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Prospects of botanical pesticides in management of Iroko gall bug, *Phytolyma fusca* (Hemiptera, Psylloidea) under laboratory and field conditions

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Abstract

Background: Iroko gall bug, *Phytolyma fusca* Walker, is a major insect pest of *Milicia excelsa* (Iroko) seedling hampering its propagation in West Africa. *Milicia excelsa* is an indigenous forest timber tree in the tropical rain forest of West Africa with a very high value in international trade due to its wood quality. Sustainable management of *P. fusca* infestations on Iroko seedlings have not been achieved due to their cryptic nature and multivoltine generations. This study evaluated the residual and contact effects of crude ethanol and aqueous extracts of four plants (*Azadirachta indica*, *Jatropha curcas*, *Piper guineense*, and *Aframomum melegueta*) on adult *P. fusca* in the laboratory and field.

Results: All the extracts had residual effects and contact effects on adult insects in the laboratory at 75% and 100% concentrations of applications. *Azadirachta indica*, *P. guineense*, and *A. melegueta* gave 80–100% adult mortality at both concentrations in the laboratory; their efficacies were comparable to cypermethrin. The ethanol extracts of *P. guineense* and *A. indica* were more effective than other extracts in protecting the seedlings against *Phytolyma* infestations in the field. They significantly ($p < 0.01$) reduced infestation compared to other extracts and control. Ethanol extracts of the tested plant materials were more effective than their aqueous extracts both in the laboratory and field.

Conclusion: The results proved that *P. guineense* and *A. indica* extracts were very potent and promising in protecting *Milicia excelsa* seedlings against *Phytolyma fusca* infestations and they can be used in the early management of *Phytolyma* infestations in the field.

Keywords: Biopesticides, Toxicity, *Milicia excelsa*, *Phytolyma fusca*, Insect pest, Control

Background

Phytolyma species Psyllidae is a key insect pest of Iroko plant (*Milicia excelsa*) seedlings in sub Saharan Africa hampering the cultivation of *Milicia excelsa* in plantations in the region (Ugwu & Omoloye, 2014a). Recent report by Ugwu, Ombura, Salifu, and Khamis (2019) using morphometric and molecular characterization has confirmed the species found in Nigeria to be *Phytolyma fusca* (Walker). *Phytolyma fusca* attack the *Milicia* seedlings by the adult psyllid laying eggs on the young leaves and the buds which later results in gall formation on the young shoots and buds when the eggs are hatched (Ofori & Cobbinah, 2007; Ugwu, Omoloye, 2014a). The gall formation is initiated as soon as the eggs are hatched into first instar nymphs, as they puncture the young shoot or leaf to feed. Galls usually enlarge to enclose nymphs until they become turgid to split and release the adult flies which later results to dieback of leaves down to the stems (Ugwu and Omoloye, 2014). Repeated attacks on young *Millicia* seedlings disrupt the growth processes resulting to growth retardation

