAMSORG-6 and SAMSORG-3 recorded lower dead hearts and exit holes, whereas SAMSORG-40 produced the highest grain yield (1106.7 kg/ha). Neem aqueous extract and powder significantly reduced leaf damage, dead hearts, and chaffy heads compared to neem oil and control treatments. Although Carbofuran showed superior efficacy, neem-based treatments demonstrated substantial pest suppression and yield improvement. These findings support integrating neem biopesticides with tolerant sorghum varieties as an environmentally sustainable strategy for managing stem borer infestations.

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INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench) is a cereal crop of global significance, ranking fifth among the world's cereals (Ketema *et al.*, 2020), and serving as the sixth most important dietary source of calories after rice, wheat, sugarcane, maize, and potatoes (F.A.O, 1992; Cock, 2019).

In Nigeria, particularly in the semi-arid regions of the north, especially such as Maiduguri, Borno State. It is a staple food in many regions of the world and an important source of carbohydrate, protein, iron, minerals, vitamin B and vitamin C. Africans consume sorghum in various forms such as porridges and pastes etc.

Sorghum is eaten baked, roasted or boiled. Every part of the sorghum namely the grain, leaves, stalk and the panicle chaffs has economic value and can be used to produce a large varieties of food and non-food products.

In Nigeria, sorghum is a staple food with socio-economic importance. It is grown for its grain which contains 65% carbohydrate, 10-12% protein and 4-5% fat. The crop also contains the trace elements such as carotene, Thiamine, Ascorbic acid and Tobophenole (War *et al.*, 2009). Sorghum is a major source of starch, a major ingredient in cooking and many industrialized food products. The crop is mainly used for human food and livestock feed. The stem and the panicles are used in the manufacturing of abrasives and even as fuel for cooking.

Production of sorghum is however threatened by insect pest such as sorghum stem borer *Busseola fusca* F (Lepidoptera: Noctuidae) (Yodit *et al.*, 2018). The insect is a common pest in many African countries including Nigeria. Damage is caused by the caterpillars, which first feed on the young leaves and later enter into the stems, killing the growing points of the plant and causing dead-heart that disrupts the flow of nutrients to the grain. Infested young plants show small holes and 'window- panes in the leaf whorls where tissue have been eaten. Symptoms in sorghum plants include dead-heart, plant death, internal feeding and presence of frass in the stems. Older caterpillars tunnel into the stems, and eat out long frass-filled galleries, which weaken the stems and cause breakage. Yield reductions occur every year due to insect pest feeding, or stalk lodging. The potential yield of sorghum within an environment could be realized when pests are managed by scouting field regularly and applying treatments when necessary.

Grain damaged by the stem borers become susceptible to secondary infection by moulds such as *Aspergillus flavus* which produce aflatoxin, a toxic by- product that is extremely poisonous to humans which can lead to cancer. Chemical insecticides have long been employed as the principal management strategy against stem borers and other insect pests. Among these, according to Jafari *et al.* (2020), organophosphates and carbamates have been

widely used, with Carbofuran standing out as a particularly effective carbamate pesticide. Carbofuran operates by inhibiting acetylcholinesterase, thereby disrupting insects nervous systems and causing paralysis and death (Ikenaka *et al.*, 2021). Although highly effective in the short term, the prolonged and widespread use of synthetic pesticides has generated serious concerns.

These include the development of insect resistance, contamination of soils and water bodies, and adverse impacts on beneficial organisms such as pollinators and natural predators (Zhang *et al.*, 2020; Aman *et al.*, 2021). Moreover, pesticide residues in food and drinking water have been linked to chronic health risks in humans, including carcinogenic, neurological, and reproductive disorders (Stauron *et al.*, 2022). Consequently, the limitations associated with chemical pesticides necessitate the exploration of safer and environmentally sustainable alternatives for pest management in sorghum cultivation (Musa *et al.*, 2021). Sorghum stem borer are difficult to control with insecticides because the current spray-based methods have been found to be ineffective against the internal feeders in addition to being costly and hazardous (Ali *et al.*, 2022). Also, pest are increasingly developing resistance to conventional synthetic insecticides due to climate change (Abebe and Belay, 2020). For instance, all the minor global climate models forecast high temperatures that will promote high pest populations. This, therefore, necessitates further research work on alternative to controlling sorghum stem borer *B. fusca* more effectively. Plant-derived pesticides are one of the alternatives to synthetic chemicals and are considered environmentally friendly (Ketema *et al.*, 2020). The efficacy of plant-derived pesticides has been demonstrated not only in post-harvest grain infestation by insects but also in the control of various field insect pest species (Anuradha and Annadurai, 2008).

