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ORIGINAL RESEARCH ARTICLE

Entomocide effect of *Alstonia boonei* De wild on reproductive performance of *Dermestes maculatus* (Coleoptera: Dermestidae) infestation on smoked catfish *Claria gariepinus* (Pisces: Clariidea)

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Abstract

Efficacy of *Alstonia boonei* powders and extracts against *Dermestes maculatus* (Coleoptera: Dermestidae) infesting stored smoked dried catfish (*Claria gariepinus)* were investigated in the laboratory. The products were tested at 2.5 g, 5.0 g, 7.5 g, 10 g, 12.5 g and 15 g and 1%, 2%, 5%, 10%, 15% and 20%/100 g of smoked catfish respectively. The ability of the plant to protect smoked catfish in terms of mortality rates, number of eggs laid and adult emergence were evaluated. All the tested plant parts caused significant mortality ($P < 0.05$) of adult *D. maculatus*. *Alstonia boonei* stem bark powder was the most potent, causing 100% mortality at 7.5 g of 8 days post exposure, followed by leaf powder which evoked 87.5% mortality after 10 days of exposure. For the extracts, adult mortality of *D. maculatus* was positively correlated with dose and exposure duration. *Alstonia boonei* product extracts significantly reduced the development of *D. maculatus* compared to the control. Stem bark extract significantly prevented oviposition. The use of *A. boonei* stem bark is advocated for the control of *D. maculatus* infestation. Further study is needed to characterize the chemical constituents and understand its mode of action with the likely formulation into herbal insecticide as alternative to synthetic insecticides.

Keywords Entomocide · *Alstonia boonei* · *Dermestes maculatus* · Mortality · Reproductive performance

Introduction

Fish is one of the cheapest source of animal protein used to reduce cholesterols that cause high blood pressure amongst elders (Ileke et al. 2020a). Fish consumption provides an important nutrient to a large number of people globally and thus makes a very substantial contribution to human nutrition (Fasakin and Aberejo 2002; Azam et al. 2004; Akinwumi 2011; Ajayi et al. 2019; Jangampalli 2019; Ileke et al. 2020a). Smoked fish is a highly preferred item of many traditional dishes in Nigeria and it is a condiment that greatly enriches the flavour of various dishes and a good alternative to fresh fish, which in many places is not readily available (Obiakor et al. 2013; Adesina et al. 2016; Ajayi et al. 2019). Smoke-dried catfish consumption have also becomes a better alternative in reducing cholesterols that cause high blood pressure amongst elders (Ileke et al. 2020a). In Nigeria and many other developing countries, fish constitutes 50% of total animal protein intake compared to other protein sources (Adesina et al. 2016). Owing to its nutritional and health benefits, fish is readily available on the menu table of most households irrespective of their socio-economic status, age and religious background (Adesina et al. 2014). However, the enormous economic, nutritive and health benefits of smoke-dried catfish (*Clarias gariepinus*) are threatened by insect infestation (Odeyemi et al. 2000; Adesina et al. 2014, 2016; Ajayi et al. 2019; Ileke et al. 2020a). *Dermestes maculatus* is considered to be one of the major and serious pests of smoked fish, hides and skins (Odeyemi and Daramola 2000; Ileke et al. 2020a). About 50% losses in smoked fish products during storage had

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been attributed to *D. maculatus* infestation which eat away the fish muscles and consequently reduce the nutritive quality and market price of fish (Osuji 1974; Owoade 1993; Lale and Sastawa 1996; Odeyemi et al. 2000) and as well making it unfit for consumption.

The need to protect smoked fish from insect infestation is imperative considering its crucial role in ensuring food security and income generation. However, in the developing countries fish handlers did little or nothing to safeguard infestation of smoked dried fish. The health risk linked with application of synthetic insecticides and the less susceptibility of *D. maculatus* larvae and adults to synthetic insecticides make their use an unpopular control agent (Amusan and Okorie 2002; Onu and Baba 2003).

In view of synthetic insecticide drawback, there has been renewed interest worldwide to screen aromatic and medicinal plant materials for its insecticidal properties as alternatives to overdependence on synthetic insecticide in the control of storage insect pests (Idoko and Ileke 2020; Ileke et al. 2020b). Over the past two decades, various researchers have documented the insecticidal potentials of various plant materials for the management of *D. maculatus* (Odeyemi et al. 2000; Akinwumi et al. 2006; Jose and Adesina 2014; Adesina et al. 2014, 2016; Nwosu et al. 2018; Ajayi et al. 2019; Ileke et al. 2020a).

Alstonia boonei De Wild (Apocyanaceae) is an African evergreen deciduous tree that shed leaves annually. Height of the plant is about 45 m, and its trunk is 1.2 m in diameter (Ileke 2019). The plant claimed to have medicinal properties in some cultures and climes (Moronkola and Kunle 2012). In traditional African medicine, *A. boonei* is used widely for the treatment of malaria, fever, intestinal helminths, rheumatism, hypertension (Asuzu and Anaga 1991; Terashima 2003; Betti 2004; Abel and Busia 2005; Majekodunmi and Odeku 2009); for the treatment of chronic diarrhea and dysentery, fever, pain, intestinal disorders and as an antidote for Strophanthus poison (Amole and Ilori 2010). The extracts of the stem bark is commonly used to treat malaria and is listed in the African pharmacopoeia as an anti-malaria drug (Olajide et al. 2000). It had been reported that a liquid made from the stem bark and fruit is drunk once daily to treat impotence (Majekodunmi et al. 2008); rheumatism, reversible antifertility (Raji et al. 2005), and hypertension (Olajide et al. 2000; Abel and Busia 2005; Betti 2004; Terashima 2003). It also an anti-venom against snake bite and antidote against arrow poisoning (Moronkola and Kunle 2012). The insecticidal activity of *A. boonei* has been reported recently against *Sesamia calamistis* Hampson (Lepidoptera: Noctuidae) (Oigiangbe et al. 2007a), *Maruca vitrata* (Lepidoptera: Pyralidae) (Oigiangbe et al. 2007b) and *Anopheles* mosquito larvae (Omoya et al. 2012). Ileke et al. (2012, 2013, 2014); Ileke and Arotolu (2018); Ileke 2019) reported the effectiveness of *A. boonei* in the management of cowpea bruchid (*Callosobruchus maculatus*). Ileke (2019) reported the efficacy of *A. boonei* stembark oil as a long-term storage protectant against cowpea bruchid (*C. maculatus)*. This study was conceived to investigate the insecticidal potential of *A. boonei* leaf, Stembark, root powders and extracts on adult mortality and reproductive performance of *D. maculatus* (oviposition, larva and adult emergence) on smoked dried catfish (*Claria gariepinus).*