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and in most cases lead to total death or dieback of the seedlings (Cobbinah, 1993; Ofori et al., 2007; Ugwu & Omoloye, 2013; Wagner, Atuahene, & Cobbinah, 1991). Sustainable management of this pest for the past years has not recorded appreciable success due to the cryptic nature of the pest and its multiple generations. However, a promising result of 80–100% seedling survival after 2 years in the field using barrier nets in combination with carbofuran and diamethoate has been reported Ugwu & Omoloye, 2014b). This approach may not be sustainable for a long period especially on a large-scale basis and are not fully ecologically friendly. Use of botanical pesticides in pest control has recently gained tremendous interest due to problems associated with the use of synthetic pesticides. The pesticides residues on the crops and persistence in the environment as well as their toxicity to the non-target organisms has necessitated the need for the search for effective bio-pesticide that are biodegradable with higher selectivity and suitable for use in integrated management programs (Guleria & Tiku, 2009). Several plants have been screened for their insecticidal properties against many insects pests both in the field and in storage. Notable success has been recorded using various plants with bioactive compounds to manage human diseases as well as pests and diseases of various agricultural crops (Karpagam & Devaraj, 2011; Thiruppathi, Ramasubramanian, Sivakumar, & Thirumalaiarasu, 2010). Many botanical pesticides from different plant sources like pyrethrum, neem, sabadilla, tobacco, and ryania has been successfully isolated and commercialized (Arnason et al., 2012). Botanical pesticides shows different modes of action on the target pests like toxicity effect, growth disruption, and repellence as well as physical alteration thus offer the appropriate crop pest management alternatives (Kushram, Yadu, Sahu, Kulmitra, & Kumar, 2017; Rattan, 2010). Neem, *Azadirachta indica* A. Juss., a sub-tropical tree native to the arid areas of Asia and Africa is a very good source of numerous insecticidal alkaloids (Saha, Islam, & Khan, 2006). It has great potential in the management of several field pests of agricultural crops, medicine, and environmental protection. *Piper guineese* is also very potent botanical insecticides against many pests and diseases of agricultural importance and have been found very effective even in their crude forms (Abiala, Ayandeko, & Odebode, 2015; Ajayi & Olufolaji, 2008; Ugwu, 2020). Similarly, *Jatropha curcas* and *Aframomum melegueta* have been used in the management of many agricultural pests and diseases (Sabbour and Abd-El-Raheem (2013). Ugwu, Umeh, Ojo, Aderemi, & Shaib-Rahim, 2015; Ugwu, Umeh, & Omoloye, 2017; Ugwu, 2020). Thus, this study investigated the efficacy of crude and aqueous extracts of four plants: *Azadirachta indica*, A. Juss *Jatropha curcas* L., *Piper guineense* Schumach. & Thonn and *Aframomum melegueta*, K. Schum against *P. fusca* under laboratory and field conditions.

Methods

Study sites

The experiment was conducted at Biology Laboratory of the Federal College of Forestry (FCF) and at the experimental field of the institution during the rainy season of 2019. The Federal College of Forestry Ibadan is located at latitude 7° and 9° N longitude 3° and 58° E of Greenwich Meridian Time (GMT) with annual rainfall of 1300 to 1500 mm and relative humidity of a 80 to 85% average (FRIN, 2017).

Collection of *Milicia excelsa* seeds and raising of seedlings

M. excelsa fruits were collected from the mother plant at the Department of Forest Resources Management, University of Ibadan. The fruits were soaked for 24 h and the seeds were extracted by macerating the pulp gently and later sieved with fine mesh to separate the seeds from the chaff. The extracted seed were air-dried for 2 weeks and then sown in a nursery tray and placed inside a germinating chamber in a screen house. They were attended to following the standard nursery activities for raising seedlings. The seedlings were later transplanted into 2-L nursery bags at 4 weeks after germination.

Sources of the plant materials and extraction

Mature fruits of *Azadirachta indica*, and *Jatropha curcas*, were collected from the mother plants at Forestry Research Institute of Nigeria, Ibadan, while *Piper guineense* and *Aframomum melegueta* seeds were purchased from a local market in Ibadan. The seeds of *A. indica* and *J. curcas* were extracted manually from the fruits and were air-dried on side benches in the laboratory for 2 weeks. The dried seeds were pulverized into powered form using an electric blender (Binatone blender/grinder BLG.450).

Aqueous extracts were prepared by soaking 100 g/200 ml of warm water (60 °C) of the powdered samples of plant materials in separate bottles. The mixtures were vortexed at intervals of 30 min manually for 2 h and then allowed to stay for 48 h at room temperature before sieving with muslin cloth to obtain the extracts (Ugwu and Nwaokolo 2020). Ethanol extraction was done by weighing the 100 g of pulverized samples into Soxhlet extractor and Soxhlet extracted separately using 250 ml of ethanol for minimum of 8 h according to the methods by Ofuya, Okoye, and Olola (1992). Seventy-five percent concentration was prepared for each extracts from the stock solution for the laboratory assay and field application.

