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Chemical composition and toxicity of some Agro waste-derived insecticides against Angoumois grain moth, *Sitotroga ceralella* (Olivier) [Lepidoptera: Gelechiidae] infesting stored paddy grains

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Abstract

Background: Agriculture being one of the major practices in the world has contributed to environmental pollution, especially in developing countries where there were no equipment to recycle the agricultural wastes. Considering the high level of infestation of paddy by *Sitotroga cerealella* and the high level of pollution caused by agricultural wastes, this research investigated the chemical composition and toxicity of agro wastes (rice husk, maize cob, groundnut and cowpea pods) as eco-friendly protectants of paddy against *Sitotroga cerealella*. Parameters assessed include adult mortality, oviposition, adult emergence and egg hatchability. Gas chromatography and mass spectrophotometry were used to isolate and characterize the active compounds present in the most effective crude extract.

Results: The results of the study revealed that all agricultural wastes showed high mortality effect on *S. cerealella*. Cowpea pod powder was the most toxic to adult paddy moth that caused 33.33%, 36.67%, 46.67%, 50% and 60% mortality of *S. cerealella* at concentrations 0.1 g, 0.2 g, 0.3 g, 0.4 g and 0.5 g/20 g of paddy grains after 24 h of exposure, respectively. The Cowpea pod, groundnut pod and maize cob extracts caused 100% mortality of *S. cerealella* at concentration 0.5 ml/20 g of paddy grains after 96 h of exposure, respectively. The lethal concentrations LC_{50} and LC_{90} of cowpea pod after 24 h were 0.16 and 0.64 ml which were the lowest of all agro waste extract tested. GC–MS analysis revealed that 19 chemical compounds were present in cowpea pod extract, 9, 12-Octadecadienoic acid (a methyl ester) has the highest percentage total of 39.57% and 4-Pentenal, 2-methylene (0.12%) has the least percentage total.

Conclusion: All the observations revealed that cowpea pod was the most effective. The findings also suggested that the selected agricultural wastes have a promising insecticidal potential and can be used as alternatives to synthetic chemical insecticides for the control of stored product insects.

Keywords: Agro wastes, Paddy, *Sitotroga cerealella*, Hatchability, Progeny development, Bioactive compounds

Background

Rice, *Oryza sativa*, is an essential component of staple foods playing a major nutritional role in the diet of people of many developing nations (Norman and Kebe 2006; FAO 2013; Padmasri et al. 2017). Rice is becoming an essential source of cash for farmers in developing countries such as Nigeria. However, rice production is threatened by a lot of lepidopteran and coleopteran pests (Ashamo and Akinnawonu 2012; Padmasri et al. 2017). Stored paddy is susceptible to a large numbers of pre- and post-harvest pests which cause losses of about 4.09–12.61% of world paddy production, if not unchecked

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(Adam 1998; Shafique and Ahmad 2003; Mahmood 2018). Angoumois grain moth (*Sitotroga cerealella*) is one of the field-to-store lepidopteran pests of paddy in temperate and tropical regions of the world (Adedire 2001; Bushra and Aslam 2014). One gravid female moth can completely devoid 50 g of paddy within the next three generations in storage, if control is neglected (Cogburn et al. 1975, Hossien et al. 2018). The moth larvae are the most destructive stage; they enter the grains and feed voraciously on the endosperm which can lead to loss of viability as a result of tunnels made within the paddy (Khattak et al. 1996; Tripathi et al. 2000; Ileke 2014; Mahmood 2018).