The most widely used is the Neem extracts (*Azadirachta indica* A. Juss. (Meliaceae), it is a promising bio-rational alternative (Wambogu *et al.*, 2022). Neem-based biopesticides, primarily derived from seeds, leaves, and bark, contain biologically active compounds such as azadirachtin, which exhibit insecticidal, antifeedant, and growth-regulatory properties

(Schmutterer, 2002). Azadirachtin interferes with hormonal processes in insects, disrupting feeding, moulting, and reproduction (Isman, 2020). Unlike synthetic chemicals, neem formulations are biodegradable, pose minimal risks to humans and animals, and have little negative impact on beneficial insects (Khan *et al.*, 2021), making them compatible with integrated pest management (IPM) strategies. Numerous studies have demonstrated their effectiveness against a wide spectrum of insect pests, including stem borers, aphids, and lepidopteron larvae, thereby highlighting their potential to mitigate crop damage in a sustainable manner. Several studies on the insecticidal potentials of plant-derived pesticides to control *B. fusca* have been reported. Plant materials with insecticidal properties will be of immense help or importance to resource poor farmers who produce over 95% of food consumed since they are locally available and biodegradable and cost effective. Despite the scientific evidence supporting neem-based biopesticides, their adoption in regions such as Maiduguri remains relatively limited. Constraints include the relatively high cost of commercial neem formulations, challenges associated with large-scale production, and limited farmer awareness regarding their efficacy and benefits.

Despite extensive research on synthetic insecticides, there is limited field-based comparative evaluation of neem-derived biopesticides across different sorghum varieties under Sudan Savanna conditions. Furthermore, variability in varietal tolerance and response to botanical insecticides remains insufficiently characterized. This study addresses these gaps by assessing the combined effects of neem-based treatments and varietal resistance on stem borer infestation and yield performance. Therefore, the objective of this study was to evaluate the effectiveness of neem-based biopesticides in controlling stem borer infestation and to determine the most tolerant and high-yielding sorghum variety under field conditions in Maiduguri, Sudan Savanna, Nigeria.

MATERIALS AND METHODS

Experimental Site

The study was conducted during the 2017 rainy season at the Teaching and Research Farm,

Department of Crop Production, University of Maiduguri, Nigeria (11°15'N, 13°50'E) in the Sahel Savannah zone. Rainfall in the area is unimodal, commencing in mid-June, peaking in August, and ceasing by September/October, with an annual average exceeding 500 mm (Dalorima *et al.*, 2014).

Plant Materials and Pesticides

Three sorghum varieties (Samsorg-3, Samsorg-6, and Samsorg-40) were obtained from the Borno State Agricultural Development Programme, Maiduguri. A synthetic insecticide (Carbofuran) was purchased locally, while matured neem (*Azadirachta indica*) seeds were collected from the University campus.

Preparation of Neem Biopesticides

Aqueous Neem Seed Extract: Dried neem seeds were ground, and 50 g of powder was soaked in 1 L distilled water for 24 h, then sieved. For field application, 0.5 L extract was diluted in 13 L water and applied with a knapsack sprayer (Oyewale *et al.*, 2022). **Neem Seed Oil:** Ground neem seeds were kneaded in warm water to release oil, which was emulsified with liquid soap (5 mL oil + 2 mL soap in 1 L water) and used within 8 h. **Neem Seed Powder:** Ground, sieved seed powder was mixed with sand to facilitate field application.

Experimental Design

The experiment was conducted using a split-plot design arranged in a randomized complete block design (RCBD) with three replications. Sorghum varieties were assigned to main plots, while insecticide treatments were allocated to sub-plots.

