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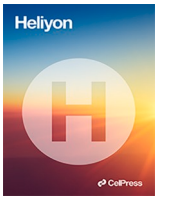

Research article

Insecticidal activity of *Aguaria salicifolia* leaf extracts on cowpea bruchid *Callosobruchus maculatus* (Coleoptera: Chrysomelidae)

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ABSTRACT

The protection of foodstuffs against insect pests constitutes a serious problem across the world. Synthetic chemical insecticides are the most widely used method for grain protection. Unfortunately, the harmful effects of these insecticides on human health and environment have increased the interest of researchers for botanical insecticides which are recognized as eco-friendly products. Therefore, the efficacy of *Aguaria salicifolia* Hook. f. ex Oliv. leaf extracts was tested against *Callosobruchus maculatus* F. on cowpea grain, at the dosage of 2, 4, 8 and 16 g/kg. To estimate the biological activity of leaf powder and aqueous extract, adult mortality, insect population growth reduction, grain damage and weight loss reduction tests were carried out. The repellency effect of *A. salicifolia* was assessed using the aqueous, methanolic and ethyl acetate extracts. The mortality was recorded at 1, 3, 5 and 6 days post-exposure. All treatments were submitted to four replications, and the experiment was carried out in a completely randomised design in the fluctuating laboratory conditions (Temp. = 23.71 ± 1.03 °C; RH. = 81.38 ± 2.03 %). Overall, all the extracts significantly exhibited insecticidal activities against cowpea bruchids. The highest dosage induced the highest mortality rates; 79.26 % and 84.08 % with aqueous extract and leaf powder, respectively. The different plant extracts considerably reduced insect population, grain damage and weight loss. The complete reduction of *C. maculatus* population was achieved by aqueous extract of *A. salicifolia*. The different solvent extracts had repellent property with repellency percentage values ranging from 30 % to 73.75 %. Considering these results, insecticidal products derived from *A. salicifolia* could constitute an alternative to the chemical synthetic insecticides used against *C. maculatus*. However, further studies are needed to be carried out concerning the mammalian toxicity and evaluation of suitable formulations of the extracts under field conditions before their promotion for grain protection.

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1. Introduction

Food insecurity remains a fundamental problem worldwide and in sub-Saharan Africa in particular [1]. In Africa, the number of persons suffering from famine has increased from 47.9 million since 2014 to 250.3 million in 2020, about one fifth of the population [1]. This progressive deterioration of food security is due to climate instability, lack of adequate infrastructure in food chain, and post-harvest food loss [2,3]. Food security can be reached in African continent by increasing agriculture productivity at the same time by reducing pre and postharvest losses.

Pulses or legumes constitute the agricultural products which are able to improve food security and human health, reduce poverty, and fight against malnutrition. Among these pulses, cowpea *Vigna unguiculata* is one of the most consumed grain legumes around the world [4,5]. This crop seriously participates in the reduction of poverty and betterment of nutrition security due to its richness in proteins and its socio-economic importance [6,7]. Cowpea is cultivated in all the intertropical zones and even beyond. It is consumed by about 200 million people in tropical Africa [8] and constitutes one of the staple food crops in Western and Central Africa [9]. Every part of this crop is consumed or used for different purposes; it is consumed as dry or fresh grain, fresh pods even fresh or dry leaves. All the parts of this crop even after harvesting of pods serve as a good source of fodder for animal husbandry [10].

The world cowpea production is about 5.59 million tons from an area of 12.61 million ha. The African production represents 70 % of that production with 80 % of world cultivated area of this crop [11]. The Cameroonian cowpea production is about 1 % of world production, about 112,501 tons per year [12]. Indeed, that production has improved but remains very low compared to the countries such as Nigeria and Niger; which remain the major cowpea producers with 2,137,000 and 549,035 tons per year, respectively.

Agriculture cannot be practiced along the whole year in Africa especially in the Sahelian zones due to the periodicity of rainy season and sometimes the climatic fluctuations [13,14]. This situation obliges farmers to store the huge quantity of their production to supply market, to ensure seed for cropping and grain for meal [14,15]. However, during storage, the foodstuffs suffer from qualitative and quantitative losses [16]. These losses on cowpea are mainly caused by Coleopteran bruchids, *Callosobruchus maculatus* (F.). This bruchid is the most damaging insect pest of cowpea grain during storage. This coleopteran starts infestation in the farm and continues in the storage. The immature stages of this bruchid develop inside the grain, where they consume the reserves contained in the cotyledons and destroy the grain embryo, inducing considerable losses [17]. In Cameroon, *C. maculatus* can induce total loss of harvest in the absence of any protection measure within a short period of storage [18].

