Int.J.Curr.Microbiol.App.Sci (2024) *13*(11): 118-128

EXCELLENT PUBLISHERS

International Journal of Current Microbiology and Applied Sciences
ISSN: 2319-7706 **Volume 13 Number 11 (2024)**
Journal homepage: http://www.ijcmas.com

Original Research Article https://doi.org/10.20546/ijcmas.2024.1311.014

Insecticidal and Repellent Effects of Some Local Plants Against the Rice Weevil (*Sitophilus oryzae* L.) Infesting Pearl Millet Stored in Northern Benin

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Keywords

Rice weevil, Repellence, Contact toxicity, Fumigation toxicity, Pearl millet

Article Info

Received:
18 September 2024
Accepted:
22 October 2024
Available Online:
10 November 2024

ABSTRACT

The rice weevil, *Sitophilus oryzae* L. is a widely distributed storage insect pest that causes tremendous damage to stored pearl millet. Farmers employ synthetic chemical insecticides to overcome this constraint, which have significant impacts on human health and the environment. The use of plant extracts and plants can be an alternative to these insecticides. The objective of this study is to evaluate the insecticidal and insect repellent properties of powders and ethanoic extracts of *Ocimum gratissimum* L., *Ocimum basilicium* L., *Parkia biglobosa* (Jacq.) R.Br. ex G.Don., and *Azadirachta indica* A. Juss. against *S.oryzae* using antixenosis and antibiosis methods. Deltamethrine insecticide and Bextoxin served as positive controls for antibiosis and antixenosis tests respectively. Untreated pearl millet were used as negative control. According to the results, the leaf powders and ethanolic extract of the four plants had repellent properties and were more repellent than synthetic insecticides. The leaf powder of *O. basilicium* was more repellent after 1 h (88.24%) and 24 h (80.11%), while that of *P. bligobosa* was more repellent after 12 h of exposure (78.57%).The *P. biglobosa* extract exhibited the highest rate of repulsion against *S. oryzae* at 5% concentration after 2 h of exposure. Deltamethrine had a greater insecticidal effect than powders and resulted in complete mortality (100%) of *S. oryzae* adults from the first day of treatment. The ethanol extract of *O. gratissimum* caused the greatest contact toxicity (100% mortality) at 2.5% concentration after 21 days of treatment. Similarly *O. gratissimum* had a high fumigant toxicity (92.5% mortality) at 7.5 % (160 µL/L of air) of concentration after 24 h after exposure. The results of this study demonstrated that the powders and extracts of the four tested medicinal plants could be utilized as biopesticides, a potential alternative for controlling *S. oryzae* in stored pearl millet.

Introduction

In the Republic of Benin, pearl millet (*Pennisetum glaucum* (L.) R. Br.) occupies an important place in the diet of the population in the northern region (Dagba *et al.,* 2014), with an estimated production of 23990 tons in 2022 (FAO, 2022). Due to its high nutritional value compared to other cereals, this cereal has a great potential for food and nutritional security (Vanisah *et al.,* 2011). However, pearl millet is considered as a neglected and underutilized crop in the Republic of Benin with a decrease in production over the years (Dansi *et al.,* 2012; FAO, 2022). The decline in productivity is a result of several factors one of them being the attack of storage insects, which is the most significant biotic factor in northern Benin (Adeoti *et al.,* 2017). In fact, stored pearl millet is frequently infested by various insect species, resulting in quantitative losses and affecting the nutritional quality and germination of grains (Rajendran and Chayakumari, 2003).

Sitophilus oryzae L. (Coleoptera: Curculionidea), also known as the rice weevil, is a pest commonly found in stored food products. This insect pest is widely spread and is one of the most economically significant pests of stored products (Pugazhvendon *et al.,* 2009). In fact, the rice weevil could caused a loss of 54.44% of stored pearl millet after 120 days of storage (Bhargude *et al.,* 2021).

The majority of farmers in northern Benin use chemical insecticides to fight pests, which have a detrimental impact on both human health and the environment (Kossou and Aho, 1993). Given this situation, it is imperative to investigate alternative methods that are respectful of the environment and the health of populations, such as using botanical biopesticides.

