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# Systemic protection of rice against African rice gall midge (Orseolia oryzivora) through seed coat treatment with selected botanical extracts

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# Abstract

The African rice gall midge (AfRGM), *Orseolia oryzivora* Harris and Gagné, is a devastating pest of lowland rice in West Africa, causing 20–100% grain yield loss. Conventional insecticides are largely ineffective against AfRGM because larvae feed within plant galls, and their indiscriminate use raises environmental and health concerns. This study investigated the systemic insecticidal activity of three botanical solvent extracts—*Ageratum conyzoides* in n-hexane (AcH), *Chromolaena odorata* in n-hexane (CoH), and *Ocimum gratissimum* in chloroform (OgC)—applied as seed coat treatments against AfRGM. Rice seeds of two varieties, BW-348-1 (moderately resistant) and ITA-306 (susceptible), were soaked for 24 h in extracts at five concentrations (20%, 10%, 5%, 2.5%, and 1.25% v/v) in a 2 × 3 × 5 factorial arrangement fitted into a completely randomized design with three replications. Seedlings were transplanted at 14 days after sowing (DAS), and adult midges were introduced at 21 DAS. Tiller infestation and agronomic parameters were assessed up to 63 days after infestation (DAI). The extracts demonstrated significant systemic insecticidal effects. Zero tiller infestation was achieved at 20% concentration for all three extracts on BW-348-1, and at 20% AcH on ITA-306 across all observation periods. Notably, BW-348-1 treated with 10% AcH also produced zero tiller infestation. The moderately resistant variety consistently outperformed ITA-306 in all agronomic parameters and grain yield, indicating a synergistic interaction between host plant resistance and botanical seed treatment.These findings provide evidence of the systemic insecticidal potential of botanical extracts against AfRGM via seed treatment.


# 1. Introduction

Rice (*Oryza sativa* L. and *O. glaberrima* Steud.) is the most rapidly growing food staple in Sub-Saharan Africa, with per capita consumption increasing by approximately 4.5% annually over the past two decades [1]. In Nigeria, rice consumption has risen to approximately 32 kg per capita per annum, making the country the largest rice importer in Africa [2]. Despite intensified domestic production efforts, Nigeria's rice yield remains below 2.5 t/ha, largely due to biotic constraints, prominently insect pest damage [3;4].

The African rice gall midge (AfRGM), *Orseolia oryzivora* Harris and Gagné (Diptera: Cecidomyiidae), is an economically devastating insect pest of rice in West and Central Africa [5;6]. AfRGM is particularly destructive in hydromorphic lowland rice ecosystems where high humidity favors larval survival and movement [7]. Yield losses of 20–100% have been documented in endemic areas, with every 1% increase in tiller infestation translating to approximately 2–3% grain yield reduction [8;9].

The biology of AfRGM presents a unique challenge for pest management. Adult females lay eggs on rice leaves and leaf sheaths. Upon hatching, larvae migrate to the growing point of the tiller, feeding on the apical meristem and inducing the formation of a tubular gall known as a "silver shoot" or "onion leaf" [10;11]. The larvae develop entirely within the gall, rendering them inaccessible to contact insecticides and natural enemies [6]. This cryptic feeding habit renders foliar sprays of conventional insecticides

largely ineffective, while their widespread use accelerates resistance development, destroys natural enemies, and poses human health hazards [12;13].

Botanical insecticides have emerged as promising eco-friendly alternatives for pest management in developing countries [14;15]. Plants produce diverse secondary metabolites, including alkaloids, terpenoids, phenolics, and flavonoids, which confer insecticidal, antifeedant, and growth-regulatory properties [16;17]. Several botanicals have demonstrated efficacy against rice pests [18;19]. However, most botanical pesticide studies have focused on foliar application and contact toxicity, with limited investigation into their systemic properties [20;21].

Systemic insecticides, which are absorbed by the plant and translocated to various tissues, represent the most logical approach for managing pests that feed within protected plant structures [22]. Seed treatment with botanical extracts offers several advantages: it provides early protection during the most vulnerable vegetative stage and confers sustained protection as bioactive compounds are translocated systemically [23;24]. For AfRGM management, systemic protection from the seed stage could provide a critical window of defense.

In a preceding study, ten botanicals were screened and *Ageratum conyzoides* in n-hexane (AcH), *Chromolaena odorata* in n-hexane (CoH), and *Ocimum gratissimum* in chloroform (OgC) were identified as the most effective extracts against adult AfRGM, with bioactivity comparable to carbofuran [25]. The present study therefore investigated the systemic insecticidal activity of these three selected botanical solvent extracts when applied as seed coat treatments against AfRGM on two rice varieties with contrasting resistance levels. Specifically, the objectives were to: (i) determine whether seed soaking with botanical extracts confers systemic protection against AfRGM; (ii) evaluate the concentration-dependent systemic efficacy of AcH, CoH, and OgC; (iii) compare systemic activity on a moderately resistant (BW-348-1) and a susceptible (ITA-306) rice variety; and (iv) assess the impact of seed treatment on agronomic performance and grain yield of AfRGM-infested rice.