During storage, different methods are used to diminish the losses induced by insect on grain [19], but the synthetic insecticides remain the most popular control method and found to be the most effective. Despite their effectiveness, synthetic insecticides cause several health and environmental problems. Their repetitive use induces the development of pest resistance, destruction of ecosystems, environmental pollution and health problems [20]. In addition, most of the African farmers are poor and they would lack the means to buy the appropriate insecticides, nor the competence to manipulate these chemicals [20–22]. These difficulties make it imperative for seeking alternative methods, which can be eco-friendly, more accessible and effective against targeted stored insect pests and less harmful to beneficial organisms [21,22]. So, it becomes necessary to search for the plants endowed with insecticidal properties and then improve their utilization by easily accessible techniques. Therefore, *Aguaria salicifolia* is a good candidate for bioinsecticide, even though few studies had been carried out on its insecticidal properties. This plant is toxic against mustard Coleoptera, *Phaedon cochleariae* [23]. It is found in Cameroon especially around Mount Cameroon and Bamboutos Mountains localities.

This study determined the insecticidal activity of *Aguaria salicifolia* leaf extracts as stored cowpea protectant against infestation of cowpea beetle *C. maculatus*.

2. Materials and methods

2.1. Insect rearing

Callosobruchus maculatus, the main cowpea pest obtained from the infested cowpea stored by smallholders in Dang, Vina Division, Adamawa region of Cameroon was reared on cleaned and non-infested cowpea in 900 mL glass jars. Five jars were used as rearing medium, in the laboratory, in order to have enough insects for bioassays. Insects of fourth generation, aged $\leq$3 days, obtained from the laboratory were used to assess the bioactivity of the plant extracts.

2.2. Cowpea used for the experiment

Cowpea "Fekem morphotype" obtained from farmers at Gobo subdivision, Mayo Danay Division and Far-North region of Cameroon. This morphotype is locally very appreciated due to its high yield and grain size. Unfortunately, it is very susceptible to bruchid attack. Before using for experiment, broken grains, the pieces of stone, sand and other foreign materials were removed from the stock and cleaned grains were kept in the freezer at -20 °C for 14 days for disinfestation of all alive organisms. Thereafter, the sample was kept in laboratory conditions for 14 days. Grain moisture content determined by using the electronic moisture tester (Pfeufer HE 50 Mess-und prüfgeräte, Hoh-express, Germany) was 11.70 %.

2.3. Plant collection and processing

Green leaves of *Aguaria salicifolia* were collected in September and October 2020 at Magha-Atuallah Road (Lebialem) in the South-west Region of Cameroon, latitude 5°40′46.1″North and longitude 10°03′39.2″East, at an altitude of 2522 m above sea level. The

identity of the plant was confirmed at the Cameroon National Herbarium in Yaounde with voucher number N°33530SRF Cam. The leaves were dried at room temperature for 10 days and then ground using locally made pestle and mortar until the powder passed through a 0.20-mm sieve. The powder was stored in a freezer at −4 °C until needed for extraction.

2.4. Extracts preparation

Extracts were gotten by dissolving 300 g of leaf powder in water, ethyl acetate and methanol. The extraction procedure is described in the previous research [24]. The extracts gotten by using organic solvent were kept in the ambient laboratory conditions for 14 days to allow complete evaporation of solvent. The aqueous extract was kept in the freezer at −18 °C for 24 h, then the water was evaporated by lyophilization. Extracts were conserved in non-transparent closed vials and stored in the freezer at −4 °C until needed for bioassays.

2.5. Phytochemical screening

The leaf powder was firstly dissolved in equivalent mixture methylene chloride/methanol (proportion of 1/1) before applying the phytochemical screening method. The extract obtained from dissolved powder and the other solvent extracts were used for phytochemical screening to detect alkaloids, phenolic compounds, terpenoids and sterols, tannins, glucosides, anthraquinones, coumarins, anthocyans and saponins using the standard methods [25].