In the Northern Benin, farmers often use the leaves of some medicinal plants such as *Ocimum gratissimum* L., *Ocimum basilicium* L., *Parkia biglobosa* (Jacq.) R.Br. ex G. Don., and *Azadirachta indica* A. Juss. to protect stored cereals against insect pest. In fact *O. gratissimum* and *O. basilicium* are aromatic plants whose essential oils are known to have insecticidal effects on several storage insect pests such as *Acanthoscelides obtectus* Say (Rodríguez-González *et al.,* 2019). *Rhyzopertha dominica* F. (Toudert-Taleb *et al.,* 2021), and *Callosobruchus maculatus* F. (Kéita *et al.,* 2001). Leaf and seed extracts of *P. bligobosa* showed insecticidal properties against *Trogoderma granarium* Everts (Musa and Lawal, 2016) and *A. obtectus* (Nta *et al.,* 2019). *Azadirachta indica* seeds and leaves extracts have been proven to be effective in protecting stored maize (Tofel *et al.,* 2024), cowpea (Tofel *et al.,* 2017) and pearl millet (Bagul *et al.,* 2023) from storage insect pests. However, little information exists on the effectiveness of the powders and leaf extracts of these medicinal plants that are proliferating in the Beninese flora in managing *S. oryzae*. Therefore, this study aims to evaluate the repellence and insecticidal properties of powders from the leaves of *O. gratissimum, P. biglobosa, A. indica,* and *O. basilicium* against *S. oryzae*.

Materials and Methods

Rearing of *S. oryzae*

The rearing of *S. oryzae* was carried out on in boxes containing healthy pearl millet seeds bought in the Dassa-Zoumé market. Strains of *S. oryzae* were collected in the rearing maintained at the Laboratory of Applied Zoology and Plant Health (ZASVE) of the National High School of Applied Biosciences and Biotechnologies (ENSBBA). Fifty pairs of newly emerged *S. oryzae* (24 h old) were placed in plastic boxes (340 x 200 x 70 mm) containing a mixture of pearl millet varieties previously sterilized in an oven at 30°C for 24 hin order to kill hidden insects and eggs. The boxes were placed on shelves at room temperature in the laboratory and covered with muslin cloth to allow ventilation. The adult insects were removed after 7 days of laying and the boxes were kept for the offspring to emerge. The experiments were conducted with the offspring of the second generation.

Plant Materials

The leaves of O. *gratissimum, P. biglobosa, A. indica,* and *O. basilicium* were collected in the town of Parakou in the north of Benin, and pearl millet seeds were collected in the local markets. The identification of plant species was made by the national herbarium of the University of Abomey-Calavi. The leaves were thoroughly cleaned and dried at room temperature in the laboratory. After two weeks of drying, the leaves were ground into powder using an electrical grinder. The powders obtained were kept in plastic boxes coated with aluminium paper.

Preparation of extracts from plants

The extractions were made in accordance with the method described by Mansoor-ul-Hasan *et al.,* (2014). For that, 50 g of leaf powder from each plant was mixed with 100 ml of ethanol. The mixture was then stirred for 30 min on a magnetic stirrer (at 6000 revolutions per minute) and left to stand for 24 h (Shah *et al.,* 2008). The extracts were filtered using Whatman filter paper to remove particles. After filtration, the ethanol extracts were left to evaporate at room temperature in the laboratory for 48 hin an oven (Hamouda *et al.,* 2014). The extracts were stored at 4°C until further use. The stock solution of each plant extract was diluted with ethanol to obtain different solution concentrations.

Bioactivity of leaf powders on *S. oryzae*

Repellence bioassays

The repellent effect of leaf powders of *O. gratissimum, P. biglobosa, A. indica,* and *O. basilicium* was carried out on a circular flat-bottomed plastic tray (26 cm in diameter by 3 cm in height) in the laboratory (Ogendo *et al.,* 2004). The base of the tray divided into nine equal parts was delimited in the center by a circle with a radius of 3 cm. Each leaf powder was evaluated at four different concentrations (2, 5, 7, and 10% w/w) with the commercial insecticide Bextoxin (aluminium phosphide 570 g/l) as a positive control. Untreated millet was used as a negative control. Ten grams of healthy pearl millet mixed with each concentration of each powder was placed in each compartment of the tray, equidistant from the center. For each treatment, 20 adults of *S. oryzae* (3-7 days old) starved for 1 h were released into the center of the tray, which was immediately covered with a transparent muslin fabric, to prevent insects from escaping outside (Isah *et al.,* 2009). The treatments were repeated 4 times for each concentration. The total number of insects found on untreated millet (P) and on treated millet grains (G) was recorded after 1 h, 12 h, and 24 h of exposure. The percentage of repulsion (PR) was calculated using the formula of McDonald *et al.,* (1970):

$$PR = [(N_C - Nt) / (N_C + Nt)] \times 100 \quad \dots (1)$$

Where N_C = number of insects present in untreated millet grains; Nt = number of insects present in treated millet grains.