## 2. Materials and Methods

# 2.1 Study Location

The experiment was conducted in the Paddy Screenhouse of the AfricaRice Center, International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria (7°29'N, 3°54'E; elevation 210 m above sea level). The screenhouse maintained ambient tropical conditions with an average temperature of 28 ± 4°C and relative humidity of 70–85%.

# 2.2 Stock Culture of AfRGM

A continuous culture of *O. oryzivora* was maintained on the susceptible rice variety ITA-306 following the protocol of Ogah and Nwilene (2014) with modifications. At two weeks after sowing (WAS), seed boxes were transferred to oviposition cages where 20 mated female adults (1–3 days old) were introduced.

Seedlings were sprayed with water daily at 07:00 h to provide the moisture film necessary for larval migration into tillers [26]. Emerging adults were collected in the early morning to infest fresh batches of seedlings, maintaining a synchronized culture.

## 2.3 Collection and Preparation of Plant Materials

Fresh leaves of *Ageratum conyzoides* L. and *Chromolaena odorata* (L.) King and Robinson were collected within the IITA campus, while leaves of *Ocimum gratissimum* L. were obtained from the IITA botanical garden. All plant materials were authenticated at the IITA herbarium. Extraction followed the protocol described by Ayangbemi et al. (2024): 200 g of freshly blended leaf material was soaked in 500 mL of the appropriate solvent (n-hexane for *A. conyzoides* and *C. odorata*; chloroform for *O. gratissimum*) for 24 h at room temperature (28 ± 4°C). The mixture was filtered through Whatman No. 1 filter paper, and the filtrate was air-dried for 24 h to evaporate the solvent. Residues were stored in sealed glass jars at 4°C until use.

## 2.4 Experimental Design and Treatments

The experiment was a 2 × 3 × 5 factorial arrangement fitted into a completely randomized design (CRD) with three replications. The factors were:

1. Two rice varieties: BW-348-1 (moderately resistant to AfRGM) and ITA-306 (susceptible).
2. Three botanical extracts: *Ageratum conyzoides* in n-hexane (AcH), *Chromolaena odorata* in n-hexane (CoH), and *Ocimum gratissimum* in chloroform (OgC).
3. Five concentration levels: 20%, 10%, 5%, 2.5%, and 1.25% (v/v).

This yielded 30 treatment combinations replicated three times (90 experimental units), plus carbofuran (1.5 kg a.i. $ha^{1}$) as the positive check and unsoaked seeds as the negative control.

## 2.5 Seed Soaking and Establishment

Rice seeds of each variety were soaked in the respective extract solutions for 24 h at room temperature. Following soaking, seeds were surface-dried briefly and sown in seed boxes the following day. Seedlings were raised in the screenhouse and transplanted at 14 days after sowing (DAS) into 11-liter planting pots filled with paddy soil, at two seedlings per stand. Dead seedlings were replaced at 7 days after transplanting (DAT). Pots were arranged in 1 × 1 × 1.3 m planting cages within the screenhouse.

## 2.6 Insect Infestation

At 21 DAS (7 DAT), six adult midges (3 males: 3 females, 1–3 days old) were introduced into each cage from the stock culture using glass vials. Cages were sprayed with water daily at 07:00 h to facilitate larval migration into tillers.

## 2.7 Data Collection

**Tiller infestation assessment**: Percentage tiller infestation was recorded at 21, 42, and 63 days after infestation (DAI) by counting the number of galled tillers (silver shoots/onion leaves) relative to total

tillers per pot, expressed as: % Tiller infestation = (Number of infested tillers / Total number of tillers) × 100

**Agronomic parameters**: At 3–9 WAP, the following parameters were recorded: plant height (cm), number of tillers, number of panicles, panicle length (cm), panicle weight (g), and grain yield (t/ha).

## 2.8 Statistical Analysis

Data were subjected to analysis of variance (ANOVA) using GenStat 12.1 (2009). Significant treatment means were separated using the Student-Newman-Keuls (SNK) test at $p < 0.05$.

# 3. Results

## 3.1 Effect of Seed Treatment on Systemic Response to AfRGM Infestation

The three-way interaction (variety × extract × concentration) significantly influenced tiller infestation across all observation periods (Table 1). On BW-348-1, AcH produced zero tiller infestation at both 10% and 20% concentrations across all DAI. CoH and OgC achieved zero infestation only at 20% on BW-348-1. On ITA-306, only AcH at 20% produced zero tiller infestation across all observation periods.

At 21 DAI, the highest infestation on BW-348-1 was recorded at 1.25% OgC (1.90%), while on ITA-306, the highest was at 1.25% OgC (2.55%). At 42 DAI, BW-348-1 treated with 1.25% OgC recorded the highest infestation (5.82%), while ITA-306 treated with 2.5% CoH recorded the highest (16.54%). At 63 DAI, the trend persisted, with OgC at 1.25% on BW-348-1 (4.40%) and OgC at 1.25% on ITA-306 (7.29%) recording the highest infestation levels.