2.6. Mortality bioassay

Fifty (50) g of cowpea grains were introduced in glass jars (450 mL capacity) and mixed with 0.1g, 0.2 g, 0.4 g and 0.8 g of aqueous extract and leaf powder, corresponding to 2, 4, 8 and 16 g/kg, respectively. Each mixture was manually shaken for 2 min to allow uniform coating of extract and leaf powder on grains. Twenty *C. maculatus* adult not more than 3 days old were added into the jars containing treated cowpea grains and then covered with perforated lids and kept on shelves in ambient laboratory conditions (Temp. = 23.71 ± 1.03 °C; RH. = 81.38 ± 2.03 %). The experiment was arranged in a completely randomised design four times replicated. Insect mortality was recorded at 1, 3, 5 and 6 days post-treatment. During observations dead and alive *C. maculatus* were counted. Temperature and relative humidity were recorded by datalogger (Data logger Model EL-USB-2, LASCAR, China).

2.7. Population increase and damage reduction

At the end of the previous bioassay (mortality test), the same treatments without insects were maintained in the same laboratory conditions for further observations. After three months of storage the number of emerging bruchids was determined. The number of perforated and non-perforated grains was also determined. The weight loss was assessed according to counting and weighing method [26]. This loss was calculated using the following formula:

$$\textit{Weight loss}\ (\%) = \frac{(W_u \times N_d) - (W_d \times N_u)}{W_u(N_d + N_u)} \times 100$$

Where W_u is the weight of undamaged grains, N_d is the number of damaged grains, W_d is the weight of damaged grains, N_u is the number of undamaged grains.

2.8. Repellency test

The area preference test [27] was used to evaluate the repellent properties of the tested products. Experiment was carried out as described in the previous research [24]. Each treatment was replicated four times. The number of insects present in the control (N_C) and treated (N_T) strip were recorded 30, 60, 90 and 120 min after exposure. Percent repellency (*PR*) values were computed as follows:

$$PR = [(N_C - N_T) / (N_C + N_T)] \times 100$$

The mean repellency values of each plant extract were calculated and assigned to repellency classes [27]: class 0 (PR < 0.1 %), class I (PR = 0.1–20 %), class II (20.1–40 %), class III (40.1–60 %), class IV (60.1–80 %), class V (80.1–100).

2.9. Data analysis

Abbott's formula [28] was used to correct for control mortality before analysis of variance (ANOVA) and probit analysis. Data on cumulative corrected mortality, damage, weight loss and repellency were arcsine-transformed [$\sqrt{(x/100)}$], and the number of population growth was log transformed (x+1). The transformed data were subjected to the ANOVA procedure using SPSS package Version 20.0 [29,30]. Probit analysis [29] was conducted to determine lethal dosages of extracts on *C. maculatus* at 1, 3, 5 and 6 days after treatment.

3. Results

3.1. Chemical composition of Aguaria salicifolia extracts

The chemical composition varied from one extract to another in term of content, but the different extracts had almost the same chemical compounds (Table 1). The phenolic compounds were very abundantly observed in all the four products. Alkaloids were abundant in the organic solvent extracts and the crude powder, but absent in the aqueous extract. Coumarins were also abundant in the organic solvent extracts, but very low in the aqueous extract. Flavonoids, tannins and anthocyans were abundantly observed in all the extracts. The terpenoids content was higher in the leaf powder than the solvent extracts. Glucosides and saponins were only present in ethyl acetate and aqueous extracts, respectively.

3.2. Toxicity of Aguaria salicifolia on Callosobruchus maculatus

Significant mortality of *C. maculatus*, increasing with the dosage and exposure periods, was recorded from treated cowpea with crude powder and aqueous extract (Table 2). The efficacy of these products was similar up to three days post-exposure. At 2 and 4 g/kg grains and within 5–6 days after treatment, powder was more effective than the aqueous extract. The highest mortality was recorded at 6 days post-treatment with aqueous extract (80.20 %) and leaf powder (84.08 %) at the dosage of 16 g/kg grains. The LD values decreased with increasing exposure (Table 3). In general, leaf powder recorded the lowest LD values compared to the aqueous extract. At 3 days exposure LD_{50} values were 20.24 and 44.04 g/kg for leaf powder and aqueous extract, respectively. The lowest LD values (0.77 and 3.14 g/kg, in the same order) were recorded at 6 days post-exposure. The R^2 values were almost all greater than 0.6 and χ^2 were in general not significant, then the parameters of plant extracts toxicity observed were close to the expected ones.