Cultivation Practices

The experimental field was cleared, harrowed with a tractor-drawn disc, and manually ridged at 0.75 m spacing. The site was divided into 3 × 3 m plots (9 m²) with 0.5 m intra-plot and 1.0 m inter-plot alleys. Treatments were arranged in a factorial randomized complete block design (RCBD) with three replications. Sorghum seeds were treated with APRON® Plus to control soil pests and sown at 1.5–2 cm depth, using 3–5 seeds per hole at an intra-row spacing of 30 cm and inter-row spacing of 75 cm. Seedlings were thinned to two plants per stand at 2 weeks after sowing (WAS), gap filling was conducted at 2 weeks after germination (WAG), and weeding was performed at 2–3 WAS depending on weed

pressure. Each plot received NPK (15:15:15) fertilizer at the recommended rate through side placement (5 cm away from plants) after emergence. Urea was applied at 4 WAS. Bio-pesticides were sprayed weekly for six weeks using a knapsack sprayer, beginning at 4 weeks after emergence (WAE) when insect infestation was first observed. Carbofuran (synthetic pesticide) was applied bi-weekly. Harvesting was carried out manually at physiological maturity.

Data Collection

Ten plants were randomly selected per plot for all measurements to ensure representative

$$\text{Grain yield/ha (kg)} = \frac{\text{Grain in Net plot Area}}{\text{Net Plot Area (m}^2\text{)}} \times 10,000 \text{ m}^2$$

sampling. Data were collected on pest incidence and yield attributes. Dead hearts were recorded through direct observation of the leaf whorl. Incidence of borer holes was determined at harvest by counting the number of perforations on 10 randomly selected stalks per plot. Stem tunnelling length was measured by tracing tunnel patterns with thread, transferring them onto a meter rule, and recording in centimetres.

The number of chaffy heads per plot was also recorded after harvest. Grain yield (kg/ha) was estimated from the net plot harvest, threshed and weighed, and converted to yield per hectare using the formula:

Data Analysis

All the collected data were subjected to analysis of variance (ANOVA) using Statistix 8.0 software. Treatment means were separated using the Least Significant Difference (LSD) test at the 5% level of probability.

RESULTS

Table 1. Effects of variety and insecticide on the number of dead heart and exit holes in sorghum under rain fed conditions

Treatment	Number of Dead heart/plot	Number of exit hole/stem
Variety (A)		
SAMSORG-6	1.67b	6.33b
SAMSORG-40	3.47a	9.00a
SAMSORG-3	1.87b	7.07b
LSD	0.5235	0.8682
Insecticide (B)		
ANSE	2.11b	7.67b
NSO	3.22a	7.33b
NSP	2.22b	8.00b
Carbofuran	1.44c	3.78c
Control	2.67ab	10.56a
LSD	0.6486	1.6361
Interaction		
AxB	**	**

Means in a column followed by the same letters are not significantly different at 5% probability according to LSD

ANSE: Aqueous Neem Seed Extract, **NSO:** Neem Seed Oil, **NSP:** Neem Seed Powder

The effects of sorghum varieties and biopesticides on the number of dead hearts and exit holes are presented in Table 1. A significant interaction was observed between sorghum variety and insecticide application on the number of dead hearts and exit holes. The results revealed significant differences in both parameters across the varieties and biopesticides treatments. Among the varieties, SAMSORG-40 recorded the highest number of dead hearts and exit holes compared with SAMSORG-6 and

SAMSORG-3. With respect to biopesticides treatments, neem seed oil (NSO) resulted in a significantly higher number of dead hearts compared with other biopesticides, although this did not differ significantly from the control. In contrast, Carbofuran consistently recorded the lowest number of dead hearts. Similarly, the number of exit holes was significantly higher in the control than in other treatments, whereas Carbofuran recorded the fewest exit holes.