Table 1
Tiller infestation (%) induced by AfRGM on two rice varieties soaked at five concentrations of three selected botanical solvent extracts.

| Days After Infestation | Concentration (%) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Variety | Botanicals | 1.25 | 2.5 | 5 | 10 | 20 | Mean |
| 21 | BW-348-1 | AcH | 1.58 | 1.59 | 1.56 | 0.00 | 0.00 | 0.95 |
| | | CoH | 1.75 | 1.75 | 1.73 | 1.60 | 0.00 | 1.37 |
| | | OgC | 1.90 | 1.76 | 1.75 | 0.00 | 0.00 | 1.08 |
| | ITA-306 | AcH | 2.13 | 2.04 | 2.01 | 0.00 | 0.00 | 1.24 |
| | | CoH | 2.45 | 2.23 | 2.61 | 2.12 | 2.18 | 2.32 |
| | | OgC | 2.55 | 2.08 | 2.13 | 2.13 | 2.06 | 2.19 |
| | | Mean | 2.06 | 1.91 | 1.97 | 0.97 | 0.71 | |
| | | LSD(0.05) | VxBxC = 0.79 | | | | | |
| 42 | BW-348-1 | AcH | 4.40 | 3.08 | 2.67 | 0.00 | 0.00 | |
| | | CoH | 5.79 | 4.93 | 4.19 | 3.24 | 0.00 | 2.03 |
| | | OgC | 5.82 | 4.83 | 3.81 | 2.74 | 0.00 | 3.63 |
| | ITA-306 | AcH | 7.20 | 5.23 | 5.04 | 3.39 | 0.00 | 3.44 |
| | | CoH | 7.82 | 16.54 | 11.80 | 9.49 | 8.34 | 4.17 |
| | | OgC | 11.06 | 9.70 | 9.07 | 8.82 | 8.77 | 10.80 |
| | | Mean | 7.02 | 7.38 | 6.10 | 4.61 | 2.85 | 9.48 |
| | | LSD(0.05) | VxBxC = 0.26 | | | | | |
| 63 | BW-348-1 | AcH | 4.26 | 4.01 | 4.01 | 0.00 | 0.00 | |
| | | CoH | 4.25 | 4.28 | 4.14 | 4.34 | 0.00 | 2.46 |
| | | OgC | 4.40 | 4.43 | 4.10 | 4.28 | 0.00 | 3.40 |
| | ITA-306 | AcH | 5.57 | 5.50 | 4.98 | 4.99 | 0.00 | 3.44 |
| | | CoH | 6.60 | 6.46 | 6.08 | 5.63 | 5.47 | 4.21 |
| | | OgC | 7.29 | 7.01 | 6.96 | 7.68 | 7.51 | 6.05 |
| | | Mean | 5.39 | 5.28 | 5.04 | 4.49 | 2.16 | 7.29 |

| Days After Infestation | | | Concentration (%) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Variety | Botanicals | 1.25 | 2.5 | 5 | 10 | 20 | Mean |
| | | LSD(0.05) | VxBxC = 0.22 | | | | | |

LSD = Least Significant Difference.

Table 2
Interaction effects of variety, extract, and concentration on selected agronomic parameters

| Agronomic parameters | | | Concentration (%) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Variety | Botanicals | 1.25 | 2.5 | 5 | 10 | 20 | Mean |
| Plant height (cm) | BW-348-1 | AcH | 67.26 | 65.29 | 85.96 | 87.22 | 87.69 | 78.68 |
| | | CoH | 59.84 | 59.98 | 60.18 | 69.88 | 76.20 | 65.22 |
| | | OgC | 60.02 | 62.18 | 68.40 | 79.22 | 79.84 | 69.93 |
| | ITA-306 | AcH | 57.15 | 57.95 | 60.55 | 70.65 | 84.95 | 66.25 |
| | | CoH | 56.20 | 57.11 | 56.15 | 58.65 | 58.77 | 57.38 |
| | | OgC | 54.11 | 54.28 | 58.00 | 59.02 | 59.67 | 57.02 |
| | | Mean | 59.10 | 59.47 | 64.87 | 70.77 | 74.52 | |
| | | LSD(0.05) | v*b*c = 0.051 | | | | | |
| Number of Tillers | BW-348-1 | AcH | 19.98 | 20.11 | 20.65 | 21.02 | 21.06 | 20.56 |
| | | CoH | 15.38 | 15.83 | 16.02 | 17.28 | 20.32 | 16.97 |
| | | OgC | 15.11 | 15.75 | 16.01 | 16.33 | 20.57 | 16.75 |
| | ITA-306 | AcH | 12.50 | 15.49 | 16.26 | 18.59 | 20.04 | 16.58 |
| | | CoH | 11.51 | 5.38 | 7.12 | 7.69 | 8.15 | 7.97 |
| | | OgC | 8.41 | 9.49 | 10.03 | 10.21 | 10.38 | 9.70 |
| | | Mean | 13.82 | 13.68 | 14.35 | 15.19 | 16.75 | |
| | | LSD(0.05) | v*b*c = 0.041 | | | | | |
| Number of Panicles | BW-348-1 | AcH | 4.02 | 4.48 | 5.18 | 6.20 | 6.33 | 5.24 |
| | | CoH | 2.53 | 3.17 | 3.46 | 4.98 | 5.84 | 3.99 |
| | | OgC | 1.63 | 2.12 | 3.35 | 4.32 | 5.41 | 3.37 |
| | ITA-306 | AcH | 1.55 | 1.91 | 2.29 | 3.54 | 4.99 | 2.86 |
| | | CoH | 1.40 | 1.41 | 1.66 | 1.99 | 2.26 | 1.74 |
| | | OgC | 1.38 | 1.40 | 1.42 | 1.69 | 2.08 | 1.59 |
| | | Mean | 2.09 | 2.41 | 2.89 | 3.79 | 4.48 | |

