African Entomology 2025, 33: e22984 (9 pages)
https://doi.org/10.17159/2254-8854/2025/a22984

AFRICAN ENTOMOLOGY
ISSN (online) 2224-8854

RESEARCH ARTICLE

Efficacy and adoption of neem-lime extract as seed and foliar treatments against African rice gall midge (*Orseolia oryzivora*) in rice production

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The African rice gall midge (AfRGM), *Orseolia oryzivora* (Diptera: Cecidomyiidae), is a major constraint to rice production in sub-Saharan Africa, causing significant yield losses, particularly under rainfed and irrigated lowland conditions. Farmers often rely on synthetic insecticides, but their high cost, associated environmental concerns and limited effectiveness necessitate sustainable alternatives. This study, conducted from 2023 to 2024 in the rice-growing community of Edozhigi, Niger State, Nigeria, evaluated the efficacy and adoption of neem-lime extract as an eco-friendly management strategy against AfRGM. A 4 × 3 factorial field experiment tested four rice varieties (FARO 37, FARO 44, FARO 66, FARO 67) with two neem-lime extract treatments: seed soaking only and seed soaking plus foliar spray, with a control. In 2023, 80 farmers were trained using a learning-by-doing approach, and adoption was assessed in 2024 through structured questionnaires. Results showed that seed soaking plus foliar spray significantly reduced AfRGM infestation compared to seed soaking alone, particularly when integrated with FARO 67. Tiller infestation negatively correlated with grain yield (R^2 = 0.34–0.84). The extract enhanced yields (5.67 t ha^{-1} in 2023; 6.92 t ha^{-1} in 2024) without adverse effects on agronomic traits. Adoption was high (79.5%), influenced by farming experience (χ^2 = 17.00, p = 0.002), farm size (χ^2 = 6.85, p = 0.032) and education level (χ^2 = 24.23, p = 0.001), but not by age or gender. Most adopters (80.6%) prepared the extract themselves. Neem-lime extract, particularly integrating with FARO 67, offers a practical and environmentally friendly alternative to chemical insecticides for AfRGM management.

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DATES
Received: 9 July 2025
Accepted: 7 December 2025

KEYWORDS
educational level
effectiveness
farming experience
farm size
grain yield
tiller infestation

INTRODUCTION

Rice (*Oryza sativa* L.) is an important staple food for more than half of the global population, playing a vital role in food security, particularly in developing nations across Africa (Mohidem et al. 2022). While rice cultivation has expanded significantly throughout Nigeria's agroecological zones in recent decades, production faces numerous challenges (Rahman et al. 2013). Among these, insect pests remain one of the constraints to rice production, especially in rainfed and irrigated lowland ecosystems (Nwilene et al. 2008). The African Rice Gall Midge (AfRGM), *Orseolia oryzivora* Harris and Gagné (Diptera: Ceccidomyiidae) emerged as the most economically important pest, capable of causing substantial yield losses, thereby threatening both food security and farmers' livelihoods (Nwilene et al. 2013; Ogah and Nwilene 2017; Ouattara et al. 2020).

The AfRGM was first reported in Sudan in 1954 and has become a major pest in Burkina Faso and Nigeria. Since then, it has spread across 16 rice-growing regions in sub-Saharan African countries (Nwilene et al. 2006). Significant damage has been reported in farmers' fields, causing yield losses ranging from 45% to 80%, and severe infestation results in total crop loss (Ouattara et al. 2020). Feeding damage to rice tillers causes the formation of tube-like galls, which prevents panicle initiation, directly impacting grain yield. Farmers in the tropics primarily depend on conventional insecticides to control this pest (Nkechi et al. 2018). However, insecticides are harmful to humans and the environment. Increasing costs of insecticides have placed a significant financial strain on smallholder farmers, and had a negative effect on the overall profitability of rice farming (Kumari et al. 2014; Damalas and Koutroubas 2015; Shabana et al. 2017).

These challenges have led to a growing interest in alternative, environmentally sustainable pest management options (Mahmood et al. 2016). Botanical pesticides, particularly plant-based extracts such as neem and lime extracts (*Azadirachta indica* and *Citrus aurantifolia*), whether applied singly or mixed with other extracts, have shown promising results on various agricultural insect pests (Ezeonu et al. 2001; Ugwu et al. 2012; Poderoso et al 2016; Geraldin et al. 2020; Ugwu 2020). Neem contains several bioactive compounds, with azadirachtin as the primary active ingredient, acting as an antifeedant, repellent and growth-regulating agent against various insect pests (Chaudhary et al. 2017; Arshad et al. 2019). Previous studies have demonstrated the efficacy of neem-based extracts in controlling many rice pests. For instance, Ogah and Ogbodo (2012) and Mohammed et al. (2024) reported a significant reduction in AfRGM infestation levels following the foliar application of neem extract. Lime extract has demonstrated notable insecticidal and fumigant effects against mosquitoes and other insects (Ezeonu et al. 2001), with its effectiveness largely being attributed to the presence of d-limonoids in the extracts (Sarma et al. 2019).

The mixture of two or more plant extracts has gained significant attention for its potential synergistic effects in pest management. When combined, these botanical mixtures often demonstrate enhanced pesticidal properties compared to individual extracts used singly (Oparaeke et al. 2005). However, there is limited research specifically investigating the combined efficacy of neem and lime extracts as seed treatments or in conjunction with foliar applications for controlling AfRGM in rice production.

While the technical effectiveness of any strategy is important, its practical success ultimately depends on adoption by farmers. Perceptions of farmers toward biopesticides and their willingness to use them greatly influence the development of effective and sustainable approaches to pest management (Abatania et al. 2009; Deng et al. 2009). As neem-lime extract is a novel intervention, a significant knowledge gap remains regarding farmer adoption in rice pest management. Therefore, the aim of this study was to investigate whether applying neem-lime extract as both seed and foliar treatments could significantly reduce AfRGM tiller infestation and improve grain yield, as well as to assess the potential adoption of this technique by smallholder farmers in rice-based farming systems in Nigeria.

MATERIALS AND METHODS

Study location

The field study was conducted in a rice-growing community from 2023 to 2024 under rainfed lowland conditions in Edozhigi, Niger State, Nigeria. It is located at 09°45' N latitude, 06°07' E longitude, and 50.57 m above sea level within the southern Guinea savanna agroecological zone. The area experiences a bimodal rainfall pattern, with an annual rainfall averaging between 900 and 1 050 mm, distributed from May to October each year. The relative humidity ranges from 52% to 73% with an annual mean temperature of 26.5 °C.