Sources of adult *Phytolyma fusca*

Matured galls were collected from *Milicia excelsa* at Forestry Research Institute of Nigeria (FRIN) arboretum, and the galls were dissected in the laboratory to remove the adults of *Phytolyma fusca* for laboratory bioassay.

Laboratory bioassay of the extracts for residual and contact effects on adult *P. fusca*

The extracts were evaluated for residual actions by applying 1 ml of each extract at 75% and 100% w/v concentrations on petri dishes lined with filter paper. Petri dishes were left to drain off for 5 min before five newly emerged adult were introduced into each dish. For contact toxicity test, 0.1 ml of each extract was applied to the abdomen of the insects separately and each treatment was replicated 3 times in a completely randomized design (CRD) Fig. 1. The mortality was recorded at 20-min intervals for 24 h.

Field assay of the extracts

Four-month-old *Milicia excelsa* seedlings were removed from the screen house and sprayed with 75% concentration of ethanol and aqueous extracts at 100% concentration. The sprayed seedlings were exposed to the field for 2 months and monitored for gall formation. Spraying was done at 2-week intervals in completely randomized block design (CRBD) experiment (Fig. 2).

Data collection and analysis

Data on the mortality of adult *P. fusca* were collected at 20-min intervals for both residual and contact toxicity for the bioassay study in the laboratory for 24 h and the number of galls was recorded in the field experiment. Data collected were subjected to square root transformation before analysis of variance (ANOVA) and significant means were separated by Duncan multiple range test at 5% level of significance using ASSISTAT statistical software 7.6 beta.

Results

Residual and contact effects of ethanol extracts on the mortality of adult *P. fusca* at 75% concentration

The residual and contact effects of ethanol extracts at 75% concentration are presented in Table 1.

Ethanol extracts of all the plants evaluated had residual and contact effects on *P. fusca* at 20 min post exposure. Cypermethrin recorded the highest mortality with mean value of 2.33 at 20 min. On the contact assay, *P. guineense* and *A. indica* recorded the highest mortality of *P. fusca* among the extracts with each mean value of 5.00. There were significant differences ($p < 0.01$) on the effect of the treatments from 20 to 40 min of post exposure. *P. guineense* and *A. indica* recorded 100% mortality after 60 min of exposure for the residual effects. All the extracts recorded 100% mortality at 80 min of exposure for the residual assay and at 60 min of exposure for contact assay, while no mortality was recorded on control experiment. The residual and contact effects of *P. guineense* and *A. indica* were comparable to cypermethrin. There were significant differences ($p < 0.01$ and $p < 0.05$) on the effects of the treatments at 20 and 40 min, respectively.

Residual and contact effects of ethanol extracts on the mortality of adult *P. fusca* at 100% concentration

All the extracts had residual effects and contact effect on *P. fusca* at 20 min of post exposure at 100% concentration (Table 2). *P. guineense*, *A. indica*, and cypermethrin gave 100% mortality on *P. fusca* at for residual assay, while *A. indica* recorded highest mortality in contact effects assay at 20 min of post exposure. There were significant differences ($p < 0.01$) on the effect of all the treatments at 20 and 40 min of post treatment. All the extracts recorded 100% mortality at 60 min of exposure in residual assay while control recorded no mortality.

Fig. 1 The experimental layout for laboratory bioassy of the extracts

Fig. 2 The experimental layout of field assay of the extracts on 4-month-old *Milicia excelsa* seedlings

Residual and contact effects of aqueous extracts on the mortality of adult *P. fusca* at 100% concentration

The residual and contact effects of aqueous extracts at 100% concentration were less effective compared with ethanol extracts at the early period of post exposure. Their efficacy increased as the time progressed (Table 3). Only *A. melegueta* recorded *P. fusca* mortality for both residual and contact assays at 20 post treatment, while *A. indica* and *P. guineense* recorded mortality of *P. fusca* for contact assay at same time of exposure. There were significant differences ($p < 0.01$) on the effects of the treatments at 20 min, 80 min, 100 min, and 24 h post treatments.