The management of pre and post-harvest pests of crops has been the major concern of entomologists all over the world. The use of synthetic chemical insecticides has been exploited for the management of rice moth in storage (Ashamo and Ogungbite 2014; Ileke 2014). The efficacy of different synthetic chemical insecticides to reduce the proliferation of *S. cerealella* in storage has been reported (Chandra et al. 1978; Mahmood 2018). Its usage has greatly reduced as a result of their limitations such as environmental health hazards, toxicity to non-targeted organisms and environmental imbalance which can lead to development of resistance and subsequent resurgence in pest population (Ashamo and Ogungbite 2014; Mahmood 2018; Ileke and Adesina 2018; Idoko and Ileke 2020; Ileke et al. 2020a, b, c, d, e; Obembe et al. 2020). Hence, the search for non-toxic to beneficial insects and environmentally friendly methods for the control of paddy moth, *S. cerealella*, is inevitable. Nigeria farmers at village level stored their grains in small quantities for consumption by their immediate family members because of the high cost associated with the use of chemical control of pests associated with large storage of grains. There is need for cheap, eco-friendly and biodegradable methods for safe storing of paddy. An indigenous source of insecticide from plant products as repellents against paddy moth, *S. cerealella*, has been reported by many researchers for more than two centuries (Ashamo and Akinnawonu 2012; Ashamo and Ogungbite 2014; Ileke 2014; Padmasri et al. 2017; Mahmood 2018). Plant products-derived insecticides definitely have active ingredients that persist for a long time with minimal or no adverse effect on germination and cooking qualities (Prakash and Mathur 1981; Mahmood 2018).

Recently, agro wastes-derived insecticides against weevils and beetles have yielded the positive results in comparison with the use of some chemical insecticides and botanical products to reduce storage losses in maize and cowpea seeds due to insects (Gueye et al. 2012; Obi et al. 2016; Akowuah et al. 2018). Agricultural wastes are residues or non-product output of production and processing of raw agricultural products such as fruits, vegetables, meat, poultry, dairy products and crops that may contain materials that can benefit man (Obi et al. 2016). The use of agro wastes in storing paddy for protection against paddy moth is eminent in Nigeria based on the recent empowerment of farmers by the Government. Though information on the usage of agro waste and toxicity effect on its protectant ability of stored paddy against *S. cerealella* is scarce in literatures. In view of this, the present research objectives are to evaluate the toxicity of rice husk, maize cob, groundnut and cowpea pods powder, ash and oil extracts against *S. cerealella* and also to isolate and characterize the crude extract from the most effective agro waste.

Methods

Experimental location

The study was conducted in the Storage Entomology Research Laboratory of Department of Biology, Federal University of Technology, Akure, Ondo State, Nigeria, and at the Central Research Laboratory, University of Lagos, Akoka Lagos State, Nigeria.

Insect culture

Newly emerged adults *S. cerealella* used for this study were gotten from already existing culture in Storage Entomology Postgraduate Research Laboratory, Department of Biology, Federal University of Technology, Akure (FUTA), Ondo State, Nigeria. One hundred pairs of *S. cerealella* were introduced into two litres plane glass kilner jar containing 500 g of paddy rice (Variety Faro-52) obtained from Agricultural Development Programme, Akure, Ondo State. (From the beginning to this poin unitalised it apart from scientific word that is *S. cerealella*. The moth colony was maintained under constant insectary conditions of 28 ± 2 °C and 75 ± 5% relative humidity.

Sampling of paddy

Paddy rice, *O. sativa* (Faro-52), free of pests and insecticides were collected from Seed Unit and Germplasm, Agricultural Development Project (ADP) in Akure. The paddy was cleaned and kept at − 5 °C for 7 days in other to kill all hidden infestations (Ileke and Oni 2011). Disinfested paddy was dried in an oven at 40 °C for 4 h (Jambere et al. 1995; Ileke 2019) before they were stored in containers with tight lids disinfested by swabbing with 90% alcohol (Adedire et al. 2011).

Preparation of Agro wastes powder and ash

Rice husks, cowpea pods, maize cobs and groundnut pods were collected from uninfected plants and free of insecticides within Akure metropolis, Ondo State, and brought to Storage Entomology Postgraduate Research Laboratory, Biology Department, Federal University of Technology Akure, Ondo State, Nigeria, for subsequent processing. The agro wastes were dried on slab in the laboratory for 14 consecutive days until completely dried up. Each type of dried agro wastes was then milled separately into powder with the help of an electric grinder. The milled agro waste powder was kept in a plastic container separately and labelled for further use. Some of the dried agro wastes were also crushed separately and burnt into ash using burning furnace at Research Laboratory, Department of Animal Production and Health, FUTA. They were sieved separately to get fine ash before application and kept inside airtight container until further use.

Extraction of agricultural wastes

Two hundred grams (200 g) of agro wastes powder was soaked separately in 400 ml of absolute ethanol in an extraction bottle. The mixture was stirred intermittently with a glass rod and extraction terminated after 72 h. The resulting mixture was filtered, and the solvent was evaporated using a rotary evaporator. Extracts were kept in a bottle and preserved in the refrigerator until further use.