Preparation of neem-lime extract

One kilogram (1 kg) of fresh neem leaves was collected from the study area, rinsed to remove dirt particles, and crushed using a wooden mortar and pestle (jumbo size). Lime fruit of 80–90 g each were purchased from the local market. Ten limes were cut into pieces and added to the crushed neem leaves, which were mixed with 2 litres of water and allowed to soak for 24 hours. Thereafter, the mixture was filtered using a clean white cloth to obtain an aqueous solution. The extracts were subsequently used for seed treatments by soaking and foliar spray applications.

Experimental design, planting procedure and treatment applications

The experiment was laid out in a randomised complete block design (RCBD) using a 4 × 3 factorial layout with three replications. The factors were the four rice varieties, FARO 37, FARO 44, FARO 66 and FARO 67, and two neem-lime extract treatments with an untreated control (i) T1= control: no seed treatment + no foliar spray; (ii) T2 = seed soaking + no foliar spray; and (iii) T3= seed soaking + foliar spray. Rice seeds were soaked in the neem-lime extracts for 24 hours before planting, while foliar application was done at weekly intervals during the vegetative stage. Rice seeds were planted in a nursery, and seedlings were maintained for 21 days before being transplanted to the field at 20 cm × 20 cm spacing. A basal fertiliser application of 30 kg ha^{-1} each of N, PO_2, O_5 and K_2O was applied before planting, followed by top dressing with 20 kg ha^{-1}of N at the maximum tillering and early panicle stage. Manual weeding was done at 21 and 42 days after crop establishment and subsequently when necessary. AfRGM tiller infestation was assessed on 20 middle hills per treatment combination at 21, 42 and 63 days after transplanting (DAT). The percentage tiller infestation was calculated as the number of tillers with galls, divided by the total number of tillers multiplied by 100. At maturity, data on agronomic traits, including the number of tillers, panicle length and grain yield, were collected.

Adoption of neem-lime extract applications as seed treatment and foliar spray by smallholder farmers

In 2023, 80 rice farmers in the Edozhigi community were trained by AfricaRice using a participatory approach in the preparation and application of neem-lime extracts as seed soaking and foliar spray for the control of AfRGM tiller infestation in rice fields. In 2024, a follow-up assessment was conducted to evaluate the adoption of the extracts among the trained farmers. Data were collected using structured questionnaires administered through oral interviews. All 80 trained farmers were surveyed to gather comprehensive information from the study area. The questionnaires were designed to collect data on the adoption and use of the neem-lime extract, as well as socioeconomic information, including the respondents' gender, age, farm size, educational level and years of farming experience.

Data analyses

Data on the tiller infestation were transformed using arcsine before analysis. All data were subjected to two-way analysis of variance (ANOVA) in a randomised design using the General Statistical Software package (GENSTAT 2009). Significant differences among means were separated using Tukey's post-hoc test at 5% probability. Regression analysis was performed to evaluate the relationship between mean AfRGM tiller infestation and grain yield, thereby determining the efficacy of the neem-lime extracts.

Data on socio-economic characteristics and technical information were analysed using descriptive statistics with IBM Statistical Package for Social Sciences (SPSS) version 21.0 (IBM Corp. 2012). Pearson's chi-square test was also used to assess the relationship between farmers' demographic information and the adoption of neem-lime extract. A p-value less than 0.05 was considered to be statistically significant.

RESULTS

The results show that rice variety, neem-lime extract and their interactions significantly influenced the tiller infestation caused by AfRGM (Table 1). Significantly lower tiller infestation was exhibited in FARO 67 (8.07% and 11.66%) compared to the other tested varieties in the 2023 ($F_{3,35}$ = 389.41, p < 0.001) and 2024 ($F_{3,35}$ = 757.60, p < 0.001) planting seasons. However, FARO 37 (14.91% and 18.65%) recorded significantly higher tiller damage (Figure 1) in both years. Similarly, in both years, plants treated with the neem-lime extract under combined seed soaking and foliar spray applications (6.62% in 2023; 6.54% in 2024) showed significantly ($F_{3,35}$ = 3890.55, p < 0.001 in 2023 and $F_{3,35}$ = 9202.90, p < 0.001 in 2024) lower mean AfRGM tiller infestation compared to plants treated with seed soaking alone (8.16% and 11.62%) (Figure 2). The highest infestation was recorded in the untreated control plots (20.93% and 25.45%).

A significant interaction was found between rice varieties and neem-lime extract in both years of assessment (Table 2). The neem-lime extract, either in combination with seed soaking and foliar spray or seed soaking alone, significantly suppressed AfRGM infestation compared to the control treatment. Particularly, FARO 66 treated with combined seed soaking and foliar spray (5.48% in 2023; 4.47% in 2024) had significantly lower tiller infestation ($F_{6,35}$ = 1 974.59, p < 0.001 in 2023; $F_{6,35}$ = 2 732.34, p < 0.001 in 2024) compared to other treatment combinations. FARO 37 (23.56% in 2023; 33.86% in 2024) was the most susceptible variety, showing the highest AfRGM pressure in the untreated control.

The number of tillers produced was significantly ($F_{3,35}$ = 9.73, p < 0.001 in 2023; ($F_{3,35}$ = 8.30, p < 0.001 in 2024) influenced by the type of rice variety planted in both years. However, in 2023, only the neem-lime extract application significantly ($F_{2,35}$ = 10.99, p < 0.001) influenced the number of tillers produced (Table 3). The number of tillers in FARO 37 (13.01 and 14.19) and FARO

Table 1: Analysis of variance showing the effect of variety, neem-lime extract treatment and their interactions on AfRGM

Year	Source of variation	df	Sum of Squares	Mean Squares	*F*-value
	Variety	3	222.18	74.06	389.41***
2023	Neem-lime	2	1 479.80	739.90	3 890.55***
	Variety × Neem-lime	6	268.35	44.73	235.18***
	Error	22	4.18	0.19	
	Total	35	1974.59		
	CV (%)		3.7		
	Variety	3	283.85	94.62	757.60***
2024	Neem-lime	2	2 298.74	1 149.37	9 202.90***
	Variety × Neem-lime	6	146.92	24.49	196.07***
	Error	22	2.75	0.12	
	Total	35	2 732.34		
	CV (%)		2.4		