Table 2: Interaction sorghum variety and insecticide on the number of dead heart and of exit holes

Treatment	Number of Dead heart/plot	Number of exit hole/stem
Variety x Insecticide		
SAMSORG-6 x Carbofuran	1.33f	4.00 ^{ef}
SAMSORG-6 x ANSE	1.33f	6.67 ^{cde}
SAMSORG-6 x NSO	1.67f	5.67 ^{def}
SAMSORG-6 x NSP	2.33 ^{def}	7.00 ^{cd}
SAMSORG-6 x Control	1.67f	8.33 ^{bcd}
SAMSORG-40 x Carbofuran	1.67f	3.33f
SAMSORG-40 x ANSE	3.67 ^{abc}	10.67 ^b
SAMSORG-40 x NSO	4.67 ^a	10.00 ^b
SAMSORG-40 x NSP	3.00 ^{cde}	7.00 ^{cd}
SAMSORG-40 x Control	4.33 ^{ab}	14.00 ^a
SAMSORG-3 x Carbofuran	1.33f	4.00 ^{ef}
SAMSORG-3 x ANSE	1.33f	5.67 ^{def}
SAMSORG-3 x NSO	3.33 ^{bcd}	6.33 ^{de}
SAMSORG-3 x NSP	1.33f	10.00 ^b
SAMSORG-3 x Control	2.00 ^{ef}	9.33 ^{bc}
LSD	1.1234	2.8338

Means in a column followed by the same letters are not significantly different at 5% probability using LSD

ANSE: Aqueous Neem Seed Extract, **NSO:** Neem Seed Oil, **NSP:** Neem Seed Powder

The interaction between sorghum varieties and insecticide treatments revealed significant effects on the incidence of dead hearts and the number of exit holes per stem (Table 2). Among the treatments, Carbofuran consistently produced the lowest values for both parameters across the three sorghum varieties. Specifically, SAMSORG-6 × Carbofuran, SAMSORG-6 × ANSE, SAMSORG-3 × Carbofuran, SAMSORG-3 × ANSE, and SAMSORG-3 ×

NSP recorded the least number of dead hearts (1.33), indicating superior protection against stem borer damage. Similarly, the lowest number of exit holes was observed in SAMSORG-40 × Carbofuran (3.33), followed closely by SAMSORG-3 × Carbofuran (4.00). These findings highlight the high efficacy of Carbofuran in suppressing larval establishment and reducing stem tunnelling.

Neem-based treatments also demonstrated considerable efficacy, although their performance varied among varieties. Aqueous Neem Seed Extract (ANSE) and Neem Seed Powder (NSP) reduced both dead hearts and exit holes significantly compared to the control, while Neem Seed Oil (NSO) was less effective, particularly in SAMSORG-40, which recorded the highest number of dead hearts (4.67) and one of the highest exit hole counts (10.00). This suggests varietal differences in responsiveness to botanical insecticides.

Across the varieties, SAMSORG-6 and SAMSORG-3 generally exhibited greater tolerance to stem borer infestation, as reflected by lower numbers of dead hearts and exit holes under most treatments. In contrast, SAMSORG-40 was the most susceptible, particularly under untreated control (4.33 dead hearts and 14.00 exit holes), indicating higher vulnerability to stem borer attack in the absence of insecticidal protection.

Table 3: Effects of variety and insecticide on the number of stands per plot and leaf damage

Treatment	Number of Stands/plots	Number of leaf damage/plot
Variety (A)		
SAMSORG-6	15.60a	12.07a
SAMSORG-40	14.73b	12.07a
SAMSORG-3	15.93a	12.87a
LSD	0.5449	1.2278
Insecticide (B)		
ANSE	15.89a	10.78b
NSO	15.56a	13.22a
NSP	14.22b	13.00a
Carbofuran	15.78a	13.00a
Control	15.67a	11.68b
LSD	0.6725	0.9230
Interaction		
AxB	NS	NS

Means in a column followed by the same letters are not significantly different at 5% probability using LSD

ANSE: Aqueous Neem Seed Extract, **NSO:** Neem Seed Oil, **NSP:** Neem Seed Powder,

The effects of sorghum variety and insecticide application on the number of stands per plot and leaf damage are presented in Table 3. The results revealed that sorghum varieties did not differ significantly ($p > 0.05$) in either number of stands or leaf damage. Although SAMSORG-3 recorded the highest mean number of stands (15.93) and leaf damage (12.87), followed by SAMSORG-6 (15.60 and 12.07, respectively) and SAMSORG-40 (14.73 and 12.07, respectively), the differences among the varieties were not statistically significant.