Efficacy of ethanol extracts at 75% concentration against *P. fusca* infestation on *M. excelsa* in the field

The effects of ethanol extracts at 75% concentration on *P. fusca* infestations on *Milicia excelsa* seedlings in the field are presented in Table 4. *P. guineense* and *A. indica* were the most effective among all the treatments in protecting *M. excelsa* seedlings against *P. fusca* infestation. No gall was observed on *M. excelsa* seedlings treated with ethanol extracts of both plants for the period of 8 weeks post exposure. Infestation was observed in seedlings treated with *A. melegueta* and the control after 2 weeks of exposure and progressed through out the period of study. Ethanol extracts of all the plant screened were more effective than cypermethrin in protecting *M. excelsa* against *P. fusca* infestations. There was no significant difference ($p > 0.05$) on the effects of cypermethrin and control on the infestation of *P. fusca* on *Milicia excelsa* seedlings.

Efficacy of aqueous extracts at 100% concentration against *P. fusca* infestations on *M. excelsa* in the field

Infestation of *P. fusca* commenced 2 weeks post treatment of aqueous extracts and progressed until the end of the experiment (Table 5). Aqueous extracts of *P. guineense* protected the *M. excelsa* seedlings for 4 weeks before the onset of infestation and recorded the least

Table 1 Residual and contact effects of ethanol extracts of four plants on the mortality of adult *P. fusca* at 75% concentration

Treatments	TAT (min)													
	20		40		60		80		100		120		1440	
	R	C	R	C	R	C	R	C	R	C	R	C	R	C
P. guineense	1.33 ^{abc}	5.00^{a}	2.67 ^{a}	0.00^{b}	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A . indica	2.00 ^{to}	5.00^{a}	2.00 ^{to}	0.00b	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
J . carcus	0.33 ^{bc}	3.00^{b}	3.33 ^{a}	1.33 ^{a}	1.00	0.67	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A . melegueta	1.67^{abc}	3.33 ^{b}	1.33 ^{ab}	1.00 ^{to}	1.33	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cypermethrin	2.33 ^{a}	5.00^{a}	1.67 ^{ab}	0.00^{b}	0.67	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Control	0.00c	0.00^{b}	0.00^{b}	0.00^{b}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sig. level	**	**	**	*	Ns	NS	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns

Means with same letters within the same column are not significantly different. *Ns* not significant, *R* residual effects, *C* contact effects
*Significant at 5%
**Significant at 1% by Duncan multiple range test (DMRT)

Table 2 Residual and contact effects of ethanol extracts of four plants on the mortality of adult *P. fusca* at 100% concentration

Treatments	TAT (min)													
	20		40		60		80		100		120		1440	
	R	C	R	C	R	C	R	C	R	C	R	C	R	C
P . Guinean	5.00[a]	4.67 [a]	0.00[b]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A . indicates	5.00[a]	5.00[a]	0.00[b]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
J . carcus	3.67 [ab]	4.33 [b]	1.00 [to]	0.67	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A . melegueta	2.33 [b]	4.67 [a]	2.00[a]	0.33	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cypermethrin	5.00[a]	5.00[b]	0.00[b]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Control	0.00[c]	0.00[b]	0.00[b]	0.00	0.00		0.00		0.00		0.00		0.00	
Sig. level	**	**	**	**Ns**	**Ns**	**Ns**	**Ns**	**Ns**	**Ns**	**Ns**	**Ns**	**Ns**	**Ns**	**Ns**

Means with same letters within the same column are not significantly different. *Ns* not significant, *R* residual effects, *C* contact effects, *TAT* time after treatments
*Significant at 5%
**Significant at 1% by Duncan multiple range test (DMRT)

number of galls at the end of the study. *P. guineense* significantly ($p < 0.01$) reduced *P. fusca* infestation more than other extracts and cypermethrin, while *A. indica* reduced *P. fusca* infestation more than cypermethrin. There were no significant differences on the number of galls recorded on *M. excelsa* seedlings treated with cypermethrin, *J. curcas*, *A. melegueta*, and control.