Materials and methods

Dermestus maculatus culture

The initial source of *D. maculatus* culture used for this study was obtained from infested smoked *C. gariepinus* collected from smoked dried fish stand at Erekesan market, Akure, Ondo State, Nigeria. Adult and larvae *D. maculatus* were introduced into 2 L plane glass kilner jar containing dried fish. The jars were covered with muslin cloth and placed in an insect rearing cage at ambient temperature of 28 ± 2 °C, 75 ± 5% relative humidity and 12 h D:L. Newly emerged larvae (0–3 days) were removed from stock culture and placed on fresh uninfected smoked fish. The parent adult insects were removed after 2 - 3 weeks oviposition period. In order to promote oviposition, water was supplied by introducing cotton soaked into the breeding cage (Odeyemi and Daramola 2000; Philip-Attah 2019). Subsequent generation was used for further bioassays.

Collection and preparation of catfish, *C. gariepinus*

Catfish (*C. gariepinus*) weighing about 100 g after smoking, free of salt and seasoning were obtained from Hatchery Research Laboratory, Department of Animal and Environmental Biology, Adekunle Ajasin University, Akungba Akoko, Ondo State, Nigeria. The smoked dried fish were sterilized by re-heating at 40 °C for one hour in a hot air oven (Gallenkamp Oven) in the laboratory (Atijegbe 2004; Adesina et al. 2016), and allow to cool at room temperature in the laboratory in other to prevent mouldiness (Adedire et al. 2011).

Collection and preparation of *Alstonia boonei* powders

The leaf, stem bark and root of *A. boonei* were harvested from a farm at Aponmu, Akure, Ondo State, Nigeria. These plant parts were brought into the laboratory, washed thoroughly with clean running water and air-dried for four weeks.

Thereafter, the plant parts were pulverized separately into fine powder using an electric blender (Supermaster ®, Model SMB 2977, Japan). Subsequently, the powders were sieved (perforation of 1 mm^2), kept separately in sealed plastic containers and stored in a refrigerator at 4 °C until use.

Preparation of *A. boonei* extracts

Alstonia boonei leaf, stem bark and root powders were extracted using absolute n-hexane as solvent. The use of n-hexane to extract *A. boonei* for toxicity test against *Callosobruchus maculatus* have been established (Ileke et al. 2013; Ileke and Arotolu 2018; Ileke 2019). Four hundred grammes (500g) of *A. boonei* leaf, stem bark and root powders were soaked separately in an extraction bottle containing 800 ml of absolute n-hexane. The mixture was stirred at an interval of 6 h with a glass rod and extraction was terminated after 72 h (Ileke et al. 2016). Filtration was carried out using a double layer of Whatman No. 1 filter papers and solvent evaporated using a rotary evaporator at 30 to 40 °C with rotary speed of 3 to 6 rpm for 8 h (Udo 2011). The resulting extracts were air dried. From this stock solution, different extract concentrations of 1, 2, 5, 10, 15 and 20% were prepared separately as follows: 1% concentration was made by diluting 0.1 ml of extract in 9.9 ml of n-hexane; 2% concentration was made by diluting 0.2 ml of extract in 9.8 ml of n-hexane t; 5% concentration was made by diluting 0.5 ml of extract in 9.5 ml of n-hexane; 10% concentration was made by diluting 1 ml of extract in 9 ml of n-hexane; 15% concentration was made by diluting 1.5 ml of extract in 8.5 ml of n-hexane. Similarly, 20% concentration was made by diluting 1 ml of extract in 8 ml of n-hexane (Ashamo and Akinnawonu 2012).

Phytochemical screening of the plants

Phytochemical tests were carried out on the n-hexane extracts of *A. boonei* leaf, stem bark and root for the qualitative determination of chemical constituents using standard procedures described by Trease and Evans (1985); Ejikeme et al. (2014); Ezeonu and Ejikeme (2016); Ahmad et al. (2017).

Qualitative analysis

Alkaloid determination

Alkaloid qualitative determination was carried out using the methods described by Trease and Evans (1985); Hikino et al. (1984). 0.5 g of *A. boonei* parts extract was added to 5 ml of 1% aqueous hydrochloric acid on a steam water bath. This was stirred regularly before filtration. Few drops of Dragendorf reagent was added to filtrate (1 ml). A blue black turbidity was formed which indicate the presence of alkaloid.

Saponin determination

Analytical qualitative determination of saponin was carried out using the methods reported by Ejikeme et al. (2014); Ezeonu and Ejikeme 2016). 50 cm^3 of distilled water was added to 0.5 g each of *A. boonei* parts powders in a beaker placed on a steam water bath for 10 min and stirred occasionally before filtration. 10 cm^3 of filtrate was added to 5 cm^3 of a mixture of distilled water and agitated vigorously to form a stable persistent lather. Three drops of olive oil formed an emulsion which indicate the presence of saponin.

Phlobatannin determination

Phlobatannin qualitative determination methodology used in this research was carried out using the methods reported by Ezeonu and Ejikeme 2016). 0.5 g each of *A. boonei* leaf, stem bark and root powders were weighed into beaker and 50 cm^3 of distilled water was added. The mixture was allowed to extract for 24 h. 10 cm^3 of each extract was boiled with 1% aqueous hydrochloric acid (5 cm^3). Deposit of red precipitate indicate the presence of Phlobatannin.