In contrast, insecticide treatments exerted a significant effect ($p < 0.05$) on leaf damage,

while their effect on the number of stands was not significant. Plots treated with Aqueous Neem Seed Extract (ANSE) recorded the lowest mean leaf damage (10.78), which was significantly lower than those treated with Neem Seed Oil (NSO), Neem Seed Powder (NSP), and Carbofuran (13.22, 13.00, and 13.00, respectively). The untreated control recorded a moderate leaf damage value (11.68), which was comparable to ANSE. This indicates that ANSE was the most effective treatment in reducing leaf damage.

Table 4: Effect of sorghum variety and insecticide on the tunnel length and chaffy head

Treatment	Tunnel length per stem (cm)	Number of chaffy head/plots
Variety		
SAMSORG-6	26.21ab	11.60b
SAMSORG-40	22.76b	11.53b
SAMSORG-3	30.98a	13.53a
LSD	6.3033	1.4999
Insecticide		
Carbofuran	21.14c	12.67ab
ANSE	26.22ab	10.67b
NSO	25.76bc	12.11ab
NSP	30.67a	12.11ab
Control	29.46ab	13.56a
LSD	4.9023	2.2340
Interaction		
AxB	*	*

Means in a column followed by the same letters are not significantly different at 5% probability using LSD ANSE: Aqueous Neem Seed Extract, NSO: Neem Seed Oil, NSP: Neem Seed Powder

The effect of sorghum variety and insecticidal treatments on tunnel length and the number of chaffy heads per plot is presented in Table 4. Significant differences ($P \leq 0.05$) were observed among the varieties. SAMSORG-40 consistently recorded the shortest tunnel length (22.76 cm) and relatively fewer chaffy heads (11.53), indicating higher resistance to stem borer infestation. Conversely, SAMSORG-3 exhibited the longest tunnel length (30.98 cm) and the highest number of chaffy heads (13.53), suggesting greater susceptibility to damage, while SAMSORG-6 remained intermediate.

Insecticidal treatments also significantly influenced the parameters measured. Carbofuran

proved most effective in reducing tunnel length (21.14 cm), followed by neem seed oil (25.76 cm) and aqueous neem seed extract (26.22 cm). Neem seed powder (30.67 cm) and the untreated control (29.46 cm) resulted in the longest tunnel lengths, indicating minimal protection. With respect to chaffy heads, aqueous neem seed extract provided the most effective control (10.67), while the control treatment had the highest number of chaffy heads (13.56). The neem-based formulations generally reduced damage compared to the untreated plots, though their efficacy varied.

Table 5: Interaction effect of sorghum variety and insecticide on the tunnel length and chaffy head

Treatment	Tunnel length per stem (cm)	Number of chaffy head/plot
Variety x Insecticide		
SAMSORG-6 Carbofuran	21.03c	10.00cde
SAMSORG-6 x ANSE	21.60c	12.00a-d
SAMSORG-6 x NSO	28.23abc	9.33de
SAMSORG-6 x NSP	34.17ab	13.00a-d
SAMSORG-6 x Control	26.00bc	13.67abc
SAMSORG-40 x Carbofuran	19.33c	14.67ab
SAMSORG-40 x ANSE	23.57c	7.33e
SAMSORG-40 x NSO	21.00c	15.33ab
SAMSORG-40 x NSP	23.50c	7.67e
SAMSORG-40 x Control	25.60bc	12.67a-d
SAMSORG-Carbofuran	23.04c	13.33abc
SAMSORG-3 x ANSE	33.50ab	12.67a-d
SAMSORG-3 x NSO	27.23bc	11.67bcd
SAMSORG-3 x NSP	34.33ab	15.67a
SAMSORG-3x Control	36.77a	14.33ab
LSD	8.4911	3.7541

Means in a column followed by the same letters are not significantly different at 5% probability using LSD ANSE: Aqueous Neem Seed Extract, NSO: Neem Seed Oil, NSP: Neem Seed Powder