The average repellence value of each extract was calculated and assigned to repellency classes from 0 to V: class 0 (PR ≤ 0.1%). class I (PR = 0.1 - 20%). class II (PR = 20.1 - 40% Class III (40.1 - 60%). class IV (60.1 - 80%) and class V (80.1 - 100%).

The repulsion index (RI) was calculated using the formula:

$$IR = 2\,G / G + P$$

Where G = percentage of insects attracted by the treatment and P = percentage of insects attracted by the control.

The values of the repulsion index (RI) are comprised between 0 and 2 (Gusmão *et al.,* 2013). According to Padín *et al.,* (2013). IR = 1 indicates a similar repulsion between the treatment and the control (neutral treatment). IR>1 indicates a lower repulsion of the treatment compared to the control (attractive treatment) and IR <1 corresponds to a greater repulsion of the treatment compared to the control (repellent treatment).

Contact toxicity

The experiment was carried out according to the methodology described by Chebet *et al.,* (2013). The powders of the leaves of the different plants were mixed with 100 g of disinfected pearl millet seeds in plastic boxes (10 cm high and 13 cm in diameter) at respective rates of 0, 2, 4, 6, 8, and 10 (% w/w). Pearl millet was impregnated with the insecticide deltamethrine, which was used as a positive control. Ten pairs of adult insects (3 to 7 days old) were introduced into treated and untreated millet grains. Each box was lined with muslin cloth to prevent insects from escaping. A completely randomized block experimental design with four repetitions was used. Adult mortality was taken at 1, 3, 5, 7, 14 and 21 days after exposure (Othira *et al.,* 2009). The percentage of adult mortality was calculated according to the formula of Asawalam *et al.,* (2006) and corrected with the Abbott's formula (Abbott, 1925). The percentage of dead insects was determined using the following formula:

$$\text{Mortality percentage} = \frac{\text{number of } S.oryzae \text{ dead}}{\text{Number of } S.oryzae \text{ introduced}} \times 100 \quad \dots (2)$$

$$\text{Corrected mortality} = \frac{(\%\, mortality\ in\ T - \%\, mortality\ in\ C)}{(100 - \%\, mortality\ in\ C)} \times 100 \quad \dots (3)$$

Where T = treated millet and C = untreated millet

Bioactivity plant extracts on *S. oryzae*

Repellence bioassays

The repellent effect of the extracts was tested according to the method described by Hamouda *et al.,* (2014). Using a micropipette, 200 µL of each concentration of plant extract was applied separately and uniformly to a first half of filter paper (Whatman No. 40. 9 cm in diameter). The second half of the filter paper, which constitutes the control, was treated with different solvents (acetone, propanol, methanol, ethanol, and distilled water) at the same concentration (200 µL).

Both halves (the treated and the controls) were exposed to ambient air for possible evaporation for 10 min. The two treated half-papers were then be glued together using adhesive tape and placed inside a 9 cm diameter petri dish.

Twenty adult insects were released into the center of each filter paper disk. The treatment was repeated 4 times with each concentration. The insects that have settled on each half of the filter paper disc were counted after 15 min, 30 min, and 2 h. The counted mean was converted to percentage repulsion (PR) using the formula of McDonald *et al.,* (1970) as the equation (1).

Topical bioassays

The thorax of 10 *S. oryzae* adults was treated with 1 µL of each preparation using a micropipette. The treated insects were put in transparent boxes (8 cm in diameter at the base and 5 cm in height) which had previously been filled with 10 g of healthy pearl millet. Simple distilled water was used as a control.

Each treatment was repeated 4 times and placed under laboratory conditions in completely randomized blocks. The mortality rate was recorded 2, 7, 14 and 21 days after treatment (Aryani and Auamcharoen, 2016). The percentage mortality of *S. oryzae* was calculated according Equations (2) and (3).

Fumigation toxicity

The fumigant toxicity of the five solvent extracts from the leaves of O. *gratissimum, P. biglobosa, A. indica,* and *O. basilicium* was tested following the method described by Nattudurai *et al.,* (2015). An aliquot of 0, 5, 10, 20 and 40 µL of each solvent extract was applied to a strip of Whatman No.1 filter paper (2 cm in diameter) corresponding to doses of 0 (as a control), 20, 40, 80 and 160 µL/L air.