3.3. Control of Callosobruchus maculatus population growth and reduction of cowpea damage

The insect population growth and grain damage were considerably reduced. As the products dosages increased the number of insects emerged from both plant extract treatments were reduced (Table 4). The complete population suppression was obtained with aqueous extract at its highest dosage (16 g/kg), while few insects emerged from grains treated with leaf powder. Even at their lowest dosage (2 g/kg), the number of insects emerged was significantly reduced by leaf powder (35 insects) and aqueous extract (27 insects) compared to the control (403.67 insects). The variation of insect population in different treatment was correlated with grain damage. At the highest dosage, grain damage and weight loss were completely suppressed by aqueous extract, and only 1.98 % grain damage and 0.29 % grain weight loss were recorded from treatment with leaf powder.

3.4. Repellency induced by Aguaria salicifolia extracts

The three *A. salicifolia* extracts (methanolic, ethyl acetate and aqueous extracts) were repellent to *C. maculatus* and this repellency varied according to the extract (Table 5). The percent of repellency increased slightly as the concentration of extracts increased. The exposure periods did not statistically influence the repellency capacity of extract. Three repellency classes were identified; aqueous extract was the most repellent and belonged to the repellent class IV whereas methanolic and ethyl acetate extracts belonged to classes III and II, respectively. A maximum repellency (73.75 %) was obtained with aqueous extract at 1 mg/cm^2 within 60 min exposure whereas the minimum repellency (30.00 %) was recorded with ethyl acetate extract at the lowest dosage (0.5 mg/cm^2).

4. Discussion

Aguaria salicifolia tested in this study for its biological activities such as insecticide, insect growth inhibition and repellency with the aim to protect stored cowpea grains against damage by *C. maculatus* proved to be effective. These insecticidal properties might be attributed to the phytochemical constituents such as flavonoids, alkaloids, tannins, total phenolic, anthocyans, terpenoids, coumarins

Table 1
Chemical composition of *Aguaria salicifolia* extracts.

Compounds	Ethylacetate	Methanol	aqueous extract	leaf powder
Alkaloids	++	++	–	++
Phenolic compounds	+++	+++	+++	+++
Flavonoids	+++	++	++	++
Terpenoidsandsterols	+	+	+	++
Tanins	++	++	++	++
Glucosides	+	–	–	–
Anthraquinones	+	++	+	++
Coumarins	++	+++	+	++
Anthocyans	++	++	+++	++
Saponins	–	–	+	–

+: present (but very low); ++: Abundant; +++: very abundant; -: Absent.

Table 2
Cumulative mortality of *Callosobruchus maculatus* induced by *Aguaria salicifolia* leaf on *Vigna unguculata* grain.

Période (jour)	Concentrations (g/kg)	Leaf powder	Aqueous extract	$t^{sig.}$
	0	0.00 ± 0.00^{b}	0.00 ± 0.00^{c}	–
1	2	3.33 ± 0.33^{b}	$6.75 \pm 1.62b^{c}$	-0.77^{ns}
	4	11.84 ± 1.59^{ab}	8.42 ± 1.58^{abc}	2.36^{ns}
	8	18.51 ± 4.24^{a}	13.42 ± 4.33^{ab}	0.69^{ns}
	16	23.68 ± 1.32^{a}	18.60 ± 1.40^{a}	2.16^{ns}
	$F_{(4; 10)}$	14.86***	9.54*	
	0	0.00 ± 0.00^{c}	0.00 ± 0.00^{c}	–
3	2	24.61 ± 1.95^{b}	25.35 ± 2.59^{b}	-0.20^{ns}
	4	36.82 ± 2.64^{ab}	30.44 ± 2.52^{b}	1.29^{ns}
	8	41.90 ± 4.34^{a}	33.86 ± 1.14^{ab}	2.50^{ns}
	16	45.42 ± 3.35^{a}	42.28 ± 3.97^{a}	0.85^{ns}
	$F_{(4; 10)}$	41.46***	42.50***	
	0	0.00 ± 0.00^{d}	0.00 ± 0.00^{d}	–
5	2	52.63 ± 2.63^{c}	34.26 ± 3.55^{c}	8.76*
	4	57.82 ± 1.28^{bc}	53.33 ± 1.67^{b}	5.53*
	8	63.09 ± 1.12^{ab}	65.19 ± 5.61^{ab}	-0.41^{ns}
	16	70.03 ± 2.54^{a}	79.26 ± 2.98^{a}	−6.77*
	$F_{(4; 10)}$	240.68***	84.76***	
	0	0.00 ± 0.00^{c}	0.00 ± 0.00^{d}	–
6	2	61.34 ± 2.05^{b}	39.44 ± 3.38^{c}	7.28*
	4	71.70 ± 4.18^{ab}	56.85 ± 1.58^{b}	5.58*
	8	73.45 ± 3.85^{ab}	68.70 ± 4.06^{ab}	1.44^{ns}
	16	84.08 ± 3.41^{a}	80.20 ± 2.91^{a}	1.00^{ns}
	$F_{(4; 10)}$	116.34***	122.70***	