| Agronomic parameters | | | Concentration (%) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Variety | Botanicals | 1.25 | 2.5 | 5 | 10 | 20 | Mean |
| | | LSD(0.05) | v*b*c = 0.01 | | | | | |
| Panicle length (cm) | BW-348-1 | AcH | 25.86 | 26.15 | 27.88 | 36.29 | 36.54 | 30.54 |
| | | CoH | 21.28 | 24.15 | 25.82 | 26.91 | 34.92 | 26.62 |
| | | OgC | 18.29 | 21.03 | 23.15 | 26.86 | 28.94 | 23.65 |
| | ITA-306 | AcH | 18.95 | 20.38 | 23.99 | 28.61 | 32.04 | 24.79 |
| | | CoH | 18.15 | 18.44 | 19.03 | 19.97 | 20.46 | 19.21 |
| | | OgC | 18.21 | 18.49 | 18.96 | 19.17 | 19.63 | 18.89 |
| | | Mean | 20.12 | 21.44 | 23.14 | 26.30 | 28.76 | |
| | | LSD(0.05) | v*b*c = 0.051 | | | | | |
| Panicle weight (g) | BW-348-1 | AcH | 28.22 | 31.50 | 32.86 | 35.97 | 36.36 | 32.98 |
| | | CoH | 23.88 | 26.22 | 30.81 | 32.43 | 34.03 | 29.47 |
| | | OgC | 18.49 | 24.67 | 29.11 | 30.68 | 32.02 | 26.99 |
| | ITA-306 | AcH | 12.29 | 17.38 | 20.05 | 26.11 | 30.28 | 21.22 |
| | | CoH | 9.48 | 10.51 | 12.59 | 14.16 | 19.38 | 13.22 |
| | | OgC | 8.33 | 9.11 | 11.59 | 12.01 | 15.33 | 11.27 |
| | | Mean | 16.78 | 19.90 | 22.84 | 25.23 | 27.90 | |
| | | LSD(0.05) | v*b*c = 0.049 | | | | | |

BW-348-1 = Moderately resistant variety. ITA-306 = Susceptible variety LSD = Least Significant Difference.

AcH = *Ageratum conyzoides* extracted in hexane, CoH =*Chromolaena odorata* extracted in hexane, OgC = *Occimum gratissimum* extracted in chloroform

# 3.2 Effect of Seed Treatment on Agronomic Parameters

Seed soaking prior to planting significantly influenced all agronomic parameters (Table 2). BW-348-1 treated with AcH recorded the highest plant height (87.69 cm at 20%), number of tillers (21.06 at 20%), number of panicles (6.33 at 20%), panicle length (36.54 cm at 20%), and panicle weight (36.36 g at 20%).

ITA-306 treated with AcH at 20% also produced the highest values among extract treatments for this variety.

## 3.3 Grain Yield

Grain yield was significantly influenced by the seed treatment (Fig. 1). BW-348-1 consistently produced higher yields than ITA-306 across all treatments. On BW-348-1, AcH at 20% produced the highest yield, followed by AcH at 10%. A higher yield was also obtained from BW-348-1 plots treated with 20% concentration levels of CoH and OgC. The least value of yield was recorded on the rice variety treated with 1.25% of all the three extracts. Similar results were obtained on the susceptible variety as well.

BW-348-1 = Moderately resistant variety. ITA-306 = Susceptible variety

AcH = *Ageratum conyzoides* extracted in hexane

CoH =*Chromolaena odorata* extracted in hexane

OgC = *Occimum gratissimum* extracted in chloroform

# 4. Discussion

The present study shows the systemic insecticidal activity of botanical solvent extracts against AfRGM via seed coat treatment. The zero-tiller infestation at 20% concentration on BW-348-1 for all three extracts, and on ITA-306 for AcH, demonstrates that bioactive compounds from these botanicals can be absorbed through the seed coat, translocated within the developing seedling, and exert insecticidal effects at the growing point where AfRGM larvae feed. This finding has profound implications for AfRGM management, as the cryptic feeding habit of larvae within galls renders contact insecticides ineffective [6;11].

The systemic activity observed is consistent with the known translocation properties of certain phytochemical classes. Terpenoids and flavonoids, which are abundant in *A. conyzoides* and *C. odorata* [26;34], and phenolic compounds present in *O. gratissimum* [29;18], have been reported to exhibit mobility within plant vascular systems [37]. Neem-based systemic activity, where azadirachtin is absorbed from soil and transported to growing tips, has been well documented [20;38;39].