Anthraquinone determination

The method described by Amadi et al. (2004) was adopted for the analytical determination of Anthraquinone. 10 ml of benzene was added to 0.5 g each of *A. boonei* leaf, stem bark and root extracts and shake gently before filtration. 5 ml of 10% NH_4 solution was added to the filtrate (10 cm^3) and shake thoroughly. The formation of pink red or violet colour in the ammonia layer shows the presence of free anthraquinone.

Tannin determination

The method described by Ezeonu and Ejikeme (2016) was adopted for the qualitative determination of tannin. 50 cm^3 of distilled water was added to 0.5 g each of *A. boonei* leaf, stem bark and root powders in a beaker placed on a steam water bath for 10 min before filtration. Thereafter, 3 drops of 0.1% ferric chloride was added to the filtrate (5 cm^3). Formation of a brownish green colouration confirmed the presence of tannin.

Flavonoid determination

Flavonoid qualitative determination using the method reported by Ejikeme et al. (2014); Ezeonu and Ejikeme (2016). 50 cm^3 of distilled water was added to 0.5 g each of *A. boonei* leaf, stem bark and root powders in a beaker and allowed to extract for 2 h

before filtration. 5 cm^3 of 1.0 M dilute ammonia (NH_4) solution was added to 10 cm^3 each of the plant part filtrates before the addition of 5 cm^3 of concentrated tetraoxosulphate (VI) acid (H_2SO_4) that formed a yellow colouration which disappeared on standing. This indicate the presence of flavonoid.

Insect bioassay

Toxicity of *A. boonei* leaf, stembark and root powders on *D. maculatus* adults

Powders of *A. boonei* leaf, stembark and root were thoroughly admixed separately at 2.5, 5.0, 7.5, 10, 12.5 and 15 g/100 g of *C. gariepinus* in plastic container (60 mm depth and 80 mm in diameter) in four replicates of the treated and controls laid out in Complete Randomised Block Design in insect cage. Ten pairs (10 males: 10 females) of newly emerged *D. maculatus* adult of <24 h were introduced. Insect mortality was assessed every 2 days for 10 days. Dead beetles were those that did not move or respond to pin probing (response to sharp pin). At the end of day 10, all insects, both dead and alive were removed from each container. Number of dead insects were counted and recorded. Percentage adult mortality was corrected (Abbott 1925).

Toxicity of *A. boonei* Leaf, Stembark and Root powders on Reproductive Performance of *Dermestes maculatus*

Powders of *A. boonei* leaf, stembark and root were thoroughly admixed separately at 2.5, 5.0, 7.5, 10, 12.5 and 15 g/100 g of *C. gariepinus* in plastic container (60 mm depth and 80 mm in diameter) in four replicates of the treated and controls laid out in Complete Randomised Block Design in insect cage. Ten pairs (10 males: 10 females) of newly emerged *D. maculatus* adult of <24 h were introduced. At the end of day 10, all insects, both dead and alive were removed from each container. Number of eggs laid by the adult female insects were counted and recorded every 24 h for 21 days until first filial adult emergence. The number reaching larva and adult stages were recorded and expressed as percentage hatching rate and adult emergence as described by Odeyemi and Daramola (2000).

$$\% \text{ Hatching rate} = \frac{\text{Total number of larva emergence}}{\text{Total number of eggs laid}} \times \frac{100}{1}$$

$$\% \text{ Adult emergence} = \frac{\text{Total number of adult emergence}}{\text{Total number of eggs laid}} \times \frac{100}{1}$$

Toxicity of *A. boonei* leaf, Stembark and root extracts on *D. maculatus* adults

Alstonia boonei leaf, stembark and root extracts were thoroughly rubbed separately using Camel brush on the sterilized smoked dried *C. gariepinus* at concentrations 1, 2, 5, 10, 15 and 20%/100 g in plastic container (60 mm depth and 80 mm in diameter). The treated fish samples were then wide-open to dryness for 5–10 min depending on concentration to eliminate traces of n-hexane. Ten pairs (10 males: 10 females) of newly emerged *D. maculatus* adult of <24 h were introduced. Four replicates of the treated and controls were laid out in Complete Randomised Block Design in insect cage. Insect mortality was assessed every 2 days for 10 days. Dead beetles were those that did not move or respond to pin probing (response to sharp pin). At the end of day 10, all insects, both dead and alive were removed from each container. Number of dead insects were counted and recorded. Percentage adult mortality was corrected (Abbot 1925).

Toxicity of *A. boonei* leaf, Stembark and root extracts on reproductive performance of *Dermestes maculatus*

Alstonia boonei leaf, stembark and root extracts were thoroughly rubbed separately at concentrations of 1, 2, 5, 10, 15 and 20%/100 g of smoked catfish, *C. gariepinus* in plastic container (80 mm depth and 100 mm in diameter). The treated fish samples were then wide-open to dryness for 5–10 min depending on concentration to eliminate traces of n-hexane. Ten pairs (10 males: 10 females) of newly emerged *D. maculatus* adult of <24 h were introduced. At the end of day 10, all insects, both dead and alive were removed from each container. Number of eggs laid by the adult female insects were counted and recorded every 24 h for 21 days until first filial adult emergence. The number reaching larva and adult stages were recorded and expressed as percentage hatching rate and adult emergence as described by Odeyemi and Daramola (2000).

Statistical analysis

All data were subjected to analysis of variance (ANOVA), and means were separated using the Tukey's Honest Significant Difference Test at 5% probability level (SAS 2003). Prior to ANOVA, data observed in percentages and counts were subjected to arcsine and square root transformation to meet the conventions of normality and homogeneity of variance (Adesina and Ofuya 2011; Adesina and Mobolade-Adesina 2016). Log-Probit model analysis was carried out on percentage mortality of the hide beetle to evaluate the 50% lethal dose and concentration (LD50

Table 1 Qualitative analysis of Phytochemicals in experimental plants hexanoic

Phytochemicals	Leaf extract	Stem bark extract	Root extract
Alkaloids	+	+	+
Saponins	+	+	+
Tannins	+	+	+
Phlobatannins	_	_	_
Anthraquinones	_	_	_
Flavonoids	–	+	–

Keys: – Absent; + Present.

and LC50) and 90% lethal dose and concentration (LD90 and LC90) (Finney 1971).