Each strip of treated paper was fixed inside the vice cap of a glass bottle (15 cm in height and 4.5 cm in diameter) containing 10 g of healthy millet. After 10 adult insects are released into the glass bottles, the bottles were closed. The treatments were repeated 4 times and placed in the laboratory conditions in completely randomized blocks. After 24 h of treatment, dead insects (immobility of antennae and legs) were recorded. The mortality rate of *S. oryzae* was calculated according Equation (2) and (3). The toxicity ratio (TR) was calculated using the formula used by Gusmão *et al.,* (2013).

$$\text{Toxicity ratio(TR)} = \frac{\text{LC50 of the extract with lowest toxicity}}{\text{LC50 of other individual extracts}}$$

Results and Discussion

Repellent effect of leaf powders

The insecticide and all plant powders showed a repellent effect against *S. oryzae* (Table 1). The repulsion of adult *S. oryzae* insects was significant after 1 h ($F=2.824$, $df= 19$, $P < 0.001$), 12 h ($F=3.760$, $df= 19$, $P < 0.000$) and 24 h ($F=5.630$, $df =9$, $P < 0.05$) of exposure at the level of all plants (Table 1).The average percentage of repulsion reached 79.24% at a dose of 2% of *P. bligobosa* powder after 24 h of exposure.

The average repellency rate showed that the powders of the four plants had repellence classes ranges from I to IV. Bextoxin presented a repellency class varying from I to II. The statistical analysis of the repulsion of *S. oryzae* by the different plants revealed that *P. biglobosa, A. indica,* and *O. basilicium* at 2g, 5g and 10g respectively, and *O. gratissimum* at 2g and 5g presented a repulsion of class IV.

Insecticidal effect of leaf powders

The contact toxicity of leaf powders of *O. gratissimum, P. biglobosa, A. indica,* and *O. basilicium*on *S. oryzae* adults varied in function of the dosage, and the exposure time (Table 2). Deltamethrin was more effective during all periods and caused up to 100% mortality from the first day of treatment. The effects of the four powders tested were significantly different from those of deltamethrin after 1 day ($F = 4.162$; $df = 35$; $P = 0.000$), 3 days ($F = 3.964$; $df = 35$; $P = 0.000$), 5 days ($F = (5.404$; $df = 15$; $P = 0.028$), 7 days ($F = 5.621$; $df = 35$; $P = 0.000$), 14 days ($F = 4.256$; $df = 35$; $P = 0.000$), and 21 days ($F = 3.782$; $df = 35$; $P = 0.000$). After 1 day of exposure, a dose of 10% (w/w) of *A. indica* powders results in the highest mortality rate (26.47%). Even though not all the plants tested achieved total mortality of *S. oryzae* compared to the insecticide, the *O. gratissimum* powder at 2% was more effective, resulting in a mortality rate of 70% (Table 2). After 21 days of treatment, the lowest mortality rates were recorded with *O. basilicium* powders at 6% (w/w).

Repellent effect of plant extracts

The repulsion tests performed with different plant extracts resulted in different repulsion rates depending on the time of exposure (Table 3). The repellent activity of the different plants tested was not significant between the treatments after 15 min (F = 1.435, df = 20, P = 0.140) and 2 h of treatment (F = 1.577, df = 20, P = 0.088). However, the repellent effect of plant extracts was significant after 30 min of exposure (F = 2.168, df = 20, P = 0.011). The ethanol extract of *O. gratissimum* at 5% was not effective in repelling *S. oryzae* (Table 3).

Contact toxicity of plant extracts

The results showed that plant extracts after 2 days (F = 3.040, df = 20, P = 0.000) of *O. basilicium* at 5% and *P. bligobosa* extract at 7.5% caused the highest mortality rates. After 7 days of treatment, the ethanol extract of *O. gratissimum* at 2.5% caused significantly (F = 2.674, df = 20, P = 0.002) the highest mortality rate (100%) followed by *O. basilicium* extract at 5% and 7.5%. The same trend was observed after 14 days (F = 2.500, df = 20, P = 0.003) and 21 days (F = 2.172, df = 20, P = 0.010) of treatment. In fact, from the first to the 21st day of treatment, the lowest mortality rates were recorded with the ethanol extracts of *A. indica* at 2.5% (42.50% mortality) and 5% (42.50% mortality) of treatment.