The dose-dependent response observed, with decreasing tiller infestation at increasing concentrations, is consistent with the fundamental principles of botanical insecticide activity [14;21]. At 20% concentration, sufficient bioactive compounds were absorbed and translocated to provide complete protection, while at 1.25%, the concentration was insufficient to prevent all larval establishment. This concentration-response relationship is similar to that reported for neem seed extracts against rice stem borers [22] and for essential oils against stored product pests [40;41].

The minimum concentration for zero infestation varied by extract and variety: AcH achieved complete protection at 10% on both varieties, while CoH and OgC required 20% on BW-348-1 and did not achieve

zero infestation on ITA-306 at any concentration tested. This suggests that AcH possesses superior systemic bioactivity among the three extracts, likely attributable to the specific phytochemical profile extracted by n-hexane from *A. conyzoides*, which includes lipophilic terpenoids, flavonoids, and coumarins known for insecticidal properties [26;42;43]. The n-hexane extraction preferentially isolates non-polar compounds including terpenoids and lipophilic alkaloids that may have greater mobility in plant tissues and readily penetrate the seed coat during germination [33;16]. The specific terpenoid constituents of *A. conyzoides*, including precocene I and II, have demonstrated juvenilizing and insecticidal hormonal effects in insects [12;43], which may disrupt larval development even at low systemic concentrations.

The consistently superior performance of BW-348-1 (moderately resistant) compared to ITA-306 (susceptible) across all parameters suggests a synergistic interaction between host plant resistance and botanical seed treatment. BW-348-1 likely possesses inherent resistance mechanisms including antixenosis and antibiosis that complement the systemic insecticidal action of the botanical extracts [27]. The combination of moderate genetic resistance with systemic botanical protection resulted in complete elimination of AfRGM infestation at lower extract concentrations (10% AcH) compared to the susceptible variety, which required 20% AcH for the same effect. This synergistic interaction aligns with IPM principles of combining multiple control tactics for enhanced efficacy [12;44].

The significant positive effects of seed treatment on agronomic parameters and grain yield demonstrate that systemic botanical protection not only prevents AfRGM damage but also supports normal plant growth. BW-348-1 treated with AcH at 20% produced plant heights (87.69 cm), tiller numbers (21.06), panicle numbers (6.33), and yields (~ 8.0 t/ha) comparable to carbofuran checks in previous studies [25]. The integration of systemic seed treatment with moderately resistant varieties represents a practical IPM strategy that reduces dependence on synthetic insecticides while maintaining effective pest control, aligning with AfricaRice recommendations for sustainable AfRGM management [12;24]. Furthermore, botanical seed treatments are biodegradable, have minimal impact on natural enemies such as parasitoids *Platygaster diplosisae* and *Aprostocetus procerae* [21;12], and pose negligible risk to human health and the environment [13;14].

# 5. Conclusion

This study provides evidence of systemic insecticidal activity of botanical solvent extracts against the African rice gall midge via seed coat treatment. The three selected extracts—AcH (*Ageratum conyzoides* in n-hexane), CoH (*Chromolaena odorata* in n-hexane), and OgC (*Ocimum gratissimum* in chloroform)—demonstrated significant concentration-dependent systemic protection against AfRGM. Complete elimination of tiller infestation (zero infestation) was achieved at 20% concentration for all three extracts on the moderately resistant variety BW-348-1, and at 20% AcH on the susceptible variety ITA-306. AcH exhibited superior systemic activity, achieving zero infestation at 10% on both varieties. The moderately resistant variety BW-348-1 consistently outperformed ITA-306 in all agronomic parameters and grain yield, demonstrating a synergistic interaction between host resistance and botanical seed treatment.

These findings establish botanical seed treatment as a viable, eco-friendly alternative to synthetic systemic insecticides for AfRGM management and recommend field validation in endemic areas to confirm efficacy under natural pest pressure and variable environmental conditions.

# Declarations

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**Ethical Approval:** Not applicable. This study did not involve human participants or vertebrate animals.

**Clinical Trial Registration:** Not applicable. This study is not a clinical trial.

**Consent to Participate declaration:** Not applicable.

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**Data Availability:** The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

**Author Contributions:** B. T. collected, analysed and interpreted the data for the research work and was the major contributor in writing this manuscript. O. J. was a major participant in the interpretation of the data and contributed in writing this manuscript. C. O. engaged in data collection monitoring, data interpretation and contributed in writing this manuscript. O. R. and F. E were involved in project supervision, monitoring and contributed in manuscript writing. All authors read and approved the manuscript.