Results

Phytochemicals screening of Hexanoic extracts of *Alstonia boonei*

Tables 1 presented the result of the phytochemical screening of the hexanoic extracts of *A. boonei* leaf, stem bark and root. Alkaloids. saponins and tannins were present in all the plant parts tested. Flavonoid was present only in *A. boonei* stem bark extract while phlobatannins and anthraquinones were absent in the experimental plant parts.

Toxicity of *A. boonei* leaf, Stembark and root powders on percentage mortality of *D. maculatus*

Results in Table 2 presented the toxicity of *A. boonei* leaf, stembark and root powders on adult mortality of *D. maculatus*. The result showed that *A. boonei* leaf, stembark and root powders were significantly ($P < 0.05$) toxic to the adult hide beetles at each tested concentrations compared to the untreated (control) in increasing order over the period of exposure. *Alstonia boonei* stembark powder was the most potent among the three powders triggering 100% adult mortality in dishes treated with 15 g/100 g and 7.5 g/100 g at 2nd and 8th days after exposure.

This was followed by the leaf powder of *A. boonei* which triggered 87.5% adult mortality at 4 and 10 days of treatment recorded in smoked fish treated with 15 and 7.5 g respectively. Also 15 g of the leave powder was able to produce 100% mortality at 10 days of exposure while the powder was the least toxic to adult hide beetle at all tested concentrations. The powder instigated highest mortality of 92.5% at 15 g dosage rate after 10 days of exposure.

Table 2 Toxicity of *A. boonei* Leaf, Stembark and Root powders on percentage Mortality of *D. maculatus*

Exposure Time (Days)	Plant Part Powders	Dose (g)/100 g of smoked catfish					
		2.5	5.0	7.5	10.0	12.5	15.0
2	Leaf	20.00 ± 2.02c	32.50 ± 2.50c	50.00 ± 3.29c	60.00 ± 4.08c	77.50 ± 3.29c	80.00 ± 4.08c
	Stembark	30.00 ± 2.08e	52.50 ± 2.50 h	70.00 ± 4.08 g	82.50 ± 3.50 g	97.50 ± 2.50i	100.00 ± 0.00i
	Root	17.50 ± 2.50b	27.50 ± 2.19b	42.50 ± 2.50b	50.00 ± 2.02b	62.50 ± 3.50b	70.00 ± 4.08b
4	Leaf	30.00 ± 2.08e	42.50 ± 2.50e	62.50 ± 3.50e	70.00 ± 4.08d	82.50 ± 3.50e	87.50 ± 2.29e
	Stembark	37.50 ± 3.19f	60.00 ± 4.08j	82.50 ± 3.50j	90.00 ± 4.08i	100.00 ± 0.00j	100.00 ± 0.00i
	Root	27.50 ± 2.50d	37.50 ± 2.19d	57.50 ± 2.19d	60.00 ± 4.08c	77.50 ± 3.29c	80.00 ± 4.08c
6	Leaf	37.50 ± 3.19f	50.00 ± 2.02 g	70.00 ± 4.08 g	82.50 ± 3.50 g	87.50 ± 2.19f	90.00 ± 4.08f
	Stembark	50.00 ± 2.02 h	67.50 ± 2.19 l	90.00 ± 4.08 l	100.00 ± 0.00 k	100.00 ± 0.00j	100.00 ± 0.00i
	Root	32.50 ± 2.50 cd	47.50 ± 2.19f	62.50 ± 3.50e	70.00 ± 4.08d	80.00 ± 4.08d	82.50 ± 2.50d
8	Leaf	42.50 ± 2.50 g	57.50 ± 2.19i	80.00 ± 4.08i	87.50 ± 2.29 h	90.00 ± 4.08 g	97.50 ± 2.50 h
	Stembark	62.50 ± 3.50i	72.50 ± 3.50 m	100.00 ± 0.00 m	100.00 ± 0.00 k	100.00 ± 0.00j	100.00 ± 0.00i
	Root	37.50 ± 3.19f	52.50 ± 2.50 h	67.50 ± 3.29f	77.50 ± 3.29e	82.50 ± 2.50e	87.50 ± 2.29e
10	Leaf	50.00 ± 2.02 h	62.50 ± 3.50 k	87.50 ± 2.29 k	92.50 ± 3.50j	92.50 ± 3.50 h	100.00 ± 0.00i
	Stembark	70.00 ± 4.08j	80.00 ± 4.08n	100.00 ± 0.00 m	100.00 ± 0.00 k	100.00 ± 0.00j	100.00 ± 0.00i
	Root	42.50 ± 2.50 g	57.50 ± 2.19i	72.50 ± 3.50 h	80.00 ± 4.08f	87.50 ± 2.19f	92.50 ± 3.50 g
	Control	00.00 ± 0.00a	00.00 ± 0.00a	00.00 ± 0.00a	00.00 ± 0.00a	00.00 ± 0.00a	00.00 ± 0.00a

Each value is a mean ± standard error of four replicates. Means with the same alphabet down the column are not significantly different using Tukey's HSD (Honest Significant Difference) at $p > 0.05$.

Lethal dose (LD) of *A. boonei* leaf, Stembark and root powders on *D. maculatus*

The lethal doses of different parts of *A. boonei* powders against adult *D. maculatus* are given in Table 3. The required dosage calculated to cause 50% (LD_{50}) and 90% (LD_{90}) insect mortality after day 2 were 6.80 and 25.44 g; 4.27 and 14.33 g; and 8.99 and 42.03 g per 100 g of smoked fish for the leaf; stembark and root powders respectively. These values were observed to reduce as the period of exposure increased. From the calculations, the stembark was observed to have the lowest lethal dose across all period of exposure.