Mean ± S.E. followed by the letter in a column do not differ significantly at $P < 0.05$ (Tukey's test). ^{ns} $P > 0.05$; *$P < 0.05$; **$P < 0.001$; ***$P < 0.0001$, $^{sig.}$: signification or probability.

Table 3
Toxicity parameters of *Aguaria salicifolia* leaf on cowpea seed beetle *Callosobruchus maculatus*.

Produits	R^2	Slope±SE	LD_{50} (95 % FL)	LD_{95} (95 % FL)	χ^2
		3 days			
Leaf powder	0.54	0.60 ± 0.11	20.24(13.45; 44.19)	–	13.72^{ns}
Water extract	0.70	0.50 ± 0.11	44.04(22.37; 227.24)	–	8.70^{ns}
		5 days			
Leaf powder	0.80	0.50 ± 0.11	1.56(0.55; 2.51)	–	4.40^{ns}
Water extract	0.80	1.32 ± 0.12	3.84(3.02; 4.66)	67.99(39.68; 164.28)	16.71^{ns}
		6 days			
Leaf powder	0.65	0.72 ± 0.12	0.77(0.11; 1.57)	–	18.64*
Water extract	0.78	1.19 ± 0.12	3.14(2.58; 3.67)	76.06(48.80; 144.47)	12.11^{ns}

FL: Fudicial limit; LD: lethal dosage.

and saponins, which are known toxic to insect pests [31,32]. The phytochemical screening revealed that the different extracts even from the same plant species had different composition qualitatively and quantitatively. According to the solvent used for extraction, the presence and content of the chemical compounds vary. Similar findings are reported by Mano et al. [33] with the hydroalcoholic extract of *Cleome viscosa*. The quantitative and qualitative variations of chemical compounds within the extracts or plant species may be explained by the structure of certain molecules that are able to link with the solvents according to their polarity.

The increase of insect mortality with product dosage and exposure period could be attributed to the content of active compounds, which remained toxic to insects through the exposure period as reported by previous researches [14,22,34]. The different LC values showed that the leaf powder was more toxic than aqueous extract on *C. maculatus* adult. This difference can be explained by chemical composition of the different plant products which varied qualitatively and quantitatively. In fact, the screening revealed that leaf powder was richer in the chemical compounds than aqueous extract. Some compounds like alkaloids were not found in aqueous extract whereas, these compounds have insecticidal properties. The compounds like terpenoids and sterols, anthraquinones and coumarins were more abundant in leaf powder than in aqueous extract. Different bioactivities have been described for these chemical compounds. Alkaloids was reported neurotoxic and as enzyme inhibitor [35]; flavonoids induce the paralysis of insect mouthparts, the reduction of respiratory movements, the instability of locomotion, the reduction of oxygen consumption, that lead to the death of insect; terpenes cause disturbance in the nervous system responsible for paralysis and mortality [31]. In addition to these mechanisms, the plant powder has tendency to block stigmata of insects, that alters the respiration and death follows [36].