*** $p < 0.001$

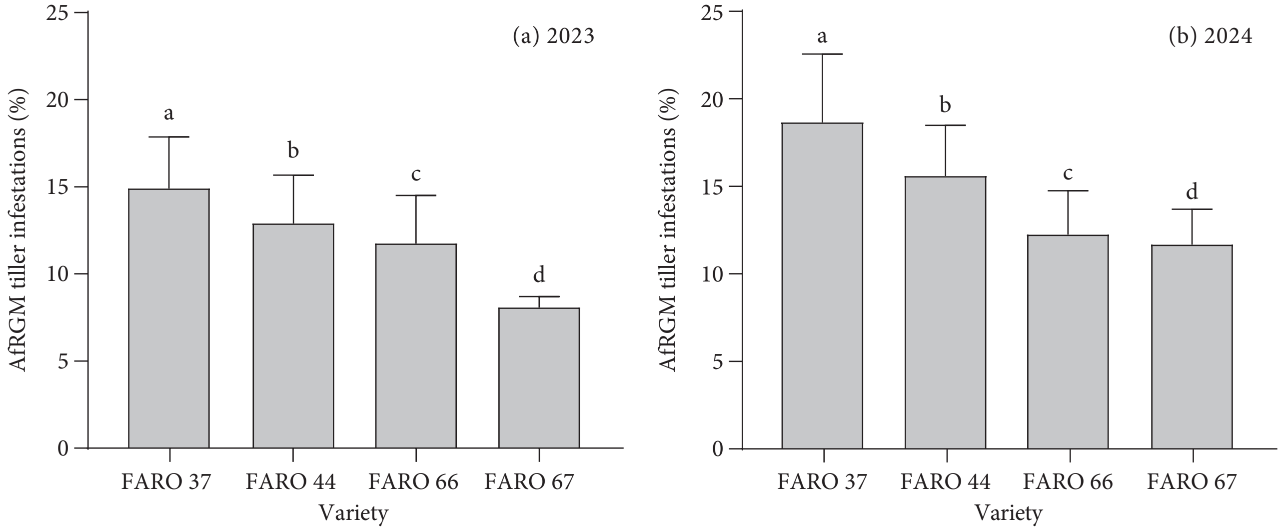

Figure 1: Effect of variety on the mean AfRGM tiller infestations

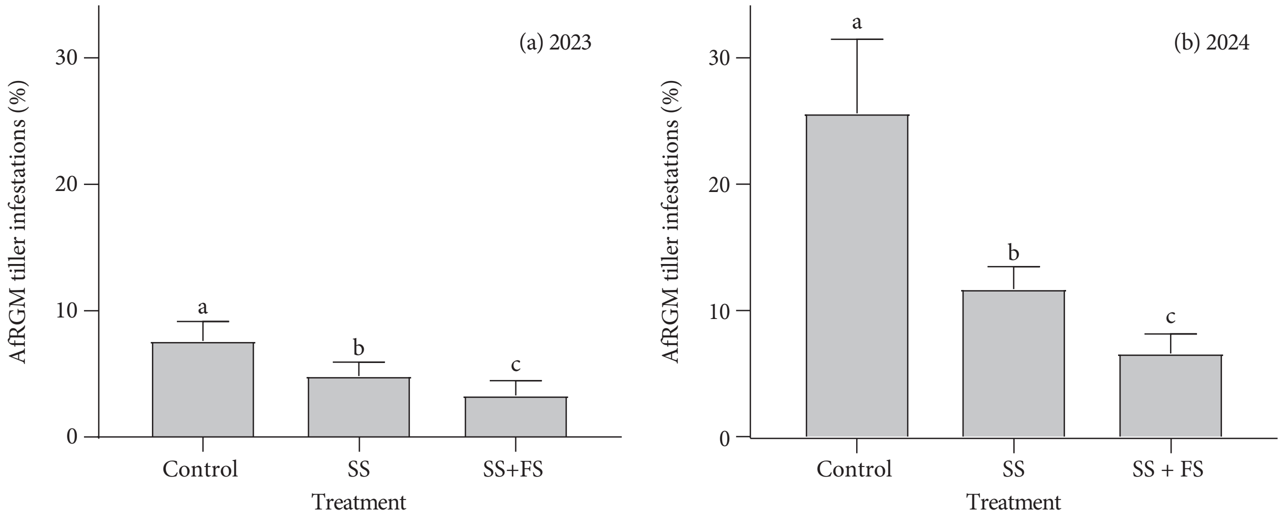

Figure 2: African rice gall midge tiller infestation in rice treated with seed soaking (SS) and foliar spray (SS + FS) of neem-lime extract

44 (13.31 and 14.09) was significantly higher than in FARO 66 (12.08 and 12.56) and FARO 67 (11.87 and 12.07). In 2023, there was no significant difference in terms of the number of tillers produced by plants that received the seed soaking (12.19) and control treatment (12.21). Meanwhile, plants treated with the combined seed soaking and foliar spray of the extract produced a significantly higher number of tillers (13.31) (Table 3).

Panicle length was significantly affected by both rice variety and neem-lime extract application in both years. In 2023, FARO 37 (24.32 cm) and FARO 67 (23.91 cm) produced significantly ($F_{3,35}$ = 44.85, p < 0.001) longer panicles compared with FARO 44 (20.61 cm) and FARO 66 (21.05 cm). In 2024, FARO 44 (24.11 cm) consistently recorded the shortest panicles, whereas FARO 37 (25.00 cm), FARO 66 (25.78 cm) and FARO 67 (25.41 cm) produced the longest panicles ($F_{3,35}$ = 8.94, p < 0.001). In both years, the neem-lime extract treatment, either seed soaking alone or combined, resulted in significantly ($F_{2,35}$ = 11.03, p < 0.001 in 2023; $F_{2,35}$ = 7.19, p < 0.001 in 2024) longer panicles than the untreated control.