Delayed cumulative effects of *A. boonei* leaf, Stembark and root powders on reproductive performance of *D. maculatus*

Effects of *A. boonei* leaf, stembark and root powders on oviposition, larval development and adult emergence of *D. maculatus* are shown in Table 4. The effect of *A. boonei* leaf, stembark and root powders on *D. maculatus* progeny development revealed significant difference ($P < 0.05$) compared to the control in a dosage dependent manner. The various plant powders completely prevented the beetle from laying eggs except stembark, leaf and root powder that led to significant reduction in the number of eggs laid on those treated with 2.5, 5 and 7.5 g that recorded between 0.5 and 5.00 eggs respectively compared to control. Similarly, there were very low numbers of emerged larvae from the copulating adults that were exposed to powder treatments. Stembark powders completely prevented the emergence of larvae and adult insects from the few eggs laid. However, 17.5% and 20% larval and adult emergence were recorded on smoked fish treated with *A. boonei* leaf and root powders at rate 2.5 g/100 g of smoked fish.

Toxicity of *A. boonei* leaf, Stembark and root Hexanoic extracts on percentage mortality of *D. maculatus*

Result in Table 5 presented the toxicity of *A. boonei* leaf, stembark and root extracts on *D. maculatus* adult mortality. All the extracts were significantly ($P < 0.05$) toxic to the adult hide beetles at each of the concentrations tested compared to the control. Stembark extract was the most lethal causing 50, 87.50 and 100% mortality at 1, 2, 5, 10%, 15 and 20% concentration/100 g smoked catfish after 2 days of exposure. This was closely followed by *A. boonei* leaf instigating 32.50, 50, 67.50, 82.50, 97.50 and 100% adult mortality at rate 1, 2, 5, 10, 15 and 20% concentration/100 g smoked after 2 days of post treatment. At 8 days of exposure of *D. maculatus* to stembark extract at all the tested concentrations, 100% adult mortality was recorded. *Alstonia boonei* root extract was the least toxic to adult hide beetle at all tested concentrations. At the end of experiment, 100% mortality of hide beetles were recorded on smoked catfish treated with *A. boonei* leaf and stembark extracts at concentration 15% after 6 days of exposure. The experiment clearly indicated that *D. maculatus* adult mortality increased with increase in length of exposure and concentration of the extracts.

Table 3 Lethal Dose (LD) of *A. boonei* Leaf, Stembark and Root powders on *D. maculatus*

Plant parts	Exposure period (Days)	Slope ± S. E	Intercept ± S. E	χ^2	LD50 (LCL-UCL) (g)	LD90 (LCL-UCL) (g)	*P* value
Leaf	2	2.28 ± 0.22	−1.91 ± 0.20	5.34	6.80(6.15–7.70)	25.44(20–34.27)	0.25
	4	2.15 ± 0.22	−1.53 ± 0.19	4.95	5.11(4.41–5.79)	19.75(16.47–26.76)	0.29
	6	2.17 ± 0.21	−1.32 ± 0.19	4.56	4.02(3.36–4.64)	15.36(13.12–20.02)	0.34
	8	2.42 ± 0.23	−1.29 ± 0.19	6.57	3.40(2.82–3.92)	11.00(9.94–13.87)	0.16
	10	2.54 ± 0.25	−1.16 ± 0.20	12.09	2.78(1.87–4.11)	9.90(6.68–14.67)	0.02
Stem bark	2	3.13 ± 0.25	−1.98 ± 0.20	17.63	4.27(3.21–5.66)	11.37(8.56–15.09)	0.00
	4	3.25 ± 0.28	−1.79 ± 0.21	13.23	3.50(2.51–4.89)	8.83(6.84–13.82)	0.01
	6	3.41 ± 0.31	−1.56 ± 0.22	17.80	2.71(1.86–3.94)	6.80(5.97–12.65)	0.00
	8	3.43 ± 0.37	−1.25 ± 0.24	29.29	2.31(0.16–3.60)	5.48(3.49–11.24)	0.00
	10	3.22 ± 0.40	−0.92 ± 0.26	20.26	1.93(0.15–3.05)	4.83(3.07–12.67)	0.00
Root	2	1.91 ± 0.22	−1.83 ± 0.21	2.74	8.99(7.92–10.34)	42.03(30.32–65.05)	0.60
	4	1.91 ± 0.21	−1.43 ± 0.19	5.89	6.04(5.21–6.86)	28.13(21.66–41.91)	0.21
	6	1.83 ± 0.21	−1.26 ± 0.19	1.44	4.83(4.02–6.50)	24.03(18.79–36.56)	0.84
	8	1.89 ± 0.21	−1.15 ± 0.19	1.53	4.07(2.68–6.17)	19.08(15.52–26.86)	0.82
	10	1.99 ± 0.22	−1.08 ± 0.19	2.99	3.53(2.36–5.28)	14.90(12.73–20.24)	0.02

$\chi 2$ = Chi-square value, S.E = Standard error, LCL = Lower confidence limit and UCL = Upper confidence limit.

Table 4 Delay cumulative effects of *A. boonei* Leaf, Stembark and Root powders on Reproductive Performance of *Dermestes maculatus*

Dosage (g)	Plant Part Powders	Number of laid eggs (means ± SD)	Hatching rate % (means ± SD)	Emergence success % (means ± SD)
2.5	Leaf	6.00 ± 1.02b	17.50 ± 1.19b	17.50 ± 1.19b
	Stembark	1.00 ± 0.01ab	00.00 ± 0.00a	00.00 ± 0.00a
	Root	9.50 ± 1.08b	20.00 ± 1.02b	20.00 ± 1.02b
5.0	Leaf	2.00 ± 0.02ab	00.00 ± 0.00a	00.00 ± 0.00a
	Stembark	00.00 ± 0.00a	00.00 ± 0.00a	00.00 ± 0.00a
	Root	5.50 ± 0.08b	17.50 ± 1.19b	17.50 ± 1.19b
7.5	Leaf	0.50 ± 0.01a	00.00 ± 0.00a	00.00 ± 0.00a
	Stembark	00.00 ± 0.00a	00.00 ± 0.00a	00.00 ± 0.00a
	Root	2.00 ± 0.02ab	00.00 ± 0.00a	00.00 ± 0.00a
10.0	Leaf	00.00 ± 0.00a	00.00 ± 0.00a	00.00 ± 0.00a
	Stembark	00.00 ± 0.00a	00.00 ± 0.00a	00.00 ± 0.00a
	Root	00.00 ± 0.00a	00.00 ± 0.00a	00.00 ± 0.00a
12.5	Leaf	00.00 ± 0.00a	00.00 ± 0.00a	00.00 ± 0.00a
	Stembark	00.00 ± 0.00a	00.00 ± 0.00a	00.00 ± 0.00a
	Root	00.00 ± 0.00a	00.00 ± 0.00a	00.00 ± 0.00a
15.0	Leaf	00.00 ± 0.00a	00.00 ± 0.00a	00.00 ± 0.00a
	Stembark	00.00 ± 0.00a	00.00 ± 0.00a	00.00 ± 0.00a
	Root	00.00 ± 0.00a	00.00 ± 0.00a	00.00 ± 0.00a
0.0	Control	97.50 ± 3.29^{c}	82.50 ± 3.50^{c}	67.50 ± 2.19^{c}