Aqueous extract was more effective than leaf powder to inhibit insect pest population growth and grain damage reduction, because the content of active compounds with ovicidal or larvicidal activity was probably more concentrated in the extract than in the raw leaf powder. Ileke et al. [37] reported that the leaf extracts of *Acanthus montanus*, *Alchornea laxiflora* and *Argyreia nervosa* were more toxic than their leaf powders on *Sitophilus zeamais*. By suppressing the population growth, extract at same time reduced the grain damage. In

Table 4
Callosobruchus maculatus population increase and grain damage in cowpea grain treated with *Aguaria salicifolia* leaf extracts in after three months storage under ambient laboratory conditions.

Dosage (g/kg)	powder	water extract
Insect number Mean ± SE		
0	403.67 ± 93.20^{a}	403.67 ± 93.20^{a}
2	35.00 ± 7.57^{b}	27.00 ± 6.00^{b}
4	35.00 ± 7.23^{b}	25.33 ± 5.33^{b}
8	29.67 ± 2.73^{b}	22.67 ± 1.20^{b}
16	25.33 ± 3.93^{b}	20.00 ± 0.00^{b}
$F_{(4;10)}$	15.74***	16.50***
Percentage of perforated grains Mean ± SE		
0	94.88 ± 0.73^{a}	94.88 ± 0.73^{a}
2	5.27 ± 2.65^{b}	2.22 ± 1.67^{b}
4	5.27 ± 2.59^{b}	1.84 ± 1.84^{b}
8	3.31 ± 0.77^{b}	1.23 ± 0.33^{b}
16	1.98 ± 1.46^{b}	0.00 ± 0.00^{b}
$F_{(4;10)}$	486.16***	1286.34***
Weight loss Mean ± SE		
0	17.38 ± 1.30^{a}	17.38 ± 1.30^{a}
2	0.86 ± 0.47^{b}	0.42 ± 0.23^{b}
4	0.733 ± 0.39^{b}	0.37 ± 0.12^{b}
8	0.36 ± 0.13^{b}	0.25 ± 0.25^{b}
16	0.29 ± 0.18^{b}	0.00 ± 0.00^{b}
$F_{(4;10)}$	133.85***	161.240***

Mean ± S.E. followed by the letter in a column do not differ significantly at $P < 0.05$ (Tukey's test, ***$P < 0.0001$.

Table 5
Repellency activity of *Aguaria salicifolia* leaf extracts on *Callosobruchus maculatus*.

Concentration (mg/cm^2)	Time (minute)				$F_{(3; 12)}$
	30	60	90	120	
Water extract					
0.5	55.00 ± 7.36^{aA}	53.75 ± 3.75^{bA}	46.25 ± 6.57^{aB}	53.75 ± 4.73^{aA}	4.87*
1	60.00 ± 4.08^{aA}	61.25 ± 1.25^{abA}	51.25 ± 3.75^{aA}	53.75 ± 5.15^{aA}	0.34^{ns}
2	60.00 ± 5.40^{aA}	70.00 ± 2.04^{aA}	58.75 ± 4.27^{aA}	65.00 ± 3.54^{aA}	0.47^{ns}
4	71.25 ± 6.58^{aA}	73.75 ± 5.15^{aA}	65.00 ± 7.91^{aA}	71.25 ± 5.54^{aA}	2.65^{ns}
$F_{(3; 12)}$	1.32^{ns}	6.95*	1.97^{ns}	3.27^{ns}	
Repellent class	R–IV	R–IV	R–III	R–IV	
Methanolic extract					
0.5	31.255 ± 4.27^{bA}	35.00 ± 0.00^{aA}	32.50 ± 1.44^{bA}	36.25 ± 1.25^{aA}	0.46^{ns}
1	46.25 ± 5.15^{abA}	43.75 ± 3.15^{aA}	41.25 ± 1.25^{abA}	42.50 ± 3.23^{aA}	0 0.38^{ns}
2	51.25 ± 5.54^{abA}	48.75 ± 2.39^{aA}	46.25 ± 4.73^{aA}	45.00 ± 5.40^{aA}	0.95^{ns}
4	52.50 ± 4.79^{aA}	50.00 ± 7.07^{aA}	52.50 ± 3.23^{aA}	48.75 ± 1.25^{aA}	0.27^{ns}
$F_{(3; 12)}$	3.67*	2.83^{ns}	7.83*	2.59^{ns}	
Repellent class	R–III	R–III	R–III	R–III	
Ethyl acetate					
0.5	38.75 ± 2.39^{aA}	30.00 ± 6.12^{aA}	31.25 ± 6.25^{aA}	33.75 ± 3.15^{aB}	0.68^{ns}
1	42.50 ± 3.23^{aA}	37.50 ± 9.24^{aA}	33.75 ± 5.91^{aA}	33.75 ± 9.44^{aA}	0.31^{ns}
2	53.75 ± 8.00^{aA}	38.75 ± 6.57^{aB}	42.50 ± 8.54^{aAB}	36.25 ± 4.27^{aB}	4.15*
4	53.75 ± 5.54^{aA}	52.50 ± 1.44^{aA}	48.75 ± 2.39^{aA}	45.00 ± 5.40^{aA}	0.92^{ns}
$F_{(3; 12)}$	2.16^{ns}	2.09^{ns}	1.70^{ns}	0.80^{ns}	
Repellent class	R–III	R–II	R–II	R–II	