Similarly, rice grain yield was significantly influenced by both variety ($F_{3,35}$ = 180.09, p < 0.001 in 2023; $F_{3,35}$ = 40.87, p < 0.001 in 2024) and neem-lime extract treatment ($F_{2,\ 35}$ = 1071.39, p < 0.001 in 2023; $F_{2,35}$ = 405.83, p < 0.001 in 2024) in both years. Among the varieties, FARO 67 (3.82 t ha^{-1} and 4.21 t ha^{-1}) consistently produced significantly higher grain yield, followed by FARO 66 (3.30 t ha^{-1} and 3.95 t ha^{-1}) and FARO 44 (2.69 t ha^{-1} and 3.89 t ha^{-1}), respectively. However, FARO 37 (2.44 t ha^{-1} and 3.57 t ha^{-1}) recorded the lowest grain yield in both years. Across treatments, plants treated with the combined application of seed soaking and foliar spray (4.45 t ha^{-1} and 4.62 t ha^{-1}) exhibited the highest grain yield compared with those treated with seed soaking alone (2.93t ha^{-1} and 3.90 t ha^{-1}), while the untreated control (1.18 t ha^{-1} and 3.19 t ha^{-1}) consistently produced the lowest yields. Also, the higher grain yield was influenced significantly ($F_{6,35}$ = 11.59, p < 0.001 in 2023) by the interactions between the variety and neem-lime extract treatment. Furthermore, linear regression analysis shows that the AfRGM tiller infestation was negatively associated with the fruit yield, leading to a 34% yield reduction in 2023 ($y = -0.3396x + 4.7895$, R^2 = 0.34, p = 0.001) and 84% in 2024 ($y = -0.0677\ + 4.8872$, R^2 = 0.84, p = < 0.001) (Figure 3).

Table 2: Interaction effect between the rice variety and the neem-lime extract on AfRGM

	Variety	Neem-lime extract		
		Control	SS	SS + FS
	FARO 37	26.65a	9.79c	8.276d
2023 (%)	FARO 44	23.95b	8.19d	6.54ef
	FARO 66	22.68b	7.09def	5.48g
	FARO 67	10.43b	7.58de	6.21f
	FARO 37	33.86a	14.14e	7.94h
2024 (%)	FARO 44	26.91b	11.94f	7.92h
	FARO 66	21.61c	10.66g	4.47i
	FARO 67	19.43d	9.73g	5.83j

Mean values in a column followed by different letters are significantly different (p < 0.05) as per Tukey's HSD test after arc-sine transformation.

Socio-economic characteristics of the rice farmers

A total of 40% of the farmers were within the age range of 18–30 years, whereas 10% were aged between 31 and 40 years, 25% were in the age range of 41–50 years, and 20% were aged between 51–60 years. The minority of the respondents, 5%, comprised individuals aged above 60 years. Among the rice farmers, a significant proportion (80%) were male, while the remaining 20% were female (Figure 4). Additionally, most farmers (55%) have over 20 years of farming experience, followed by 15% with 16–20 years of experience, 12.5% with 6–10 years and 11–15 years of experience, and only 5% with 1–5 years of experience. In terms of land usage, 45% of farmers cultivated less than 1 hectare, while 40% cultivated between 1 and 2 hectares. The remaining 15% cultivated the largest farmland areas, ranging from 2 to 5 hectares. Meanwhile, the highest proportion (50%) of respondents have secondary education, 27.5% have tertiary, 17.5% have no formal education, and 5% attended primary education (Figure 5).

Table 3: Effect of rice variety and neem-lime extract application on agronomic traits and grain yield

	No. of tiller		Panicle length (cm)		Grain yield (t ha^{-1})	
Variety (V)	2023	2024	2023	2024	2023	2024
FARO 37	13.01a	14.19a	24.32a	25.00a	2.44d	3.57c
FARO 44	13.31a	14.09a	20.61b	24.11b	2.69c	3.89b
FARO 66	12.08b	12.56b	21.05b	25.78a	3.30b	3.95b
FARO 67	11.87b	12.07b	23.91a	25.41a	3.82a	4.21a
F-value	9.73	8.30	44.85	8.94	180.09	40.87
p-value	< 0.001	< 0.001	< 0.001	< 0.001	0.001	< 0.001
Neem-lime extract (N)						
Control	12.21b	12.94a	21.53b	24.44b	1.81c	3.19c
SS	12.19b	13.18a	22.83a	25.50a	2.93b	3.90b
SS + FS	13.31a	13.55a	23.05a	25.28a	4.45a	4.62a
F-value	10.99	0.92	11.03	7.19	1071.39	405.83
p-value	< 0.001	0.42	< 0.001	0.004	< 0.001	< 0.001
Interaction (V × N)						
F-value	11.37	3.59	3.26	5.25	11.59	1.89
p-value	NS	NS	NS	NS	< 0.001	NS

Mean values in a column followed by different letters are significantly different (p < 0.05) as per Tukey's HSD test after arc-sine transformation. SS = seed soaking; SS + FS = foliar spray

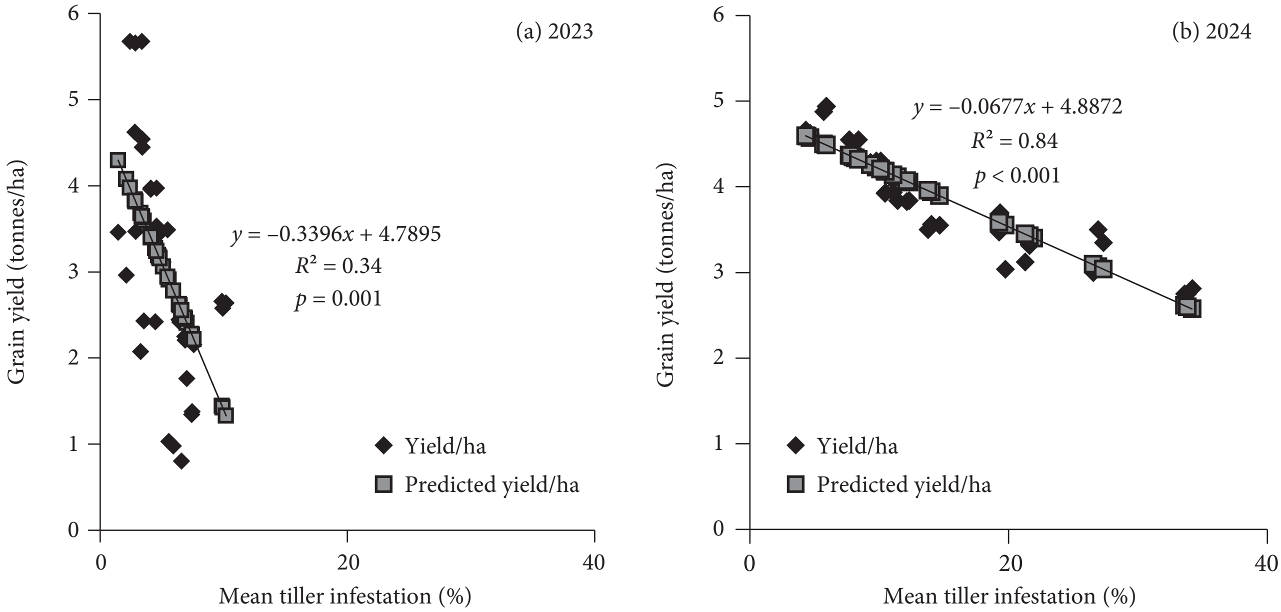

Figure 3: Linear regression between mean AfRGM tiller infestation and grain yield