Moth bioassay

Assessment of response of *S. cerealella* in paddy treated with agro wastes powders

Ten pairs of *S. cerealella* (0–24 h old) were introduced into the treated paddy with agro waste powders (rice husk, cowpea pod, maize cob and groundnut pod) at dosage 0.1 g, 0.2 g, 0.3 g, 0.4 g and 0.5 g/20 g of paddy rice in 150 ml plastic containers and replicated three times. Mortality of adult moths was evaluated daily for four consecutive days. Percentage adult mortality was corrected using Abbott formula (Abbott 1925).

$$P_T = \frac{P_o - P_c}{100 - P_o} \times \frac{100}{1} \quad (1)$$

where P_T = corrected mortality (%), P_O = observed mortality (%) and P_C = control mortality (%).

Dead and live moths were removed at the end of day 4 before returning the paddy to their respective containers. The treated containers were kept in insect cage for emergence of the first filial (F1) generation. At the end of 35 days, containers were sieved out separately and newly emerged adults moth were totalled and documented as described by Odeyemi and Daramola (2000).

Similarly, twenty (0–24 h old) eggs of *S. cerealella* were introduced into treated paddy with agro wastes powders at concentrations 0.1 g, 0.2 g, 0.3 g, 0.4 g and 0.5 g/10 g of paddy. The containers were observed daily for 35 days, and the number of adults emerging from each treatment was recorded.

Assessment of response of *S. cerealella* in paddy treated with agro wastes extracts

The toxicity of agro wastes (rice husk, cowpea pod, maize cob and groundnut pod) extracts against the *S. cerealella* was tested at concentrations 0.1 ml, 0.2 ml, 0.3 ml, 0.4 ml and 0.5 ml/20 g of paddy. The agro wastes extracts were thoroughly mixed to ensure uniform coating of the paddy grains. Control experiment was also set up and replicated three times. Ten pairs of teneral adult (0–24 h) old of *S. cerealella* were introduced into each of the containers and covered. Mortality of adult moth was evaluated after twenty-four hours for four days using standard method.

Similarly, twenty (0–24 h old) eggs of *S. cerealella* were introduced into the treated paddy with agro waste extracts at concentrations 0.1 ml, 0.2 ml, 0.3 ml, 0.4 ml and 0.5 ml/10 g of paddy. The jars were observed daily for 35 days, and the number of adults emerging from each treatment was recorded.

Isolation and characterization of the most effective agro waste

Gas chromatography coupled with mass spectrum (GC–MS) analysis was used to reveal profiles of compounds in cowpea pod extract. About 1 μl of cowpea extract was analysed using Agilent Technologies. The models of machine are as follows: mass spectrum (5975C VLMSD), injector (7683B Series) and GC (7890A). Helium was used as carrier gas. The capillary column was HP-5MS with the dimensions: 30 cm in length, 0.320 mm internal diameter and a film thickness of 0.25 μm. The GC oven temperature was set at 80 °C for 2 min. The temperature increased steadily at 6 °C per minutes to 240 °C and was held for 6 min. The sample was run for 36 min. The peak of each chemical compound was expressed based on its retention time and balance.

Statistical analysis

All data were subjected to analysis of variance (ANOVA), and means were separated using the new Duncan's

$$\%\ \text{Adult emergence} = \frac{\text{Total number of adult emergence}}{\text{Total number of eggs laid}} \times 100 \quad (2)$$

multiple range test. Log-probit model analysis was carried out on the percentage mortality of paddy moth results to evaluate the 50% lethal concentrations (LD_{50} and LC_{50}) and 90% lethal concentrations (LD_{90} and LC_{90}).