# References

1. AfricaRice. Africa Rice Outlook 2021: Building Resilience in Rice Systems. Bouaké (Côte d'Ivoire). Africa Rice Center; 2021.
2. USDA. Grain and Feed Annual: Nigeria. GAIN Report No. NI2023-0012. Washington (DC): United States Department of Agriculture, Foreign Agricultural Service; 2023.
3. Nwilene FE, Nwanze KF, Youdeowei A, Van Mele P, Okhidievbie O. Rice Insect Pests in Africa: Biology, Ecology and Management. Cotonou (Benin): Africa Rice Center; 2013.
4. Ojo SO, Ojo TO, Baiyegunhi LJS, Ogundele OM. Technical efficiency of rice production in Nigeria: implications for food security. Food Secur. 2021;13:1035–47.
5. Harris KM, Gagné RJ. Description of the African rice gall midge, *Orseolia oryzivora* sp. n., with comparative notes on the Asian rice gall midge, *Orseolia oryzae* (Wood-Mason) (Diptera: Cecidomyiidae). Bull Entomol Res. 1982;72(3):467–72.

6. Williams CT, Harris KM, Ukwungwu MN, Nacro S, Dakouo D, Nwilene FE, et al. African Rice Gall Midge Research Guide. Bouaké (Côte d'Ivoire). Wallingford (UK): CABI;: West Africa Rice Development Association; 2002.
7. Ogah EO, Odebiyi JA, Omoloye AA, Nwilene FE. Evaluation of some rice genotypes for incidence of African rice gall midge and its parasitoid (*Platygaster diplosisae*). Afr Crop Sci J. 2012;20(2):137–47.
8. AfricaRice. Africa Rice Trends: Overview of Recent Developments in the Sub-Saharan Africa Rice Sector. Africa Rice Center Brief. Cotonou (Benin): Africa Rice Center; 2007.
9. Bashir M, Maji AT, Gana AS. Effect of African rice gall midge on yield and its components on inter-specific rice progenies, using correlation and principal component analysis tools. J Plant Breed Crop Sci. 2013;5(11):214–9.
10. Ogah EO, Odebiyi JA, Omoloye AA, Nwilene FE. Parasitism and development of *Platygaster diplosisae* (Hymenoptera: Platygastridae) on the African rice gall midge *Orseolia oryzivora* (Diptera: Cecidomyiidae). Int J Trop Insect Sci. 2010;30(2):93–100.
11. Nwilene FE, Nwanze KF, Okhidievbie O. African rice gall midge: biology, ecology and control. Field Guide and Technical Manual. Bouaké (Côte d'Ivoire). Africa Rice Centre; 2006. pp. 22–5.
12. Nwilene FE, Togola A, Agunbiade T, Ogah EO, Ukwungwu MN, Hamadoun A, et al. Parasitoid biodiversity conservation for sustainable management of the African rice gall midge, *Orseolia oryzivora* (Diptera: Cecidomyiidae) in lowland rice. Biocontrol Sci Technol. 2008;18(10):1075–81.
13. Damalas CA, Koutroubas SD. Farmers' exposure to pesticides: toxicity types and ways of prevention. Toxics. 2015;4(1):1. PubMed PMID: 29371176; PubMed Central PMCID: PMC5527985.
14. Isman MB. Botanical insecticides in the twenty-first century—fulfilling their promise? Annu Rev Entomol. 2020;65:233–49. PubMed PMID: 31614102.
15. Dougoud J, Toepfer S, Bateman M, Jenner WH. Efficacy of homemade botanical insecticides based on traditional knowledge: a review. Agron Sustain Dev. 2019;39:37.
16. Abubakar AR, Haque M. Preparation of medicinal plants: basic extraction and fractionation procedures for experimental purposes. J Pharm Bioallied Sci. 2020;12(1):1–10. PubMed PMID: 32499730; PubMed Central PMCID: PMC7235685.
17. Adeyemi HMM. A review of secondary metabolites from plant materials for post-harvest storage. Int J Pure Appl Sci Technol. 2011;6(2):94–102.
18. Afzal I, Iqbal A, Nawaz A, Farooq M, Al-Karaki GN, Saddique S. Plant extracts and their role in enhancing seed germination and crop growth: a review. Int J Agric Biol. 2015;17(6):1143–52.
19. Ayangbemi BT, Pitan OOR, Atayese MO, Onifade OS, Nwilene FE. Influence of solvent medium on the bioefficacy of ten plant materials against adult African rice gall midge (AfRGM – *Orseolia oryzivora*). J Appl Entomol. 2024;147(9–10):812–25.
20. Buxton T, Takahashi S, Eddy Doh AM, Baffoe-Ansah J, Owusu EO, Kim CS. Insecticidal activities of cinnamic acid esters isolated from *Ocimum gratissimum* L. and *Vitellaria paradoxa* Gaertn leaves against *Tribolium castaneum* Hebst (Coleoptera: Tenebrionidae). Pest Manag Sci. 2020;76(1):257–67.