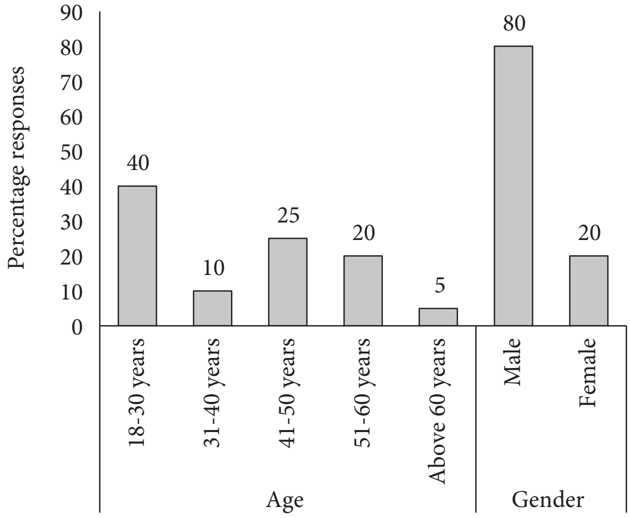

Figure 4: Age and gender of the respondents

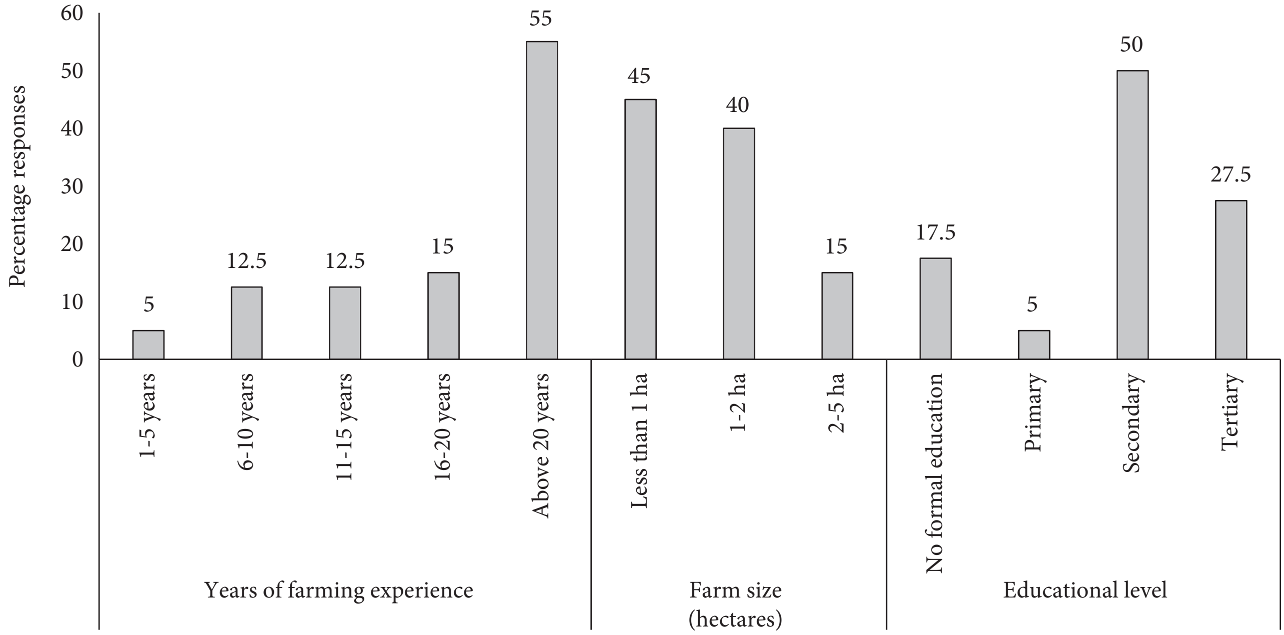

Figure 5: Years of farming experience, farm size and educational levels of the respondents

Adoption of neem-lime extract usage among rice farmers

Most respondents (79.5%) adopted neem-lime extract to control AfRGM in rice fields, while 20.5% did not adopt this technology (Table 4). Of those who used the extract, 80.6% prepared it by themselves, while 19.4% depended on co-farmers for its preparation. Meanwhile, with respect to the area of rice farm coverage, 32.3% did not use the extract on up to 25% of their rice farms, another 32.3% applied it to 25–50% of their farms, 9.7% treated 51–75%, and 25.8% covered more than 75% of their farms with the extract. Regarding the frequency of application, 6.5% applied the extract once a week, 19.4% used it twice a week, 48.4% applied it three times a week, and 25.8% used it more than three times a week. All respondents who adopted the neem-lime extract found it effective in reducing AfRGM tiller infestation and encountered no challenges during implementation.