Percentage mortality of *P. fusca* at 24 h post treatment with different concentrations of ethanol and aqueous extracts in the laboratory

All the ethanol extracts of the screened plants recorded 100% mortality of *P. fusca* in the laboratory for both contact and residual assay at 24 h post treatment (Fig. 3). Their efficacies were comparable to cypermethrin (synthetic insecticide). Aqueous extracts of *P. guineense* and *A. melegueta* were more effective than other extracts for the residual effects compared to contact effects. They both recorded 100% mortality on the residual effects at 24 h post treatment. No mortality was recorded on the control experiment for both residual and contact assays at 24 h post exposure.

Percentage infestation of *P. fusca* on *M. excelsa* seedlings treated with ethanol and aqueous extracts in the field.

The ethanol extracts of *P. guineense* and *A. indica* were the most effective among the extracts in protecting *M. excelsa* seedlings against *P. fusca* infestation in the field (Fig. 4). They both recorded 0% infestation at the end of the experiment. Their aqueous extracts were also effective compared to other extracts, with *P. guineense* (5.13%) infestation being the most effective followed by *A. indica* (13.23%). *A. melegueta* extracts was least effective among the plant extracts tested against *P. fusca* on *M. excelsa* in the field with 23.08 % and 30.61% infestation for ethanol and aqueous extracts, respectively. Control experiment recorded highest percentage infestation for aqueous extracts. Ethanol extracts of all the screened plants were more effective than their aqueous extracts in protecting *M. excelsa* against *P. fusca* infestation in the field.

Discussion

The results of this study have established the potential of the four plant extracts tested against *P. fusca* in the laboratory and the potency of ethanol extracts of *P.*

Table 3 Residual and contact effects of aqueous extracts of four plants on the mortality of adult *P. fusca* at 100% concentration

Treatments	TAT (min)													
	R	C	R	C	R	C	R	C	R	C	R	C	R	C
P . Guinean	0.00[c]	0.67 [bc]	0.67 [ab]	0.33	0.00	0.00	0.67	0.33 [b]	1.33 [a]	1.67 [a]	1.67	0.33	1.67	1.00
A . indicates	0.00[c]	1.00[b]	0.67 [ab]	0.00	0.33	1.33	0.33	0.00[b]	0.33 [b]	1.67 [a]	1.00	0.33	1.33	0.00
J . carcus	0.00[c]	0.00[c]	0.00[b]	1.00	0.33	1.00	1.33	1.67 [a]	1.33 [a]	0.33 [b]	0.33	0.67	1.33	0.67
A . melegueta	0.67 [a]	1.33 [a]	1.00[a]	0.67	0.67	1.00	1.33	1.67 [a]	0.00[b]	0.00[b]	0.67	0.00	0.67	0.00
Cypermethrin	5.00[b]	5.00[b]	0.00[b]	0.00	0.00	0.00	0.00	0.00[b]	0.00[b]	0.00[b]	0.00	0.00	0.00	0.00
Control	0.00[c]	0.00[c]	0.00[b]	0.00	0.00	0.00	0.00	0.00[b]	0.00[b]	0.00[b]	0.00	0.00	0.00	0.00
Sig. level	**	**	**	Ns	Ns	Ns	Ns	**	*	**	Ns	Ns	Ns	Ns

Means with same letters within the same column are not significantly different. *Ns* not significant, *R* residual effects, *C* contact effects, *TAT* time after treatments
**Significant at 5%
**Significant at 1% by Duncan multiple range test (DMRT)

Table 4 Effect of ethanol extracts on the number of galls on *Milicia* seedlings in the field at 75% concentration