21. Chude CF, Okorie CJ, Ayegbunam ES, Aghalu UC. Larvicidal activity of leaf extracts of *Ageratum conyzoides* and *Hyptis suaveolens* against *Aedes aegypti*. Int J Eng Appl Sci Technol. 2020;4(10):304–9.
22. Ekundayo O, Sharma S, Rao EV. Essential oil of *Ageratum conyzoides*. Planta Med. 1988;54:55–7.
23. El-Kamali HH. Medicinal plants in east and central Africa: challenges and constraints. Ethnobot Leaflets. 2009;13:364–9.
24. Harris KM, Williams CT, Okhidievbie O, Lasalle J, Polaszek A. Description of a new species of *Orseolia* (Diptera: Cecidomyiidae) from *Paspalum* in West Africa with notes on its parasitoids, ecology and relevance to national biological control of African rice gall midge, *O. oryzivora* Harris and Gagne. Bull Entomol Res. 1999;89:441–8.
25. Iriti M, Faoro F. Chemical diversity and defence metabolism: how plants cope with pathogens and ozone pollution. Int J Mol Sci. 2009;10(8):3371–99. PubMed PMID: 19742160; PubMed Central PMCID: PMC2748575.
26. Kamboj A, Saluja AK. *Ageratum conyzoides* L.: a review on its phytochemical and pharmacological profile. Int J Green Pharm. 2008;2(2):59–68.
27. Keita SM, Vincent C, Schmit JP, Ramaswamy S, Bélanger A. Effect of various essential oils on *Callosobruchus maculatus* (F.) (Coleoptera: Bruchidae). J Stored Prod Res. 2000;36(4):355–64.
28. Lawal OA, Opoku AR, Ogunwande IA. Phytoconstituents and insecticidal activity of different solvent leaf extracts of *Chromolaena odorata* L., against *Sitophilus zeamais* (Coleoptera: Curculionidae). Eur J Med Plants. 2015;5(3):237–47.
29. Mai TV, Yoshimura A, Yasui H. Characterization of resistance to the green rice leafhopper (*Nephotettix cincticeps* Uhler) in a core collection of landraces in rice (*Oryza sativa* L). Am J Plant Sci. 2017;8:236–56.
30. Moreira MD, Marcelo CP, Luiz Claudio AB, Raul Narciso CG, Emerson CB, Mateus RC. Compounds from *Ageratum conyzoides*: isolation, structural elucidation and insecticidal activity. Pest Manag Sci. 2007;63:615–21.
31. Nnamonu LA, Onekutu A. Green pesticides in Nigeria: an overview. J Biol Agric Healthc. 2015;5(9):48–56.
32. Nwilene FE, Williams CT, Ukwungwu MN, Dakouo D, Nacro S, Hamadoun A, et al. Reactions of differential rice genotypes to African rice gall midge in West Africa. Int J Pest Manag. 2002;48(3):195–201.
33. Ogah EO, Ogbodo EN. Comparative efficacy of neem seed extract with carbofuran in the management of African rice gall midge, *Orseolia oryzivora* Harris and Gagne (Diptera: Cecidomyiidae). J Biol Agric Healthc. 2012;2(5):147–53.
34. Ogendo JO, Kostyukovsky M, Ravid U, Matasyoh JC, Deng AL, Omolo EO. Bioactivity of *Ocimum gratissimum* L. oil and two of its constituents against five insect pests attacking stored food products. J Stored Prod Res. 2008;44:328–34.
35. Okunade AL. *Ageratum conyzoides* L. (Asteraceae). Fitoterapia. 2002;73(1):1–16.

36. Omoloye AA. Mechanism of resistance in rice cultivars to the African rice gall midge, *Orseolia oryzivora* Harris and Gagne in Ibadan, Nigeria [PhD thesis]. Ibadan (Nigeria): University of Ibadan; 1998.
37. Oyetunji OE, Nwilene FE, Togola A, Adebayo KA. Antixenotic and antibiotic mechanisms of resistance to African rice gall midge in Nigeria. Trends Appl Sci Res. 2014;9:174–86.
38. Pavela R, Benelli G. Essential oils as ecofriendly biopesticides? Challenges and constraints. Trends Plant Sci. 2016;21(12):1000–7. PubMed PMID: 27816597.
39. Pratheeba T, Chinnasamy R, Devarajan N. Larvicidal, pupicidal and adulticidal potential of *Ocimum gratissimum* plant leaf extracts against filariasis inducing vector. Int J Mosq Res. 2015;2(2):1–8.
40. Ragesh PR, Bhutiab TN, Gantaa S, Singh AK. Repellent, antifeedant and toxic effects of *Ageratum conyzoides* (Linnaeus) (Asteraceae) extract against *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae). Arch Phytopathol Plant Prot. 2016;49(1–4):19–30.
41. Rioba NB, Stevenson PC. *Ageratum conyzoides* L. for the management of pests and diseases by small holder farmers. Ind Crops Prod. 2017;110:22–9.
42. Rocha O, Riboldi-Montero JA, Dias FCF, Sallam N. Seed treatment with microbial inoculants and botanicals: advances and challenges. Front Plant Sci. 2020;11:1–14. PubMed PMID: 32117370; PubMed Central PMCID: PMC7024225.
43. Saxena RC, Dixit OP, Sukumaran P. Laboratory assessment of indigenous plant extracts for anti-juvenile hormone activity in *Culex quinquefasciatus*. Indian J Med Res. 1992;95:204–6.
44. Sesan TE, Enache E, Iacomi BM, Oprea M, Oancea F, Iacomi C. Antifungal activity of some plant extracts against *Botrytis cinerea* Pers. in the blackcurrant crop (*Ribes nigrum* L). Acta Sci Pol Hortorum Cultus. 2015;14(1):29–43.
45. Schmutterer H. The Neem tree, *Azadirachta indica* A. Juss and other meliaceous plant sources of unique natural products for integrated pest management, medicine and purposes. Mumbai (India): Neem Foundation; 2002. pp. 893–5.
46. Truong DH, Nguyen DH, Ta NTA, Bui AV, Do TH, Nguyen HC. Evaluation of the use of different solvents for phytochemical constituents, antioxidants, and in vitro anti-inflammatory activities of *Severinia buxifolia*. J Food Qual. 2019;2019:1–9.
47. Udebuani AC, Abara PC, Obasi KO, Okuh SU. Studies on the insecticidal properties of *Chromolaena odorata* (Asteraceae) against adult stage of *Periplaneta americana*. J Entomol Zool Stud. 2015;3(1):318–21.