Mean ± S.E. followed by the letter in a column do not differ significantly at $P < 0.05$ (Tukey's test. ^{ns} $P > 0.05$; *$P < 0.05$.

the previous studies [38,39], plant extracts were reported to be effective against each developmental stages of *C. maculatus*. The bioactivity of plant extracts can be due to tannins and total phenolic compounds, which are able to disrupt eggs development and hatchability. It was demonstrated that alkaloids, saponins and flavonoids have inhibitor effect on growth and oogenesis in insects [40]. In the same order, Kouninki et al. [41] showed that terpenes reduce oviposition and disturb different developmental stages of insect.

The Repellent action of plants extracts or any insecticidal products may be used to control hidden infestation before newly harvested grain is introduced in storage facility [42]. The repellent plant extracts may be incorporated into packaging materials of storage facilities to prevent insects from entering stored cereals or pulses. Murugesan et al. [43] reported high repellency (RC V; 82 %) induced by 1500 ppm/cm^2 of *Solanum torvum* leaf ethanol extract within 60 min exposure, but the same plant extracted with methanol within the same duration caused 52 % (RC III). Such difference was also observed in the present work, ethyl acetate extract was in repellency class II whereas the methanol extract had class III as repellency class. This discrepancy can be attributed to the variation of

phytochemical compounds according to the plant species. In addition, the type of solvents influences the repellency capacity of extract because the extracted active compounds vary according to the solvent polarity. Similar findings were reported by Kamruzzaman et al. [44]. These authors found that aqueous or organic solvent plant extracts showed different repellency classes. They observed that ethanolic extracts of these plants were the most effective. Repellency effectiveness was inversely correlated with the time of exposure as observed by Shoukat et al. [45]. This result can be explained by high volatility of repulsive chemical compounds with low molecular weight [46].

5. Conclusion

Damage induced by beetles on stored food grains constraint the smallholders and famers for searching the suitable methods. The most used conventional methods are chemicals, those ones are expensive and sometimes less environmentally friendly. Thus, the search for alternative methods become obligatory. *Aguaria salicifolia* products, especially aqueous extract and crude powder, revealed to be effective as insecticide and population growth inhibitors against *C. maculatus* infesting cowpea. The repellency varied according to the types of solvent used, aqueous extract was fairly repellent. In addition to induce mortality of insect pests, the extracts of this plant can keep the grains out of their reach by the repellent activity. These results show promise for using *A. salicifolia* leaf extracts in the protection of cowpea against infestation by bruchids. However, study needs to be carried out concerning the toxicity effects of treated grains on consumers before promoting these plant products in the stored grain protection. The present results encourage the use of *A. salicifolia* leaf in the preservation of cowpea against infestation by bruchids and even other stored grains since it is effective and easily accessible.

Data availability statement

The data sets used and/or analysed during this study are available from the corresponding author on reasonable request.

CRediT authorship contribution statement

Jean Wini Goudoungou: Writing – review & editing, Writing – original draft, Software, Methodology, Conceptualization. **Arindo Félicité:** Methodology, Investigation, Data curation. **Raoul Borkeum Barry:** Writing – review & editing, Methodology, Investigation, Data curation. **Jean Pierre Abdou:** Writing – review & editing, Methodology, Formal analysis. **Daniel Kosini:** Writing – review & editing, Resources, Investigation. **Elias Nchiwan Nukenine:** Visualization, Validation, Supervision, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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