Treatments	WHAT							
	1	2	3	4	5	6	7	8
P . Guinean	0.00	0.00[b]	0.00[a]	0.00[b]	0.00[b]	0.00[b]	0.00[b]	0.00[b]
A . indicates	0.00	0.00[b]	0.00[a]	0.00[b]	0.00[b]	0.00[b]	0.00[b]	0.00[b]
J . carcus	0.00	0.00[b]	1.00[a]	1.33 ab	2.00 to	2.67 ab	3.33 a	3.67 a
A . melegueta	0.00	0.33 a	0.67 a	1.00 to	1.67 ab	2.33 ab	3.33 a	3.67 a
Cypermethrin	0.00	0.00[b]	0.33 a	1.00 to	1.67 ab	2.33 ab	3.00[a]	3.33 a
Control	0.00	1.00[a]	1.67 a	2.00[a]	3.00[a]	3.33 [a]	4.00[a]	4.67 a
Sig. level	Ns	**	**	**	**	**	**	**

Means with same letters within the same column are not significantly different. *Ns* not significant, *WAT* weeks after treatments
*Significant at 5%
**Significant at 1% by Duncan multiple range test (DMRT)

guineense and *A. indica* in protecting *P. fusca* infestations on *M. excelsa* in the field.

Golob, Moss, and Males (1999) reported that powder, oil, hexane, and acetone extracts of *P. guineense* were effective against various insects of crops like maize or cowpea in storage. *Piper guineense* has also been reported to be effective against both field and stored insect pests by several researchers. Fasakin and Aberejo (2002) reported that powdered form of *P. guineense* inhibited egg hatchability and adult emergence of *Dermestes maculatus* Degeer in smoked catfish (*Clarias gariepinus*) in storage. Idoko and Adesina (2012) reported that powders of *P. guineense* caused adult mortality of *Callosobrunchus maculatus*, inhibited their oviposition on cowpea and suppressed F1 adult emergence. Golob et al.

Table 5 Effect of aqueous extracts on the number of galls on *Milicia* seedlings in the field at 100% concentration

Treatments	WHAT							
	1	2	3	4	5	6	7	8
P . Guinean	0.00	0.00[b]	0.00[b]	0.33	0.67 [b]	1.00[b]	1.00[b]	1.00[c]
A . indicates	0.00	0.00[b]	0.67 a	1.00	1.33 ab	1.67 ab	2.67 a	2.67 [b]
J . carcus	0.00	0.33 ab	0.00[a]	1.00	2.00 to	3.33 [a]	3.33 a	4.67 [a]
A . melegueta	0.00	0.33 ab	1.33 a	1.67	2.00 to	2.67 ab	2.67 a	5.00[a]
Cypermethrin	0.00	0.00[b]	0.33 a	1.00	1.67 ab	2.33 ab	3.00[b]	3.33 ab
Control	0.00	1.00[a]	1.67 a	2.00	3.00[a]	3.33 [a]	4.00[a]	4.67 [a]
Sig. level	Ns	*	*	Ns	*	**	**	**

Means with same letters within the same column are not significantly different. *Ns* not significant, *WAT* weeks after treatments
*Significant at 5%
**Significant at 1% by Duncan multiple range test (DMRT)

(1999) also reported that *P. guineense* powder, oil, hexane, and acetone extracts were effective in causing mortality and reducing oviposition of several insects of cowpea and maize. Similarly, Ugwu, Ojo, Aderolu, and Aderemi (2014) also reported that *A. indica* and *P. guineense* extracts proved effective against major insect pests of okra in the field. The prospective of products from *A. indica* for the control of field insect pests of eggplant and okra has been proven earlier (Schmutterer, 1995). Adedire and Lajide (2000) reported that *A. indica* plants have provided a rich source of biologically active chemical compounds which are highly potent in protecting crops against pests. *Azadirachta indica* derivatives provide broad spectrum control of over 200 species of phytophagous insects (Ascher, 1993). Ojo and Ugwu (2012) also reported that ethanol seed extracts of *A. indica* were very effective in controlling insect pests of *Adansonia digitata* L. (Baobab) seedlings in the field.

Correspondingly, A. *indica* was also reported to be very effective in reducing legume pod borer and legume flower thrips infestations in the field (Ugwu, 2020).

The insecticidal properties of *P. guineense* are Piperine which is the main amide active in *Piper guineense* (Scott et al., 2004).