Fumigant toxicity of plant extracts

The fumigant effect of plant extracts was significantly different from one treatment to another (df = 20, F = 5.332and P = 0.000). After 24 h of exposure, the ethanol extract of *O. gratissimum* at 7.5% and 2.5% caused the highest mortality rate (92.5% and 73.12% mortality for a maximum concentration of 160 µL / L of air). While the lowest mortality rates were recorded with ethanol extracts of *P. biglobosa* at 2.5% for a minimum concentration of 20 µL/L of air. The use of plants in the fight against crop pests constitutes an alternative method to the use of the most widespread chemical insecticides against insect pests that attack stored food products. Our study based on the different results obtained showed that the powders and ethanol extracts of four tested plants have a repellent and toxic effect on *S. oryzae*. These observed repellent effects could be due on the one hand to the volatile chemical compound contained in the different plants (Isman, 2002). It is also known that the exposure period is the most important factor influencing the repellent effect (Kłyś *et al.,* 2017). Plant powders have the ability to act as vapour on olfactory receptors (Chebet *et al.,* 2013). The fact that leaf powders of *A. indica* and *O. gratissimum* have caused high mortality of *S. oryzae* is not surprising because many authors have already pointed out the strong insecticidal effect of these plants on various storage insect pests (Kéita *et al.,* 2001; Tofel *et al.,* 2017; Toudert-Taleb *et al.,* 2021; Bagul *et al.,* 2023; Tofel *et al.,* 2024). The crude powder (2.0–4.4% w/w) of *O. gratissimum* and *A. indica* could cause significant mortality (more than 60%) of *C. maculatus* and *S. zeamais* adults (Iloba and Ekrakene, 2006). Leaf powder of these local plants can be used as biopesticides against the rice weevil in the stored pearl millet.

The results of the topical application of ethanol extracts of *O. gratissimum, P. biglobosa, A. indica,* and *O. basilicium* showed a strong insecticidal effect against *S. oryzae*. However, the low contact toxicity of *A. indica* against *S. oryzae* is not overwhelming.

Indeed, neem extract has only a weak or no contact toxicity effect when applied topically because within the insect body, azadirachtin is rapidly excreted and the remaining amount is mainly critical for insect development (Akol *et al.,* 2002).

The high insecticide potential by contact of *O. gratissimum* extract on *S. oryzae* could be explained by its high content in thymol, which exhibits strong contact and fumigant toxicity against this pest (Remesh *et al.,* 2022). This explains why after 24 h of exposure, the ethanolic extract of *O. gratissimum* caused the highest mortality rate. It would therefore be interesting to formulate a biopesticide or to find a form of use of this plant that maximizes these effects for efficient use by smallholder pearl millet producers.

This study revealed the repellent and insecticidal effects of leaf extracts from four local plants against *S. oryza*e, the pest infesting pearl millet. The repellent and insecticidal properties of *O. gratissimum* are promising and could be used as a foundation for a biopesticides that is accessible to smallholder pearl millet producers.

Table.1 Repellency percentage (mean ± SE) and the repellency classes of the different powders of *P. bligobosa, O. basilicium, O. gratissimum*, and *A. indica on S. oryzae* adults in function of time and different concentrations.