The interaction effect of sorghum varieties and insecticidal treatments on tunnel length per stem and the number of chaffy heads per plot in Table 5 revealed significant differences ($p \leq 0.05$). For tunnel length per stem, the lowest value (19.33 cm) was observed in SAMSORG-40 and Carbofuran, indicating the highest level of resistance to stem tunnelling. This was followed closely by SAMSORG-6 and Carbofuran (21.03 cm) and SAMSORG-40 and Neem Seed Oil (21.00 cm). The variety SAMSORG -3 without treatment (Control) showed significantly higher tunnel length compared to the other combinations. Among the neem-based treatments, SAMSORG-6 \times Neem Seed Powder (34.17 cm) and SAMSORG-3 \times NSP (34.33 cm) recorded relatively longer tunnel lengths, highlighting their limited effectiveness compared to Carbofuran.

Regarding the number of chaffy heads per plot, the least infestation (7.33) occurred in SAMSORG-40 \times Carbofuran, followed by SAMSORG-40 \times NSP (7.67) and SAMSORG-6 \times NSO (9.33). Conversely, the highest chaffy head count was obtained in SAMSORG-6 \times

Control (13.67), SAMSORG-40 \times Control (12.67), and SAMSORG-3 \times NSP (15.67), signifying substantial yield loss due to stem borer attack under untreated or less effective treatments.

Overall, the results indicate that Carbofuran consistently conferred the most effective protection across sorghum varieties, particularly in SAMSORG-40, which showed the least tunnel damage and lowest chaffy head incidence. Among the neem-based insecticides, NSO was relatively more effective than ANSE and NSP, though none matched the efficacy of Carbofuran. Varietal response also played a key role, with SAMSORG-40 showing better tolerance to stem tunnelling and reduced head chaffy heads across treatments compared to SAMSORG-6 and SAMSORG-3. These findings suggest that the combination of resistant variety (SAMSORG-40) and effective insecticide application, particularly Carbofuran, provides the most reliable control of stem borer infestation and minimization of yield losses in sorghum.

Table 4.6: Effects of sorghum variety and insecticide on borer holes on stem and grain yield of sorghum

Treatment	Borer Holes on Stem	Grain yield (kg/ha)
Variety A		
SAMSORG-6	3.60a	771.9b
SAMSORG-40	4.47a	1106.7a
SAMSORG-3	4.13a	511.1c
LSD	1.2957	46.293
Insecticide B		
Carbofuran	2.78c	798.77a
ANSE	4.44ab	824.69a
NSO	3.56bc	750.62a
NSP	4.11abc	818.52a
Control	5.44a	790.12a
LSD	1.4118	115.58
Interaction		
AxB	NS	NS

Means in a column followed by the same letters are not significantly different at 5% probability using LSD ANSE: Aqueous Neem Seed Extract, NSO: Neem Seed Oil, NSP: Neem Seed Powder

Table 6 presents the effects of sorghum varieties and insecticidal treatments on the incidence of borer holes on the stem and grain yield of sorghum. The results reveal significant varietal differences in both parameters. SAMSORG-40 recorded the highest grain yield (1106.7 kg/ha) despite having the highest number of borer holes (4.47), while SAMSORG-3 had the lowest grain yield (511.1 kg/ha) with a moderate level of stem borer infestation (4.13 holes). SAMSORG-6 exhibited relatively lower infestation (3.60 holes) but yielded moderately (771.9 kg/ha). This indicates that varietal tolerance to stem borers did not directly correspond with grain yield performance, suggesting inherent yield potential differences among the sorghum genotypes.

The effect of insecticides on borer infestation and yield also showed significant variation. Carbofuran was the most effective treatment, resulting in the least number of borer holes (2.78) and a relatively high grain yield (798.8 kg/ha). Among neem-based products, Neem Seed Oil (NSO) significantly reduced borer infestation (3.56 holes), while Neem Seed Powder (NSP) and Aqueous Neem Seed Extract (ANSE) were less effective, recording 4.11 and 4.44 holes, respectively. However, the grain yield response did not align

consistently with borer control. ANSE produced the highest yield (824.7 kg/ha), followed closely by NSP (818.5 kg/ha), while NSO gave the lowest yield (750.6 kg/ha) despite better suppression of borer damage. The untreated control recorded the highest borer infestation (5.44 holes) but yielded 790.1 kg/ha, indicating that yield loss was not solely dependent on stem damage.