Azadirachta indica was reported to exhibit broad spectrum functions like repellency, toxicity, growth regulatory, and antifeedant effects against insect pests (Gianotti, Bomblies, Mustata, & Duchemin, 2008) Ugwu, Omoloye, and Obasaju (2012) also reported that leaf powders of *A. indica* and *Cymbopogon citratus* were found very effective in protecting *Irvingia wombolu* kernel against *Oryzaephilus mercator* in storage. Several reports have been recorded on the efficacy of plant extracts against hemipteran insects, *A. indica* (flowers), and ippia. sidoides extracts caused moderately high mortality rates in adults *Podisus nigrispinus* (Hemiptera; Pentatomidae) (Poderoso, Correia-Oliveira, Chagas, Zanuncio, & Ribeiro, 2016) Ethanol leaves extracts of *Petiveria alliaceae* and *Trichilia arborea* exhibited high insecticidal effects on eggs and nymphs of *B. tabaci* (Hemiptera: Aleyroideae) (Cruz-Estrada, Gamboa-Angulo, Bórges-Argáez, & Ruiz-Sanchez, 2013). Similarly, Fabrick, Yool, and Spurgeon (2020) reported that marigold *Tagetes patula* significantly reduced oviposition of *B. tabaci* and caused significantly high mortality of *Lygus hesperus* Knight (Hemiptera: Miridae) and *B. tabaci* adults. The plant extracts of *P. guineense* and *A. indica* were found to be more efficacious than cypermethrin synthetic insecticide in protecting *M. excelsa* seedlings against *P. fusca* infestation in the field. These results have confirmed the earlier report by of Basedow et al. (2002) that *A. indica*-based products were more effective than synthetic insecticides for the control of aphids and white flies. Likewise, Ojo and Ugwu (2012) also

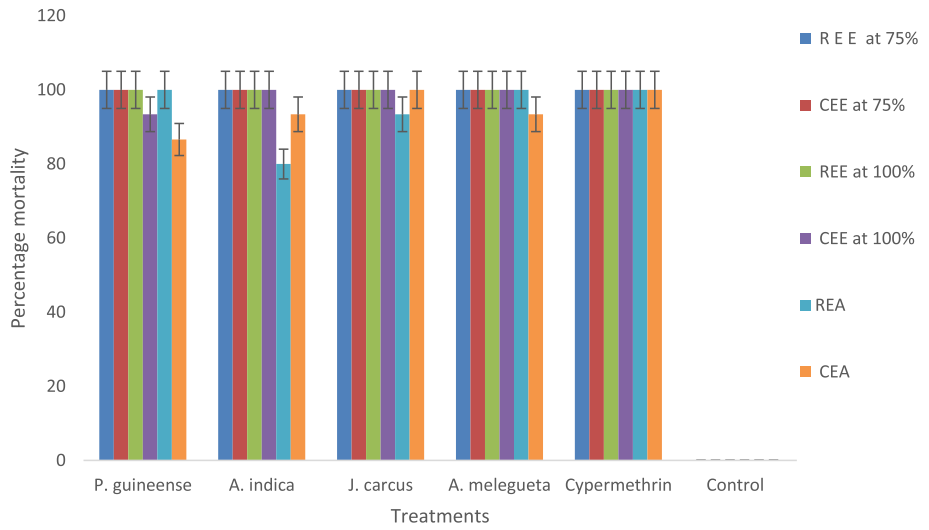

Fig. 3 The mortality percentage of *P. fusca* under the laboratory conditions at 24 h post treatments with different ethanol concentrations and aqueous extracts (REE, residual effects of ethanol extracts; CEE, contact effects of ethanol extracts; REA, residual effects of aqueous extracts; CEA, contact effects of aqueous extracts)