Relationship between farmers' socioeconomic characteristics and the adoption of neem-line extract

A significant relationship was observed between farming experience and neem-lime extract adoption (χ^2 = 17.004, p = 0.002) (Table 5). Farmers with more than 20 years of experience had the highest adoption rate (36 out of 44), whereas those with less than five years of experience showed the lowest adoption rate (2 out of 4). However, age distribution (χ^2 = 3.722,

Table 4: Adoption and implementation of the neem-lime extract application by the respondents

		Frequency	Percent
Have you used the neem-lime extract on your rice farm	Yes	62	79.5
	No	16	20.5
Who prepared the neem-lime extract for you	Myself	50	80.6
	Co-farmer	12	19.4
What percentage of your rice farm did you treat with neem-lime extract	Less than 25%	20	32.3
	25–50%	20	32.3
	51–75%	6	9.7
	More than 75%	16	25.8
How often did you apply the extract during the growing season	Once a week	4	6.5
	Twice a week	12	19.4
	Three times a week	30	48.4
	More than three times a week	16	25.8
Was the extract effective against AfRGM?	Yes	62	100
Did you face any challenges in implementing the neem-lime extract method	No	62	100

Table 5: Relationship between farmers' demographic information and the adoption of neem-line extract

Demographic information		Have you used the neem-lime extract on your rice farm				
		Yes	No	Total	χ^2	***p*-value**
Age	18–30 years	24	8	32	3.722	0.445
	31–40 years	8	0	8		
	41–50 years	14	4	18		
	51–60 years	12	4	16		
	Above 60 years	4	0	4		
Gender	Male	52	10	62	3.562	0.059
	Female	10	6	16		
Years of farming experience	1–5 years	2	2	4	17.004	0.002*
	6–10 years	4	6	10		
	11–15 years	10	0	10		
	16–20 years	10	0	10		
	Above 20 years	36	8	44		
Farm size (hectares)	Less than 1 ha	24	10	34	6.853	0.032*
	1–2 ha	30	2	32		
	2–5 ha	8	4	12		
Education level	No formal education	4	8	12	24.233	0.001*
	Primary	2	2	4		
	Secondary	34	6	40		
	Tertiary	22	0	22		

*Relationship significant at $p < 0.05$; χ^2 = Chi square value

$p = 0.445$) and gender ($\chi^2 = 3.562$, $p = 0.059$) of the farmers did not have a significant relationship with the adoption of neem-lime extract. Additionally, farm size showed a significant association with the farmer's adoption ($\chi^2 = 6.853$, $p = 0.032$). Farmers cultivating less than 1 hectare recorded the lowest adoption rates (24 out of 34), while those with 1 to 2 hectares exhibited the highest adoption (30 out of 32). Likewise, the farmers' educational level had a highly significant relationship with the adoption of the extract ($\chi^2 = 24.233$, $p = 0.001$). Those with tertiary education had the highest adoption rate (22 out of 22), while farmers with no formal education showed the lowest adoption rate (4 out of 12).

DISCUSSION

The irreversible nature of damage inflicted by AfRGM poses a significant threat to rice production systems across Africa, necessitating the urgent need for the development of effective and sustainable pest-management strategies. Plant-based extracts hold strong potential for use in integrated pest control. In this study, the combined seed soaking and foliar spray of neem-lime extract showed greater efficacy in managing AfRGM than seed soaking alone. This demonstrates the positive impact of the holistic approach in pest management, where plant extracts offer improved pest control through dual-mode delivery, both as seed treatments and foliar applications (Kumar 2021; Srinivasan et al. 2021). This aligns with the findings of Singh et al. (2019), who successfully reduced *Meloidogyne graminicola* damage by applying plant extracts both as a seed treatment and as a foliar spray to rice plants. Although total eradication of the pest was not achieved with the combined applications, this approach still provides reasonable levels of protection to the crop and could ultimately reduce reliance on synthetic insecticides. The reduction in the tiller infestation observed might be attributed to the bioactive compounds possessed by the extracts, such as azadirachtin and limonene, which are known for their broad-spectrum effects on insect pests, including repellency, growth inhibition and antifeedant properties (Ugwu 2020). Previous research confirms that neem products act as antifeedants and growth inhibitors against rice stem borer (Ogah et al. 2011). These effects are primarily attributed to the tetranortriterpenoid azadirachtin, which disrupts hormone and enzyme activity in target pests (Nathen et al. 2004; 2005).

The notable interaction of neem-lime treatments with rice varieties shows the differential responses to AfRGM management strategies. In both years, FARO 67 demonstrated consistently decreased infestation levels across all treatment regimens. According to Ba et al. (2008), this raises the possibility of synergistic effects between the applied plant extracts and innate varietal resistance features. Similar varietal differences showed responsiveness to pest management tactics, finding that some rice cultivars exhibit biochemical or morphological features that enhance external control measures (Nwilene et al. 2008). However, FARO 37 recorded the highest infestation level in all treatments, indicating possible susceptibility factors that the extracts did not sufficiently address. This corresponds with the findings of Togola et al. (2018), who showed that to control pests effectively, varieties lacking genetic resistance need more intense management measures.

It was evident from this study that the neem-lime extract did not adversely affect key agronomic traits. Instead, the increased number of tillers and panicle length observed under the combined treatment of seed soaking and foliar spray suggest potential growth-enhancing properties of the extracts, as previously reported by Godlewska et al. (2021) and Kumar et al. (2021), who found that botanical extracts can stimulate plant growth parameters beyond their pest control functions. Yield performance varied significantly across varieties, with FARO 67 consistently recording the highest yields, while FARO 37 produced the lowest. The interaction between rice variety and neem-lime treatment suggests the importance of selecting suitable genetic backgrounds, especially varieties with moderate level of resistance, to maximise the benefits of botanical pest management. Grain yield improvements under combined neem-lime applications reveal the economic significance of AfRGM management, as yield reductions of up to 34 to 84% were associated with increasing infestation levels. This agrees with previous studies showing that AfRGM can cause severe yield losses if not effectively managed (Ogah and Ogbodo 2012; Nwilene et al. 2013).

The adoption of neem-lime extract among trained farmers was high (79.5%). Particularly, farmers with over 20 years of experience and those cultivating between 1 and 2 hectares were more likely to adopt the practice. This suggests that knowledge gained by small landholdings and experience may encourage openness to innovative pest management techniques, a finding supported by Adeogun et al. (2018). The significant association between education level and adoption is consistent with the findings by Mokgadi and Oladele (2013), who found that farmers with higher levels of education are better able to interpret and synthesise complex agricultural information and are more receptive to innovations that are presented to them than those with lower levels of education.

Interestingly, male farmers constituted 80% of the study group, although the relationship between age, gender and adoption was not statistically significant. This implies a disparity in access to training and farming resources between the genders (Midamba and Ouko 2024). Agidew (2017) found similar results: male farmers have better access to extension training compared to female farmers. Furthermore, the high proportion (80.6%) of farmers who prepare the plant extract themselves (80.6%) supports both the availability and the adaptive capacity of the botanical technology. The fact that every respondent shared a common belief in the effectiveness of AfRGM confirms the high confidence placed in the indigenous knowledge-based method. This is in line with the early work of Pretty (1995) on participatory agricultural research, showing that those technologies developed using farmer participation and local resources, as opposed to top-down approaches delivered from outside, can result in up to 50% greater rates of adoption.