Each value is a mean ± standard error of four replicates. Means with the same alphabet down the column are not significantly different using Tukey's HSD (Honest Significant Difference) at $p > 0.05$.

Lethal concentration of *A. boonei* leaf, Stembark and root extracts on *D. maculatus*

The lethal concentrations of different parts of *A. boonei* powders against adult *D. maculatus* are given in Table 6. The required concentrations calculated to cause 50% (LC_{50}) and 90% (LC_{90}) mortality in the insect after day 2 were 2.10 and 10.83%; 1.00 and 2.09%; and 3.39 and 31.76% per 100 g of smoked fish for the leaf; stembark and root powders respectively. These values were observed to reduce as the period of exposure increased. Some values were not calculated because most concentration caused maximum percentage mortality at such period of exposure.

Delayed cumulative effects of *A. boonei* leaf, Stembark and root Hexanoic extracts on reproductive performance of *D. maculatus*

Table 7 shown effects of *A. boonei* leaf, stembark and root powders on oviposition, larval development and adult emergence of *D. maculatus*. The effect of *A. boonei* leaf, stembark and root extracts on progeny development of *D. maculatus* revealed significant difference ($P < 0.05$) compared to the control. *Alstonia boonei* stembark extract significantly prevented the beetle from laying eggs. Similarly, there were very low mean numbers of emergent larvae of the insects from the new copulating adults that were exposed to extracts treatments. Stembark powders and leaf extract completely prevented the emergence of larvae and adult insects from the few eggs laid. However, 22.5% and 22.5% larva and adult emergence were recorded on smoked fish treated with *A. boonei* leaf and root extract at 1%/100 g concentration of the smoked catfish.

Discussion

The use of *A. boonei* in the management of insect pest of cereals, legumes and vectors of malaria as well as inhibition of bacteria and fungi growth have been reported (Oigiangbe et al. 2007a, b; Ileke and Oni 2011; Omoya et al. 2012; Ileke et al. 2012, 2013; Ojo and Ogunleye 2013; Ileke and Arotolu 2018; Ileke 2019). Although, this may be the first attempt to screen *A. boonei* for insecticidal potential against *D. maculatus*. The result obtained in this study is in agreement with the reports of many earlier researchers on the use of botanicals against suppression of *D. maculatus* infestation on smoked-dried fish (Onu and Baba 2003; Adebote et al. 2006; Akinwumi et al. 2007, 2011; Abdullahi et al. 2011;

Table 5 Toxicity of *A. boonei* Leaf, Stembark and Root Hexanoic Extracts on percentage Mortality of *D. maculatus*

Exposure Time (Days)	Plant Part Extracts	Concentration %/100 g of smoked catfish					
		1	2	5	10	15	20
2	Leaf	32.50 ± 2.50f	50.00 ± 2.02f	67.50 ± 3.29 g	82.50 ± 3.50f	97.50 ± 2.50f	100.00 ± 0.00 g
	Stembark	50.00 ± 2.02i	87.50 ± 3.29 l	100.00 ± 0.00 k	100.00 ± 0.00i	100.00 ± 0.00 g	100.00 ± 0.00 g
	Root	27.50 ± 2.19e	40.00 ± 2.02e	50.00 ± 2.50e	70.00 ± 4.08e	82.50 ± 3.50e	87.50 ± 3.29e
	Solvent treated	00.00 ± 0.00a	00.00 ± 0.00a	00.00 ± 0.00a	00.00 ± 0.00a	00.00 ± 0.00a	00.00 ± 0.00a
4	Leaf	47.50 ± 2.19 h	67.50 ± 2.19i	77.50 ± 3.29 h	97.50 ± 2.50 h	100.00 ± 0.00 g	100.00 ± 0.00 g
	Stembark	70.00 ± 4.08 k	100.00 ± 0.00n	100.00 ± 0.00 k	100.00 ± 0.00i	100.00 ± 0.00 g	100.00 ± 0.00 g
	Root	37.50 ± 2.19 g	52.50 ± 2.50 g	62.50 ± 3.50f	82.50 ± 3.50f	97.50 ± 2.50f	90.00 ± 4.08f
	Solvent treated	00.00 ± 0.00a	00.00 ± 0.00a	0.00 ± 0.00a	0.00 ± 0.00a	0.00 ± 0.00a	0.00 ± 0.00a
6	Leaf	67.50 ± 2.19j	80.00 ± 4.08j	92.50 ± 3.50j	100.00 ± 0.00i	100.00 ± 0.00 g	100.00 ± 0.00 g
	Stembark	87.50 ± 3.39n	100.00 ± 0.00n	100.00 ± 0.00 k	100.00 ± 0.00i	100.00 ± 0.00 g	100.00 ± 0.00 g
	Root	50.00 ± 2.02i	60.00 ± 4.08 h	77.50 ± 3.29 h	90.00 ± 4.08 g	100.00 ± 0.00 g	100.00 ± 0.00 g
	Solvent treated	5.00 ± 0.02b	5.00 ± 0.02b	5.00 ± 0.02b	5.00 ± 0.02b	5.00 ± 0.02b	5.00 ± 0.02b
8	Leaf	82.50 ± 3.50 m	90.00 ± 4.08 m	100.00 ± 0.00 k	100.00 ± 0.00i	100.00 ± 0.00 g	100.00 ± 0.00 g
	Stembark	100.00 ± 0.00p	100.00 ± 0.00n	100.00 ± 0.00 k	100.00 ± 0.00i	100.00 ± 0.00 g	100.00 ± 0.00 g
	Root	67.50 ± 2.19j	82.50 ± 3.50 k	82.50 ± 3.50i	100.00 ± 0.00i	100.00 ± 0.00 g	100.00 ± 0.00 g
	Solvent treated	10.00 ± 1.02c	10.00 ± 1.02c	10.00 ± 1.02c	10.00 ± 1.02c	10.00 ± 1.02c	10.00 ± 1.02c
10	Leaf	90.00 ± 4.08o	100.00 ± 0.00n	100.00 ± 0.00 k	100.00 ± 0.00i	100.00 ± 0.00 g	100.00 ± 0.00 g
	Stembark	100.00 ± 0.00p	100.00 ± 0.00n	100.00 ± 0.00 k	100.00 ± 0.00i	100.00 ± 0.00 g	100.00 ± 0.00 g
	Root	77.50 ± 3.29 l	90.00 ± 4.08 m	100.00 ± 0.00 k	100.00 ± 0.00i	100.00 ± 0.00 g	100.00 ± 0.00 g
	Solvent treated	12.50 ± 1.50d	12.50 ± 1.50d	12.50 ± 1.50d	12.50 ± 1.50d	12.50 ± 1.50d	12.50 ± 1.50d
0.0	Control	00.00 ± 0.00a	00.00 ± 0.00a	00.00 ± 0.00a	00.00 ± 0.00a	00.00 ± 0.00a	00.00 ± 0.00a