Treatment	Concentration (% w/w)	% repulsion at different time intervals			Average repulsion	Repulsion class	Repulsion index	Classification
		1h	12h	24h				
Bextoxin	2	60 ± 43.75ab	31.50 ± 5.10ab	18.63 ± 8.87b	36.71 ± 12.22ab	II	0.66 ± 0.03	Repellent
	5	48.47 ± 10.69ab	19.37 ± 12.12ab	43.05 ± 18.71ab	36.96 ± 8.93ab	II	0.63 ± 0.08	Repellent
	7	16.51 ± 24.09c	1.58 ± 5.58b	30.48 ± 8.00ab	15.13 ± 9.28b	I	0.84 ± 0.08	Repellent
	10	26.21 ± 8.70bc	20.00 ± 11.38ab	15.09 ± 13.06b	20.43 ± 3.21b	II	0.79 ± 0.06	Repellent
P. bligobosa	2	77.36 ± 64.11a	62.40 ± 14.02a	62.09 ± 13.70a	67.28 ± 5.03a	IV	0.37 ± 0.06	Repellent
	5	75.56 ± 6.49a	80.11± 7.03a	74.97 ± 5.81a	76.88 ± 1.62a	IV	0.23 ± 0.03	Repellent
	7	57.19 ± 15.06ab	45.80 ± 25.50a	63.00 ± 10.16a	55.33 ± 5.05a	III	0.44 ± 0.09	Repellent
	10	53.83 ± 17.15ab	59.24 ± 8.04a	77.38 ± 5.47a	63.48 ± 7.12a	IV	0.36 ± 0.06	Repellent
A. indica	2	80.77 ± 69.75a	74.71 ± 3.25a	79.24 ± 2.82a	78.24 ± 1.81a	IV	0.25 ± 0.03	Repellent
	5	77.80 ± 6.28a	70.07 ± 9.80a	69.05 ± 8.50a	72.30 ± 2.76a	IV	0.27 ± 0.04	Repellent
	7	47.09 ± 16.76ab	50.43 ± 13.41a	68.86 ± 9.91a	55.46 ± 6.76a	III	0.44 ± 0.07	Repellent
	10	77.70 ± 1.90a	70.69 ± 13.83a	78.36 ± 6.10a	75.58 ± 2.45a	IV	0.24 ± 0.04	Repellent
O. basilicium	2	94.44 ± 79.13a	69.42 ± 7.25a	75.17 ± 12.05a	79.67 ± 7.56a	IV	0.25 ± 0.04	Repellent
	5	73.57 ± 10.26a	64.55 ± 9.35a	57.38 ± 11.98a	65.16 ± 4.68a	IV	0.34 ± 0.05	Repellent
	7	62.75 ± 12.14a	39.61 ± 16.90ab	64.16 ± 12.27a	55.50 ± 7.95a	III	0.44 ± 0.08	Repellent
	10	68.25 ± 11.38a	50.33 ± 14.91a	78.57 ± 8.13a	65.71 ± 8.25a	IV	0.34 ± 0.07	Repellent
O. gratissimum	2	88.24 ± 72.03a	70.98 ± 5.71a	74.66 ± 12.21a	77.96 ± 5.24a	IV	0.27 ± 0.04	Repellent
	5	79.78 ± 3.59a	49.73 ± 16.06a	63.99 ± 6.39a	64.50 ± 8.67a	IV	0.35 ± 0.06	Repellent
	7	72.05 ± 17.83a	45.78 ± 12.02a	53.84 ± 17.22a	57.22 ± 7.76a	III	0.42 ± 0.08	Repellent
	10	59.32 ± 11.97ab	48.79 ± 10.62a	42.45 ± 15.50ab	50.18 ± 4.91a	III	0.49 ± 0.07	Repellent

Table.2 Mortality rate of *S. oryzae* adults and weight lost (mean ± SE) of millet treated with different concentrations of leaf powders of the seven plants after 21 days of observation.

Treatments	Concentration (%w/w)	Corrected mortality rate after different periods of exposure (days)					
		1	3	5	7	14	21
Deltamethrine	0.05	100 ± 0.00a	100 ± 0.00a	100 ± 0.00a	100 ± 0.00a	100 ± 0.00a	100 ± 0.00a
A. indica	2	1.26 ± 1.46c	7.79 ± 4.91c	15.78 ± 5.68cd	18.05 ± 6.15bc	16.17 ± 5.02	17.64 ± 5.36c
	4	1.26 ± 1.46c	24.67 ± 10.05bc	42.10 ± 15.04b	50.00 ± 14.87b	55.88 ± 14.70bc	63.23 ± 14.68b
	6	1.26 ± 1.46c	31.16 ± 4.43b	51.31 ± 4.49b	55.55 ± 7.17b	55.88 ± 5.63bc	57.35 ± 6.94b
	8	1.26 ± 1.46c	20.77 ± 9.57bc	40.78 ± 12.22b	47.22 ± 11.67b	48.52 ± 12.56bc	51.47 ± 12.33b
	10	1.26 ± 1.46c	24.67 ± 6.18b	52.63 ± 12.34b	56.94 ± 12.29b	54.41 ± 13.01bc	54.41 ± 13.01b
O. gratissimum	2	8.86 ± 5.46bc	14.28 ± 2.59	23.68 ± 4.55c	22.22 ± 5.07bc	30.88 ± 6.52c	32.35 ± 5.09bc
	4	10.12 ± 2.42bc	19.48 ± 6.18bc	25 ± 4.49c	26.38 ± 6.15bc	26.47 ± 7.00bc	30.88 ± 7.73bc
	6	2.53 ± 2.42c	7.79 ± 5.35c	17.10 ± 9.21cd	18.05 ± 10.72bc	13.23 ± 11.35cd	16.17 ± 11.61cd
	8	10.12 ± 4.32bc	15.58 ± 6.83c	26.31 ± 9.11c	25 ± 10.51bc	23.52 ± 12.00c	26.47 ± 10.87bc
	10	26.47 ± 10.87b	3.79± 2.06c	5.19 ± 1.29d	17.10 ± 6.21bc	26.38 ± 10.48c	36.76 ± 14.07bc
P. bligobosa	2	6.32± 3.26bc	38.96 ± 4.43b	64.47 ± 10.82b	69.44 ± 10.75b	70.58 ± 12.93b	70.58 ± 12.93b
	4	1.26 ± 2.07c	19.48 ± 5.40bc	28.94 ± 4.55c	33.33 ± 3.92bc	32.35 ± 3.79c	38.23 ± 5.09bc
	6	2.53 ±1.26c	32.46 ± 6.70b	44.73 ± 9.72b	48.61 ± 6.56b	48.52 ± 7.73bc	54.41 ± 9.71b
	8	1.26 ± 2.53c	23.37 ± 5.35b	35.52 ± 7.85bc	36.11 ± 7.34b	36.76 ± 8.09c	42.64 ± 9.10b
	10	0.39 ±1.26c	12.98 ± 4.43bc	22.36 ± 4.49c	26.38 ± 4.74bc	27.94 ± 6.06bc	27.94 ± 6.06bc
O. basilicium	2	3.79 ±2.92c	7.79 ± 4.91c	10.52 ± 3.72cd	6.94 ± 4.16c	5.88 ± 5.36d	8.82± 3.79d
	4	3.79 ± 2.92c	11.68 ± 6.36bc	15.78 ± 5.68cd	12.5 ± 6.15c	13.23 ± 9.71cd	13.23 ± 9.71cd
	6	1.26 ± 2.07c	1.29 ± 1.49c	2.63 ± 3.39d	1.26 ± 1.46c	1.47± 1.46d	1.56 ± 5.88d
	8	1.26 ± 1.46c	5.19 ± 2.48c	13.15 ± 3.39cd	12.5 ± 3.49bc	10.29 ± 4.41cd	11.76 ± 5.36cd
	10	1.26 ± 1.46c	7.79 ± 2.48c	7.89 ± 3.39d	4.16 ± 2.65c	4.41 ± 2.81d	8.82 ± 3.79d