reported that *A. indica* seed extract was more effective than cypermethrin synthetic insecticides in controlling the insect pests of *Adansonia digitata* seedling in the field. Petroleum ether seed extracts of *A. indica*, *P. guineense*, *A. muricata*, and *J. curcas* were also reported to be more effective than lambdacyhalothrin in against legume flower thrips and legume pod borer on cowpea in the field (Ugwu, 2020; Ugwu et al., 2017). Ethanol extracts of all the screened plants were more effective than their aqueous extracts in protecting *M. excelsa* against *P. fusca* infestation in the field in this study. This corroborate the report of Huerta, Chiffelle, Puga, Azúa, and Araya (2010) that ethanol leaf extracts of *Schinus molle* caused greater mortality of elm leaf beetle *Xanthogaleruca luteola* than the water extracts at similar concentrations

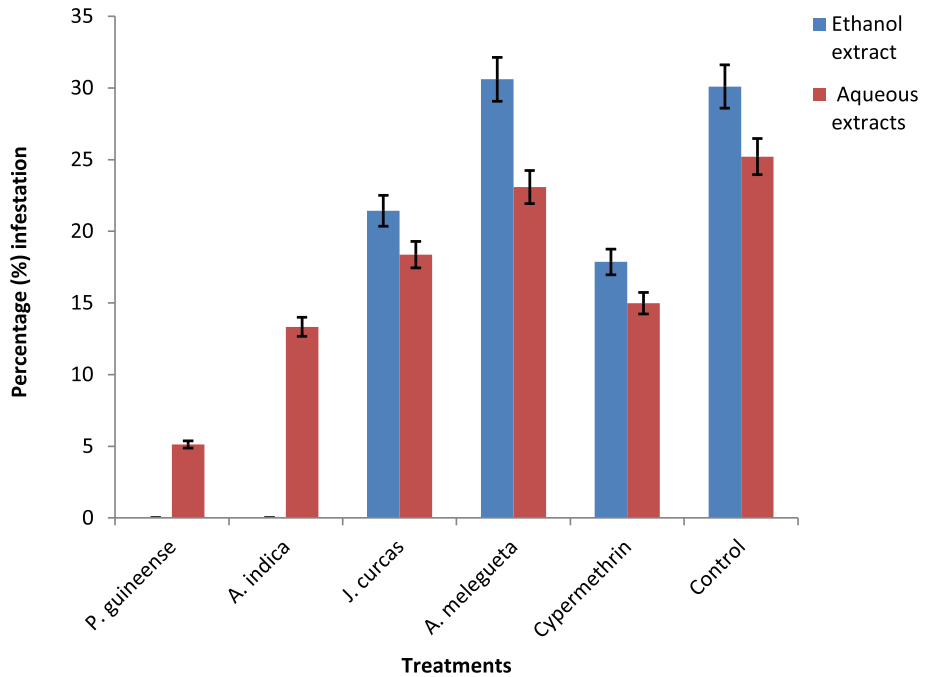

Fig. 4 Effect of ethanol and aqueous extracts on the rate of *P. fusca* infestation on *M. excelsa* seedlings in the field

Conclusion

Ethanol extracts from *P. guineense* and *A. indica* were potent and highly promising in managing *P. fusca* infestation on *M. excelsa* in the field. Their ethanol extracts were more effective than aqueous extracts both in the laboratory and in the field. Results obtained suggest remarkable prospects of developing a bio-insecticide from the combination of *P. guineese* and *A. indica* for integrated pest management (IPM) of *P. fusca* and other pests of trees species. The use of these plant extracts will reduce dependence on conventional chemical products for pest control and curtail human and environmental hazards associated with the use of synthetic insecticides and also minimize cost of production.

Abbreviations

CEA: Contact effects of aqueous extracts; CEE: Contact effects of ethanol extracts; FCF: Federal College of Forestry; FRIN: Forestry Research Institute of Nigeria; GMT: Greenwich Meridian Time; REA: Residual effects of aqueous extracts; TAT: Time after treatments; WHAT: Weeks after treatments

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Author's contributions

The single author is solely responsible for conceptualization, design, and implementation of the research; the analysis of the results; and the writing of the manuscript. The author(s) read and approved the final manuscript.

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