Results

Mortality of adult *S. cerealella* in treated paddy with agricultural waste powders

Mortality of adult paddy moth in treated paddy with agro waste powders (rice husk, cowpea pod, maize cob and groundnut pod) is presented in Table 1. Moth mortality is dosage dependent. The higher the concentration, the higher the mortality rate. The toxicity of tested agro waste powders was significantly ($p < 0.05$) different from the control. Cowpea pod powder was the most toxic to paddy moth that caused 33.33%, 36.67%, 46.67%, 50.00% and 60.00% mortality of *S. cerealella* at concentrations 0.1 g, 0.2 g, 0.3 g, 0.4 g and 0.5 g/20 g of paddy grains after 24 h of exposure, respectively. This was followed by groundnut pod powder that evoked 30%, 33.33%, 43.33%, 46.67% and 56.67% mortality of paddy moth at concentrations 0.1, 0.2, 0.3, 0.4 and 0.5 g/20 g of paddy grains after 24 h of exposure, respectively. The least toxic agro waste powder was rice husk that causes 23.33%, 26.67%, 36.67%, 40.00% and 46.67% mortality of *S. cerealella* at concentrations 0.1, 0.2, 0.3, 0.4 and 0.5 g/20 g of paddy grains after 24 h of exposure, respectively. Cowpea pod powder evoked 70.00% and 86.67% mortality of paddy moth at rate 0.4 and 0.5 g/20 g of paddy grains after 96 h of exposure, respectively. Toxicity trend of agro waste powders was dosage dependent and exposure time.

Lethal dose (LD) of agro waste powders against *S. cerealella*

The lethal dose of the agro waste powders against *S. cerealella* is given in Table 2. The dosage calculated that is required for the rice husk, groundnut pod, cowpea pod and maize cob powders to cause 50% (LD_{50}) and 90% (LD_{90}) mortality against the test organism calculated after 24 h were 0.80 and 2.97 g, 0.64 and 1.79 g, 0.62 and 1.67 g, and 0.76 and 2.77 g, respectively. However, it was observed that these values continued to reduce after 48, 72 and 96 h of exposure. From the calculation, Cowpea pod powder was observed to have the lowest lethal dose across all periods of exposure. All these values have different confidence limits that might be effective aside from the calculated values.

Table 1 Dose–response of adult *S. cerealella* treated with agro waste powders

Agro waste treatments powders	Conc. (g)	Mean % mortality ± SE after			
		24 h	48 h	72 h	96 h
Rice husk	0.1	23.33 ± 2.67^{b}	33.33 ± 2.67^{bc}	40.00 ± 3.88^{bc}	43.33 ± 3.67^{b}
Groundnut pod		30.00 ± 2.88^{cde}	36.67 ± 2.33^{cde}	43.33 ± 3.67^{bc}	46.67 ± 3.67^{c}
Cowpea pod		33.33 ± 2.67^{bcd}	40.00 ± 3.88^{bcd}	46.67 ± 3.33^{bcd}	50.00 ± 3.88^{bc}
Maize cob		26.67 ± 2.33^{bc}	30.00 ± 2.88^{b}	40.00 ± 3.88^{b}	43.33 ± 3.67^{b}
Rice husk	0.2	26.67 ± 2.33^{bc}	36.67 ± 2.33^{cde}	40.00 ± 3.88^{bc}	43.33 ± 3.67^{cde}
Groundnut pod		33.33 ± 2.67^{def}	40.00 ± 3.88^{def}	46.67 ± 3.33^{bcd}	53.33 ± 3.67^{cde}
Cowpea pod		36.67 ± 2.33^{cde}	43.33 ± 3.67^{def}	50.00 ± 3.88^{cde}	56.67 ± 3.33^{def}
Maize cob		30.00 ± 2.88^{bcd}	36.67 ± 2.33^{cde}	43.33 ± 3.67^{bc}	50.00 ± 3.88^{bcd}
Rice husk	0.3	36.67 ± 3.33^{def}	40.00 ± 3.88^{def}	46.67 ± 3.33^{cde}	53.33 ± 3.67^{cde}
Groundnut pod		43.33 ± 3.67^{efg}	46.67 ± 3.33^{efg}	53.33 ± 3.67^{def}	60.00 ± 3.88^{def}
Cowpea pod		46.67 ± 3.33^{fgh}	50.00 ± 3.88^{efg}	56.67 ± 3.33^{def}	63.33 ± 3.67^{efg}
Maize cob		40.00 ± 3.88^{efg}	43.33 ± 3.67^{efg}	50.00 ± 0.00^{cde}	56.67 ± 3.33^{cde}
Rice husk	0.4	40.00 ± 3.88^{fgh}	43.33 ± 3.67^{fgh}	53.33 ± 3.67^{fgh}	60.00 ± 3.88^{fgh}
Groundnut pod		46.67 ± 3.33^{fgh}	50.00 ± 3.88^{fgh}	60.00 ± 3.88^{fgh}	66.67 ± 3.33^{gh}
Cowpea pod		50.00 ± 3.88^{ghi}	53.33 ± 3.67^{ghi}	63.33 ± 3.67^{ghi}	70.00 ± 3.88^{h}
Maize cob		43.33 ± 3.67^{ghi}	46.67 ± 3.33^{fgh}	56.67 ± 3.33^{efg}	63.33 ± 3.67^{fgh}
Rice husk	0.5	46.67 ± 3.33^{hi}	53.33 ± 3.67^{ijk}	63.33 ± 3.67^{ghi}	76.67 ± 3.33^{i}
Groundnut pod		56.67 ± 3.33^{hi}	63.33 ± 3.67^{jk}	66.67 ± 3.33^{hi}	83.33 ± 3.67^{i}
Cowpea pod		60.00 ± 3.88^{hi}	66.67 ± 3.33^{k}	70.00 ± 3.88^{i}	86.67 ± 3.33^{i}
Maize cob		50.00 ± 3.88^{i}	60.00 ± 3.88^{ijk}	66.67 ± 3.33^{hi}	80.00 ± 3.88^{i}
Control		0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}