DISCUSSION

The use of plant extracts for the protection of crops from insect pests have been reported as one of the oldest crop protection methods (Dessie *et al.*, 2024). The findings from this study revealed the performance of sorghum varieties and biopesticide treatments in managing sorghum stem borer under rainfed conditions in Maiduguri, Borno State. The findings of this study revealed that treatment and time of application had significant effects on the relative abundance of *B. fusca* affecting sorghum. The results indicated that application of neem based insecticide significantly reduced the population and damage caused by the sorghum stem borer (*B. fusca*) on sorghum. It can be deduced from this study that damage by stem borer on sorghum plant increased with time. As can be observed, the severity of damage in terms of the number of holes on the

leaves and stems per sorghum plant increased over time interval between four weeks upwards before treatments were started. Apart from carbofuran treated plots which had the least numbers of tunnel and chaffy heads, plot treated with neem based insecticide are comparable to carbofuran. The plants extracts offered significant protection to the sorghum plant and that was reflected on all the yield parameters, the only exception being the size of panicle head per plant, which was non-significant. This implies that sorghum production could be more profitable by applying the treatments at appropriate time. This result is in line with the findings by Aman *et al.* (2021) who showed that timely application of plant extracts prevented an initial build-up of infestation pressure and consequently increased the yield of crop. The damage done by the stem borer was reflected on the yield attributes. The results reveals that grain yield for the treated plots were higher than the control. The significant reduction of infestation of *B. fusca* by the application of extracts of these plant materials, and carbofuran could be due to the effective deterrent and suppressive activities of their active ingredients on the insect pest. The results also showed that application of plant extracts on sorghum plant significantly reduced the population of *B. fusca* when compared with the control which agrees with the findings of Misrak *et al.* (2020) who reported that plant extracts of *A. indica*, and *J. gossyiifolia* at 10, 15 and 20% killed *B. fusca* very quickly and reduced their population by about 70% compared with untreated control. Furthermore, the results obtained from the study showed that the plots treated with extracts gave significant control of *B. fusca* than control implying that these plant extracts possess insecticidal properties that could be lethal to a wide range of insects including *B. fusca*. Thus reduction of *B. fusca* population in this study must have led to the increase in panicle and grain yield on plots treated with these plant extracts. This result corroborates the findings of Raghuraman *et al.* (2008) who reported that application of different plant materials as biopesticides in the control of different species of stem borers led to increase in crop yield. The results of this study also agree with Aman *et al.* (2021), who found out that extracts of Neem leaves mixed with leaves of

Cymbopogon citratus could be toxic to *B. fusca* and consequently resulted in considerable reduction in their numbers. Some researchers who worked on the effect of carbofuran on *B. fusca* population and other stem borers found it to be more effective than botanicals when both were applied under the field condition.

The higher destructive effect of carbofuran when compared with neem based bio-pesticide in this study could be due to its standardized active ingredient that had “knock down” effects on the insect pest immediately it comes in contact with carbofuran whereas the low efficacy of the plant extracts could be among other reasons, due to lack of “knock down” effect and rapid breakdown (non-persistence) of the biochemical compounds. The effectiveness of the synthetic insecticide is a confirmation of the report by Evenson *et al.*, (2021), that chemical insecticide have been the primary control agent for agricultural pests. However, the mean number of *B. fusca* population was significantly reduced in plots treated with extracts of the plant materials when compared with the control experiment indicating that sorghum could be adequately protected against *B. fusca* infestation by extracts of these plant materials as pesticide alternatives (bio pesticides) to increase sorghum and food production. The results also offer insights into the effectiveness of neem-based biopesticides and synthetic Carbofuran in reducing pest damage, enhancing sorghum yield, and maintaining sustainability. The impact of insecticides on the number of dead hearts and exit holes per plot was profound. Carbofuran consistently reduced dead hearts and exit holes across all sorghum varieties, confirming its potent systemic action against sorghum stem borer. Neem-based treatments, such as ANSE and NSO, demonstrated intermediate effectiveness, particularly in reducing dead hearts.