Table.3 Repulsion rate of the different extracts from the leaves of *O. gratissimum. P. biglobosa, A. indica*, and *O. basilicium* towards *S. oryzae* after different periods of exposure

Plants	Concentration of extracts (%)	Percentage of repulsion after treatments			Average repulsion	Repulsion class	Repulsion index	Classification
		15 min	30 min	2h				
P. biglobosa	2.5	15.01 ± 27.53ab	20.00 ± 29.44a	5.00 ± 17.08b	13.33 ± 4.41ab	IV	0.86 ± 0.13	Repellent
	5	10.00 ± 26.45ab	80.00 ± 11.55b	45.00 ± 12.58b	45.00 ± 20.21a	V	0.55 ± 0.12	Repellent
	7.5	25.00 ± 15.00ab	29.62 ± 17.25ab	30.00 ± 10.00b	28.21 ± 1.61ab	III	0.72 ± 0.14	Repellent
O. basilicium	2.5	0.00 ± 17.32a	15.00 ± 15.00c	10.00 ± 5.77c	5.00 ± 7.64	I	0.95 ± 0.07	Repellent
	5	0.00 ± 25.82a	40.00 ± 8.16b	30.00 ± 10.00b	23.33 ± 12.02ab	III	0.76 ± 0.10	Repellent
	7.5	15.00 ± 20.62a	25.00 ± 18.93c	00.00 ± 11.55d	6.67 ± 13.64b	I	0.93 ± 0.10	Repellent
O. gratissimum	2.5	40.00 ± 14.14b	0.00 ± 38.62e	52.50 ± 13.77e	29.17 ± 17.46ab	I	0.96 ± 0.15	Repellent
	5	0.00 ± 22.17a	0.00 ± 5.00d	42.50 ± 8.54b	6.83 ± 25.67b	I	0.93 ± 0.13	Repellent
	7.5	5.00 ± 17.08ab	0.00 ± 8.16c	40.00 ± 7.07b	15.00 ± 12.58ab	I	0.88 ± 0.08	Repellent
A. indica	2.5	0.00 ± 30.95a	60.00 ± 11.55ab	20.00 ± 32.66b	25.00 ± 18.93ab	II	0.75 ± 0.16	Repellent
	5	45.00 ± 20.61b	60.00 ± 8.16ab	60.00 ± 14.14a	55.00 ± 5.00a	III	0.62 ± 0.11	Repellent
	7.5	40.00 ± 8.16b	35.00 ± 18.93ab	10.00 ± 10.00b	28.33 ± 9.28ab	II	0.71 ± 0.07	Repellent

Table.4 Mortality rate of *S. oryzae* after topical application with ethanol extracts of *O. gratissimum. P. biglobosa, A. indica,* and *O. basilicium* leaves and weight losses (mean ± SE) of millet 21 days after treatment. Mortality rate corrected by the Abbott' formula (4).