Also, effective self-preparation of the extracts implies that knowledge has been transferred in training towards the technical aspects of making the formulation. It is an approach towards an agricultural innovation pathway in which this becomes a demand-driven approach, and farmers become part of the process and not merely recipients of a technology, thereby ensuring sustainable ownership of it at the local level (Mgendi et al. 2019).

The findings of this study indicate that the integrated use of neem-lime extract through seed soaking and foliar spray provides effective control of AfRGM with improved grain yield when integrated with moderately susceptible rice genotypes such as FARO 66 and FARO 67. The high rate of adoption by trained rice farmers (79.5%), particularly those with high experience and medium landholdings, indicates strong acceptance of this technology among the target population. Therefore, neem-lime extract offers a promising, environmentally friendly component of integrated pest management for rice cultivation that balances effectiveness, accessibility and sustainability while reducing dependence on synthetic pesticides.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge Mr Adebayo Kehinde for his technical assistance during the experiments.

DECLARATION OF COMPETING INTEREST

Authors declare that they have no conflict of interest.

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REFERENCES

Abatania LN, Gyasi KO, Salifu AB, Coulibaly ON, Razak A. 2009. Factors affecting the adoption of botanical extracts as pesticides in cowpea production in northern Ghana. Ghana Journal of Agricultural Science. 43: 9–15.

Adeogun SO, Ajana AM, Ayinla OA, Yarhere MT, Adeogun MO. 2018. Application of logit models in adoption decisions: A study of hybrid clarias in Lagos State, Nigeria. American-Eurasian Journal of Agricultural & Environmental Sciences. 4: 468–472.

Agidew A. 2017. Gender disparity in access to agricultural resources and services (evidence from Arba Minch Zuria Woreda of Southern Ethiopia). Agriculture, Forestry and Fisheries. 6: 184–187. https://doi.org/10.11648/j.aff.20170606.11

Arshad M, Ullah MI, Çağatay NS. Abdullah A, Dikmen F, Kaya C, Khan RR. 2019. Field evaluation of water plant extracts on sucking insect pests and their associated predators in transgenic *Bt* cotton. Egyptian Journal of Biological Pest Control Publication. 29: 39. https://doi.org/10.1186/s41938-019-0142-8

Ba NM, Dabire CB, Drabo I, Sanon A, Tamo M. 2008. Combination of varietal resistance and neem-based insecticides for controlling the key insects of cowpea in the central region of Burkina Faso. Science and technique. Natural Science and Agronomy. 30: 113–121.

Chaudhary S, Kanwar RK, Sehgal A, Cahill DM, Barrow CJ, Sehgal R, Kanwar JR. 2017. Progress on *Azadirachta indica* based biopesticides in replacing synthetic toxic pesticides. Frontiers in Plant Science. 8: 610. https://doi.org/10.3389/fpls.2017.00610

Damalas CA, Koutroubas SD. 2015. Farmers' exposure to pesticides: toxicity types and ways of prevention. Toxics. 1: 1–10.

Deng AL, Ogendo JO, Owuor G, Bett PK, Omolo EO, Mugisha-Kamatenesi M, Mihale JM. 2009. Factors determining the use of botanical insect pest control methods by small-holder farmers in the Lake Victoria basin, Kenya. African Journal of Environmental Science and Technology. 3: 108–115. https://doi.org/10.5897/AJEST09.034

Ezeonu FC, Chidume GI, Udedi SC. 2001. Insecticidal properties of volatile extracts of orange. Bioresource Technology. 76: 273–274. https://doi.org/10.1016/S0960-8524(00)00120-6

GENSTAT. 2009. GenStat for Windows. 12th ed. Hemel Hempstead, UK: VSN International. www.genstat.co.uk

Geraldin MWL, Muthomi JW, Mbega ER. 2020. Phytochemical activity and role of botanical pesticides in pest management for sustainable agricultural crop production. Scientific African. 7: e00239. https://doi.org/10.1016/j.sciaf.2019.e00239

Godlewska K, Pacyga P, Michalak I, Biesiada A, Szumny A, Pachura N, Piszcz U. 2021. Effect of botanical extracts on the growth and nutritional quality of field-grown white head cabbage (*Brassica oleracea* var. *capitata*). Molecules. 26: 1992. https://doi.org/10.3390/molecules26071992

IBM Corp. 2012. IBM SPSS Statistics for Windows, Version 21.0. Armonk, NY, USA: IBM Corp.

Kumar A. 2021. Role of botanical pesticides in integrated pest management. Agriculture and Food: E-Newsletter. 2: 51–54.

Kumar S, Bhowmik D, Chiranjib B, Tiwari P. 2021. Potential of neem-derived products in agricultural management. Journal of Agricultural Science. 13: 15–28.

Kumari KA, Kumar KNR, Rao CN. 2014. Adverse effects of chemical fertilizers and pesticides on human health and environment. Journal of Chemical and Pharmaceutical Research. 3: 150–151.

Mahmood I, Imadi SR, Shazadi K, Gul A, Hakeem KR. 2016. Effects of Pesticides on Environment. In: Hakeem K, Akhtar M, Abdullah S (eds). Plant, Soil and Microbes. Cham: Springer. pp 253–269. https://doi.org/10.1007/978-3-319-27455-3_13

Mgendi G, Shiping M, Xiang C. 2019. A review of agricultural technology transfer in Africa: Lessons from Japan and China case projects in Tanzania and Kenya. Sustainability. 11: 6598. https://doi.org/10.3390/su11236598

Midamba DC, Ouko KO. 2024. Gender disparities in agricultural extension among smallholders in Western Uganda. Cogent Economics and Finance. 12: 2391938. https://doi.org/10.1080/23322039.2024.2391938

Mohammed IG, Adeoti AO, Gbadeyan ST, Isong A, Fatima AJ, Amos T. 2024. Assessment of plant extracts on the management of rice gall midge (*Orzeolia Oryzivora)* infestation on rice (*Oryza sativa)*. Nigerian Journal of Entomology. 40: 119–125. https://doi.org/10.36108/NJE/4202/04.0101

Mohidem NA, Hashim N, Shamsudin R, Che Man H. 2022. Rice for food security: Revisiting its production, diversity, rice milling process and nutrient content. Agriculture. 12: 741. https://doi.org/10.3390/agriculture12060741

Mokgadi JF, Oladele OI. 2013. Factors affecting sustainability of agricultural projects on poverty alleviation in Gauteng Province of South Africa. Journal of Food, Agriculture and Environment. 11:1078–1086.