Each value is a mean ± standard error of four replicates. Means with the same alphabet down the column are not significantly different using Tukey's HSD (Honest Significant Difference) at $p > 0.05$.

Table 6 Lethal concentration of *A. boonei* Leaf, Stembark and Root extracts on *D. maculatus*

Plant parts	Exposure period (Days)	Slope ± S. E	Intercept ± S. E	χ^2	LC50 (LCL-UCL) (%)	LC90 (LCL-UCL) (%)	P value
Leaf	2	1.79 ± 0.14	−0.57 ± 0.10	14.64	2.10(1.28–3.44)	10.83(7.05–18.94)	0.00
	4	1.89 ± 0.16	−0.16 ± 0.10	14.34	1.21(0.45–1.95)	5.75(3.71–10.94)	0.00
	6	1.89 ± 0.24	−0.36 ± 0.11	4.77	0.64(0.41–0.86)	3.06(2.49–3.95)	0.31
	8	*	*	*	*	*	*
	10	*	*	*	*	*	*
Stem bark	2	4.04 ± 0.59	−0.82 ± 0.19	0.37	1.00(0.85–1.14)	2.09(1.82–2.61)	0.99
	4	*	*	*	*	*	*
	6	*	*	*	*	*	*
	8	*	*	*	*	*	*
	10	*	*	*	*	*	*
Root	2	1.30 ± 0.12	−0.69 ± 0.10	5.36	3.39(2.71–4.13)	31.76(23.56–53.15)	0.25
	4	1.40 ± 0.13	−0.39 ± 0.10	12.63	1.92(1.09–3.39)	15.45(8.75–27.27)	0.01
	6	1.66 ± 0.16	−0.16 ± 0.10	13.33	1.13(0.57–2.24)	7.38(5.73–19.72)	0.01
	8	1.61 ± 0.27	−0.55 ± 0.18	21.66	0.57(0.04–0.57)	3.82(1.73–5.12)	0.00
	10	*	*	*	*	*	*

$\chi 2$ = Chi-square value, S.E = Standard error, LCL = Lower confidence limit and UCL = Upper confidence limit.

*=values not calculated due maximum % mortality at such period of exposure

Table 7 Delay cumulative effects of *A. boonei* Leaf, Stembark and Root Extracts on Reproductive Performance of *Dermestes maculatus*

Conc. (%)	Plant Part extracts	Number of laid eggs (means ± SD)	Hatching rate % (means ± SD)	Emergence success % (means ± SD)
1	Leaf	2.50 ± 0.50b	0.50 ± 0.01a	0.00 ± 0.00a
	Stembark	0.00 ± 0.00a	00.00 ± 0.00a	00.00 ± 0.00a
	Root	4.50 ± 0.50b	22.50 ± 1.50b	22.50 ± 1.50b
	Solvent treated	00.00 ± 0.00a	00.00 ± 0.00a	00.00 ± 0.00a
2	Leaf	0.00 ± 0.00a	00.00 ± 0.00a	00.00 ± 0.00a
	Stembark	00.00 ± 0.00a	00.00 ± 0.00a	00.00 ± 0.00a
	Root	1.00 ± 0.02ab	00.00 ± 0.00a	00.00 ± 0.00a
	Solvent treated	00.00 ± 0.00a	00.00 ± 0.00a	00.00 ± 0.00a
5	Leaf	0.00 ± 0.00a	00.00 ± 0.00a	00.00 ± 0.00a
	Stembark	00.00 ± 0.00a	00.00 ± 0.00a	00.00 ± 0.00a
	Root	00.00 ± 0.00a	00.00 ± 0.00a	00.00 ± 0.00a
	Solvent treated	00.00 ± 0.00a	00.00 ± 0.00a	00.00 ± 0.00a
10	Leaf	00.00 ± 0.00a	00.00 ± 0.00a	00.00 ± 0.00a
	Stembark	00.00 ± 0.00a	00.00 ± 0.00a	00.00 ± 0.00a
	Root	00.00 ± 0.00a	00.00 ± 0.00a	00.00 ± 0.00a
	Solvent treated	00.00 ± 0.00a	00.00 ± 0.00a	00.00 ± 0.00a
15	Leaf	00.00 ± 0.00a	00.00 ± 0.00a	00.00 ± 0.00a
	Stembark	00.00 ± 0.00a	00.00 ± 0.00a	00.00 ± 0.00a
	Root	00.00 ± 0.00a	00.00 ± 0.00a	00.00 ± 0.00a
	Solvent treated	00.00 ± 0.00a	00.00 ± 0.00a	00.00 ± 0.00a
20	Leaf	00.00 ± 0.00a	00.00 ± 0.00a	00.00 ± 0.00a
	Stembark	00.00 ± 0.00a	00.00 ± 0.00a	00.00 ± 0.00a
	Root	00.00 ± 0.00a	00.00 ± 0.00a	00.00 ± 0.00a
	Solvent treated	00.00 ± 0.00a	00.00 ± 0.00a	00.00 ± 0.00a
0.0	Control	100.00 ± 4.08^{c}	87.50 ± 3.29^{c}	70.00 ± 4.08^{c}