Plants	Concentration of extract	Mortality rate (%) after different exposure periods			
		2	7	14	21
P.biglobosa	2.5	90.00 ± 4.08a	94.94 ± 2.50 a	94.94 ± 2.50a	97.50 ± 2.50a
	5	65.00 ± 20.61ab	79.48 ± 11.84ab	92.30 ± 7.69a	92.50 ± 7.50a
	7.5	95.00 ± 2.88a	94.87 ± 2.96a	94.87 ± 2.96a	95.00 ± 2.88a
O. basilicium	2.5	90.00 ± 7.07a	97.43 ± 2.56a	97.43 ± 2.56a	100.00 ± 0.00a
	5	95.00 ± 5.00a	97.43 ± 2.56a	97.43 ± 2.56a	97.50 ± 2.50a
	7.5	77.50 ± 16.52ab	84.61 ± 15.38a	84.61 ± 15.38a	85.00 ± 15.00a
A. senegalensis	2.5	32.50 ± 17.96ab	53.84 ± 13.56ab	53.84 ± 13.56a	60.00 ± 14.14a
	5	32.50 ± 16.00ab	46.15 ± 14.12ab	58.97 ± 9.36a	62.50 ± 7.50a
	7.5	17.50 ± 14.36b	38.46 ± 25.12ab	48.71 ± 19.63a	57.50 ± 16.52a
O. gratissimum	2.5	92.50 ± 4.78a	100.00 ± 0.00a	100.00 ± 0.00a	100.00 ± 0.00a
	5	90.00 ± 4.08a	92.30 ± 4.90a	92.30 ± 4.90a	95.00 ± 5.00a
	7.5	55.00 ± 8.66ab	55.00 ± 8.66ab	82.05 ± 14.72a	82.50 ± 14.36a

Table.5 Percentage of mortality of *S. oryzae* adults after 24 hours of treatment with ethanol extracts of *O. gratissimum, P. biglobosa, A. indica,* and *O. basilicium,* Mortality corrected by the Abbott' formula.

Plants	Concentration of extract (%)	Mortality rate after 24h (%) /concentration (µL /L d'air)			
		5.00	10 .00	20.00	40.00
P. biglobosa	2.5	3.75 ± 7.47b	14.38 ± 18.77ab	42.50 ± 21.75b	8.75 ± 5.91b
	5	4.38 ± 5.63b	1.13 ± 5.15c	3.75 ± 7.47a	3.75 ± 1.14b
	7.5	0.00 ± 9.21b	0.00 ± 0.00c	3.75 ± 9.86a	2.50 ± 2.50b
A. indica	2.5	0.00 ± 8.26b	24.38 ± 13.78ab	34.38 ± 2.58b	15.00 ± 6.45ab
	5	13.75 ± 13.75ab	11.25 ± 12.97ab	3.75 ± 9.87a	17.50 ± 11.81ab
	7.5	18.13 ± 4.49ab	11.25 ± 12.31ab	3.75 ± 10.68a	45.00 ± 16.58a
O. gratissimum	2.5	36.88 ± 6.24a	36.88 ± 2.37ab	43.13 ± 11.96b	66.88 ± 10.87a
	5	46.88 ± 3.13a	63.13 ± 2.37a	50.63 ± 6.16b	92.50 ± 7.50a
	7.5	15.63 ± 4.83b	6.25 ± 6.25a	23.75 ± 24.10b	73.13 ± 7.17a
O. basilicium	2.5	6.88 ± 6.88ab	10.63 ± 4.13a	12.50 ± 4.79b	1.25 ± 8.75b
	5	16.88 ± 10.87ab	30.63 ± 10.43ab	26.88 ± 13.75b	23.75 ± 2.39ab
	7.5	27.50 ± 11.09ab	13.75 ± 13.75a	20.63 ± 3.59b	25.63 ± 12.5ab

Author Contributions

Tayé Obédatou Alagbe: Investigation, formal analysis, writing—original draft. Yeyinou Laura Estelle Loko: Validation, methodology, writing—reviewing.

Data Availability

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

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors declare no competing interests.

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How to cite this article:

Tayé Obédatou Alagbe and Yeyinou Laura Estelle Loko. 2024. Insecticidal and Repellent Effects of Some Local Plants Against the Rice Weevil (*Sitophilus oryzae* L.) Infesting Pearl Millet Stored in Northern Benin. *Int.J.Curr.Microbiol.App.Sci.* 13(11): 118-128. **doi:** https://doi.org/10.20546/ijcmas.2024.1311.014