Nathan SS, Chung PG, Murugan K. 2004. Effect of botanical insecticides and bacterial toxins on the gut enzyme of the rice leaffolder *Cnaphalocrocis medinalis*. Phytoparasitica. 32: 433–443. https://doi.org/10.1007/BF02980437

Nathan SS, Kalaivani K, Murugan K, Chung PG. 2005. The toxicity and physiological effect of neem limonoids on *Cnaphalocrocis medinalis* (Guenee) the rice leaf folder. Pesticide Biochemistry and Physiology. 81: 113–122. https://doi.org/10.1016/j.pestbp.2004.10.004

Nkechi EF, Ejike OG, Ihuoma NJ, Maria-goretti OC, Francis U, Godwin N, Njokuocha R. 2018. Effects of aqueous and oil leaf extracts of *Pterocarpus santalinoides* on the maize weevil, *Sitophilus zeamais*, pest of stored maize grains. African Journal of Agricultural Research. 13: 617–626. https://doi.org/10.5897/AJAR2018.13014

Nwilene FE, Nwanze KF, Okhidievbie O. 2006. African rice gall midge: Biology, ecology and control; field guide and technical manual. Africa rice center, 28. WARDA.

Nwilene FE, Souleymane MT, Philippe M, Elvis AH, Abdoulaye H, Dona D, Togola A. 2013. Managing insect pests of rice in Africa. In Wopereis MCS, Johnson DE, Ahmadi N, Toliens E, Jalloh A (eds), Realizing Africa's rice promise. UK: CAB International. pp. 229–240. https://doi.org/10.1079/9781845938123.0229

Nwilene FE, Togola A, Agunbiade TA, Ogah EO, Ukwungwu MN, Anegbeh P, Woin N. 2008. Parasitoid biodiversity conservation for sustainable management of the African rice gall midge, *Orseolia oryzivora* (Diptera: Cecidomyiidae) in lowland rice. Biocontrol Science and Technology. 18: 1075–1081. https://doi.org/10.1080/09583150802420231

Ogah EO, Nwilene FE. 2017. Incidence of insect pests on rice in Nigeria: A review. Journal of Entomology. 14: 58–72. https://doi.org/10.3923/je.2017.58.72

Ogah EO, Ogbodo EN. 2012. Comparative efficacy of neem seed extract with carbofuran in the management of African rice gall midge, *Orseolia oryzivora* Harris and Gagne (Diptera: Cecidomyppdae) Journal of Biology, Agriculture and Healthcare. 2(5): 147–153.

Ogah EO, Omoloye AA, Nwilene FE, Nwogbaga AC. 2011. Effect of neem seed kernel extracts in the management of rice stem borers in the field in Nigeria. Nigerian Journal of Biotechnology. 23: 13–21.

Oparaeke AM, Dike MC, Amatobi CI. 2005. Evaluation of botanical mixtures for insect pests management on cowpea plants. Journal of Agriculture and Rural Development in the Tropics and Subtropics. 106: 41–48.

Ouattara D, Nacro S, Latévi K, Coulibaly A, Somda I. 2020. Ecology of the African rice gall midge, *Orseolia oryzivora* (Diptera: Cecidomyiidae) in Western Burkina Faso, West Africa. Advances in Entomology. 8: 1–14. https://doi.org/10.4236/ae.2020.81001

Poderoso JCM, Correia-Oliveira ME, Chagas TX, Zanuncio JC, Ribeiro GT. 2016. Effects of extracts on developmental stages of the predator *Podisus nigrispinus* (Hemiptera: Pentatomidae). Florida Entomologist. 99: 113–116. https://doi.org/10.1653/024.099.0121

Pretty JN. 1995. Participatory learning for sustainable agriculture. World Development. 23: 1247–1263. https://doi.org/10.1016/0305-750X(95)00046-F

Rahman MC, Siddique Md, Abdus S, Islam MA, Al-Faisal MS. 2013. Assessment of technical efficiency of rice farmers in a selected empoldered Area of Bangladesh. European Journal of Agricultural Sciences. 10: 102–110.

Sarma R, Adhikari K, Mahanta S, Khanikor B. 2019. Insecticidal activities of *Citrus aurantifolia* essential oil against *Aedes aegypti* (Diptera: Culicidae). Toxicology Reports. 6: 1091–1096. https://doi.org/10.1016/j.toxrep.2019.10.009

Shabana YM, Abdalla ME, Shahin AA, El-Sawy MM, Draz IS, Youssif AW. 2017. Efficacy of plant extracts in controlling wheat leaf rust disease caused by *Puccinia triticina* Egypt. Journal of Basic and Applied Science. 4: 67–73. https://doi.org/10.1016/j.ejbas.2016.09.002

Singh S, Tanwar RK, Singh SP, Balodi R. 2019. Evaluation of components of IPM for basmati rice against rice root-knot nematode, *Meloidogyne graminicola*. Indian Journal of Agricultural Sciences. 89: 1728–1731. https://doi.org/10.56093/ijas.v89i10.94639

Srinivasan R, Tamò M, Malini P. 2021. Emergence of *Maruca vitrata* as a major pest of food legumes and evolution of management practices in Asia and Africa. Annual Review of Entomology. 66: 141–161. https://doi.org/10.1146/annurev-ento-021220-084539

Togola A, Boukar O, Serge B, Chamarthi SK, Tamò M. 2018. Host plant resistance to insect pests of cowpea (*Vigna unguiculata* L. Walp.): Achievements and future prospects. Euphytica. 214: 198.

Ugwu JA. 2020. Insecticidal activity of some botanical extracts against legume flower thrips and legume podborer on cowpea *Vigna unguiculata* L. Walp. Journal of Basic Applied Zoology. 81:13. https://doi.org/10.1186/s41936-020-00153-3

Ugwu JA, Omoloye AA, Obasaju FT. 2012. Potentials of *Azadirachta indica* (A. Juss) and *Cymbopogon citratus* (Staph) powder for the control of *Oryzae philusmercator* (Fauvel) on *Irvingia wombolu* kernel. Journal Sustainable Environmental Management. 4: 75–80.