Each value is a mean ± standard error of four replicates. Means with the same alphabet down the column are not significantly different using Tukey's HSD (Honest Significant Difference) at $p > 0.05$.

Mufutau 2012; Adesina et al. 2014, 2016; Ajayi et al. 2019; Philip-Attah 2019; AI Nta et al. 2019; Ileke et al. 2020a).

Alstonia boonei plant parts exhibited dosage dependent and period of exposure activities, the higher the concentration and period of exposure the more the mortality. The results are similar to the findings of Oigiangbe et al. (2007a), (b); Ileke and Oni (2011); Ileke et al. (2012); Omoya et al. (2012) who reported the susceptibility of *Maruca vitrata, Sesamia calamists, Sitophilus zeamais, Callosobruchus maculatus* and vector of malaria, *Anopheles gambiae* to *Alstonia boonei* leaf, stembark and root. This is also in agreement with Okorie et al. (1990) who reported 93% mortality of *D. maculatus* larvae and 100% mortality of all adults, when treated with neem seed powder at the rate of 2 g/25 g of the smoked Tilapia fish. Akinwumi (2011) reported 100% mortality of adult *D. maculatus* on exposure of *Pipper guineense* powder at the rate of 10 g/100 g of smoked fish after 7 days of experimental period. The study evidently shown that the both plant powders were most effective at higher concentration compared to the low concentration.

The mortality caused by the powders and extracts of *A. boonei* might be through desiccation of insects or through occlusion of their spiracles, thereby preventing respiration via tracheal system. (Adedire et al. 2011). Medicinal and aromatic plant products have been linked with paralysis and blockage of electron transportation in respiratory processes of insects, immobilization and toxicity and ultimately resulting in mortality (Singh et al. 2001; Moreira et al. 2007). Plant products had been reported to consist of complex mixtures of monoterpenes, sesquiterpenes and biogenetically related phenols (Trivedi et al. 2018; Ileke et al. 2020b). Their mode of actions against insect pests is through neurotoxic mode of action (Trivedi et al. 2018). The complex mixtures in plant products inhibited acetyl cholinesterase enzyme (AChE) action (Houghton et al. 2006). The inhibited acetyl cholinesterase enzyme (AChE) activity interferes with the neuromodulator octopamine (Kostyukovsky et al. 2002; Trivedi et al. 2018) which block GABA-gated chloride channels of the insect pest resulting to their death (Priestley et al. 2003). This supports the findings of other researchers who had earlier reported on

the efficacy of insecticidal activities of various plant products as surface protectant against *D. maculatus* infestation (Okorie et al. 1990; Akinwumi et al. 2007; Akinwumi 2011).

In addition to adult mortalities, *A. boonei* stem bark powder and extract prevented egg laying as fewer eggs were laid on smoked fish treated with *A. boonei* stem bark powder and extract compared with control. Complete oviposition suppression was observed with stembark power at 5-15 g, leaf and root powder at 10-15 g; while for extracts treated fish samples, zero oviposition was recorded from 1% stembark, 2–20% leaf and 5–20% root extract. The significant reduction in the number of egg laid, could be due to toxicity of the plant products. Plant products were known to interfere with oviposition, egg hatching and also impede the production of important enzymes such as those responsible for moulting thus inhibiting growth and general development of the insect pests (Moreira et al. 2007; Ileke and Oni 2011). The observed significantly low oviposition and larvae emergence from this study collaborates with the findings of Kosini and Nukenine (2017) who stated that, apart from adult toxicity, extracts of *Gnidia kaussiana* significantly inhibited *C. maculatus* oviposition and/or exterminated the larvae at developmental stages after eggs laid on *Vigna subterranea*. Jamil et al. (1984) opined that crude extracts retard development and caused mortality of larvae, cuticle melanisation resulting in the disruption of the endocrine system controlling the growth and moulting of larvae.

The insecticidal activity of *A. boonei* may be attributed to its active chemical components. Botanicals are known to possess bioactive chemical substances like terpenes, saponins, tannins, flavonoids and alkaloids among others which have been found to possess reasonable antifungal, antibacterial, antioxidant or insecticidal efficacy (Fernando et al. 2005). The presence of flavonoids in *A. boonei* stem bark could be responsible for higher mortality of *D. maculatus.*

Conclusion

The results obtained from the study showed that *A. boonei* stem bark powder and extract were the most potent in the management of *D. maculatus,* causing significant adult mortality and suppressed larva and adult emergence. Thus, it use should be promoted among fishermen and fish traders for the control of *D. maculatus* infestation. Further study is needed to characterize and isolate the plant bioactive chemical constituents and understand the plant products mode of action with the likely formulation into herbal insecticide as alternative to synthetic insecticides.

Authors' contribution **KDI**, conceived and design the study, source for and prepared the plant materials, carried out data analysis and proofread the manuscript. **JMA**, carried out the phytochemical screening, source for relevant literatures and prepared the manuscript. **AOA**, source for and prepared the fish samples **KDI** and **MSA** carried out the insect bioassay and collect all data.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Research involving human participants and /or animals The research work did not involve animals.

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