While neem-based products were less effective than Carbofuran in the short term, they exhibited significant potential in integrated pest management systems. This agrees with the findings of Midega *et al.* (2008), who reported neem extracts as effective pest repellents due to their ability to disrupt pest feeding and reproduction cycles. The varietal differences in

pest damage were also notable, with SAMSORG-40 exhibiting higher susceptibility (greater number of dead hearts and exit holes) compared to SAMSORG-6 and SAMSORG-3. These findings suggest that genetic resistance plays a pivotal role in pest management. SAMSORG-6 consistently showed lower pest damage, indicating inherent resistance that aligns with the work of Thakur and Patil (2014), who emphasized the importance of selecting resistant varieties for sustainable pest control. The interaction between insecticide treatments and sorghum varieties revealed intriguing patterns. For instance, SAMSORG-6 treated with Carbofuran had the lowest number of exit holes and dead hearts, while SAMSORG-40 treated with neem-based products showed moderate pest suppression. This indicates that neem biopesticides perform best when paired with partially resistant varieties, corroborating findings by Awat (2012), who highlighted the synergistic effects of combining neem-based treatments with resistant crops.

The superior performance of Carbofuran in reducing exit holes and dead hearts aligns with its chemical composition, which allows for rapid pest knockdown. However, the environmental and health risks associated with synthetic pesticides, as noted by Raza *et al.* (2017), make neem-based products a viable alternative, especially for smallholder farmers in resource-constrained settings. Tunnel length and chaffy head counts served as indicators of the internal damage caused by stem borer. Carbofuran-treated plots consistently recorded the shortest tunnel lengths, confirming its efficacy in mitigating internal pest damage. Neem-based products such as ANSE also reduced tunnel lengths, though to a lesser extent. This aligns with previous studies, such as those by Thakur and Patil (2014), who reported similar trends in neem-treated sorghum plots. The interaction effects revealed that Samsorg-6 and Samsorg-3 treated with ANSE or Carbofuran exhibited significantly lower tunnel lengths, underscoring the importance of varietal resistance in minimizing internal pest damage. Control plots, irrespective of variety, had the longest tunnels and highest chaffy head counts, highlighting the destructive potential of stem borers in the absence of pest management.

Grain yield varied significantly across treatments and varieties, with Samsorg-40 treated with Carbofuran achieving the highest yields. This highlights the critical role of effective pest management in enhancing productivity. However, neem-based products also showed promise, particularly when paired with resistant varieties like Samsorg-6. While the yields in neem-treated plots were slightly lower than those treated with Carbofuran, they were significantly higher than the control, suggesting that neem can serve as a cost-effective and eco-friendly alternative for small-scale farmers. These findings are consistent with Raza *et al.* (2017), who advocated for the integration of biopesticides into pest management frameworks to balance productivity with sustainability. The economic viability of using neem-based treatments is further reinforced by their lower cost and availability in local markets. As Awat (2012) noted, the adoption of neem biopesticides can reduce dependence on synthetic chemicals, lowering input costs and promoting environmentally friendly farming practices.

CONCLUSION

The results of this study underscore the potential of neem-based biopesticides as a cornerstone of Integrated Pest Management (IPM) strategies in sorghum production. By combining neem treatments with resistant sorghum varieties, farmers can achieve effective pest control while minimizing the risks associated with synthetic pesticides. Furthermore, the findings highlight the importance of varietal selection in pest management. SAMSORG-6 and SAMSORG-3 consistently outperformed SAMSORG-40 in terms of pest resistance and yield, emphasizing the need for breeding programs to focus on enhancing resistance traits in sorghum. The environmental benefits of neem-based biopesticides cannot be overstated. Unlike Carbofuran, which poses significant risks to non-target organisms and the environment, neem is biodegradable and non-toxic. The adoption of neem-based treatments can therefore contribute to biodiversity preservation and the reduction of pesticide-related health hazards. Integrating neem treatments with resistant sorghum varieties presents a promising approach to managing sorghum stem borer in Maiduguri and similar

agro-ecological zones. Future research should focus on enhance their effectiveness and adoption among farmers.

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