# Figures

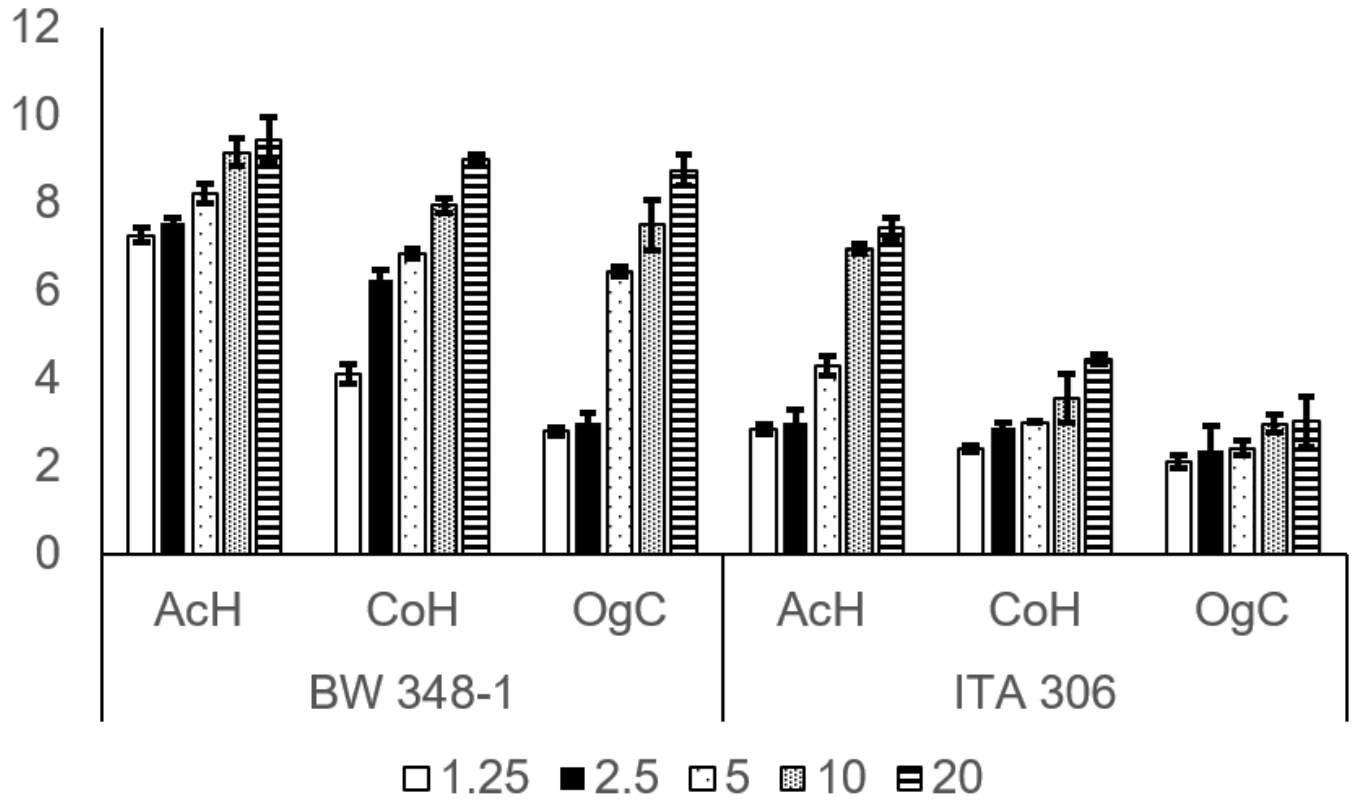



**Figure 1**

Yield (t/ha) of two African Rice Gall Midge infested rice varieties soaked with different concentrations of three selected botanical solvent extracts

BW-348-1= Moderately resistant variety. ITA-306 = Susceptible variety

AcH = *Ageratum conyzoides*extracted in hexane

CoH =*Chromolaena odorata*extracted in hexane

OgC = *Occimum gratissimum*extracted in chloroform