Mean followed by the same letters within the same column are not significantly different ($p > 0.05$)

Table 2 Lethal dose (LD) of adult *S. cerealella* treated with agro waste powders

Agro waste	Slope ± SE	Intercept ± SE	χ^2	Exposure period (h)	LD_{50} (LCL-UCL) (g)	LD_{90} (LCL-UCL) (g)	*P* value
Rice husk	2.25 ± 1.42	0.22 ± 0.42	0.35	24	0.80 (0.47–6.01)	2.97 (1.61–5.03)	0.84
	3.82 ± 3.51	0.55 ± 0.10	0.33	48	0.72 (0.36–4.22)	1.55 (0.82–5.94)	0.55
	4.47 ± 2.36	1.06 ± 0.78	0.08	72	0.58 (0.20–3.75)	1.12 (0.51–2.62)	0.95
	5.88 ± 2.34	1.94 ± 0.79	0.75	96	0.47 (0.38–0.58)	0.77 (0.61–4.60)	0.69
Groundnut	2.88 ± 1.53	0.56 ± 0.49	0.42	24	0.64 (0.41–5.03)	1.79 (0.56–4.86)	0.81
Pod	4.07 ± 2.51	0.96 ± 0.81	0.67	48	0.59 (0.23–4.06)	1.21 (0.74–4.54)	0.72
	0.83 ± 0.23	0.59 ± 0.15	1.70	72	0.58 (0.11–3.54)	1.23 (0.30–4.20)	0.64
	5.76 ± 2.88	2.08 ± 0.96	1.59	96	0.44 (0.01–0.51)	0.73 (0.57–3.19)	0.45
Cowpea pod	2.95 ± 1.57	0.62 ± 0.51	0.42	24	0.62 (0.43–5.24)	1.67 (0.46–6.50)	0.81
	4.21 ± 2.62	1.05 ± 0.85	0.69	48	0.56 (0.17–3.43)	1.17 (0.51–2.62)	0.71
	2.69 ± 1.66	0.69 ± 0.51	0.30	72	0.55 (0.07–0.61)	1.66 (0.42–3.52)	0.86
	2.48 ± 0.43	0.31 ± 0.14	3.01	96	0.12 (0.02–0.18)	0.64 (0.54–0.83)	0.39
Maize cob	2.29 ± 1.49	0.27 ± 0.04	0.33	24	0.76 (0.41–4.41)	2.77 (1.52–5.42)	0.85
	3.01 ± 1.71	0.64 ± 0.54	0.90	48	0.76 (0.42–4.24)	2.77 (0.42–4.13)	0.64
	3.81 ± 2.00	0.98 ± 0.66	0.94	72	0.53 (0.41–3.42)	1.20 (0.26–4.47)	0.95
	5.32 ± 2.66	1.84 ± 0.88	1.44	96	0.45 (0.03–0.57)	0.78 (0.60–1.35)	0.49

χ^2 Chi-square value, *SE* standard error, *LCL* lower confidence limit, *UCL* upper confidence limit

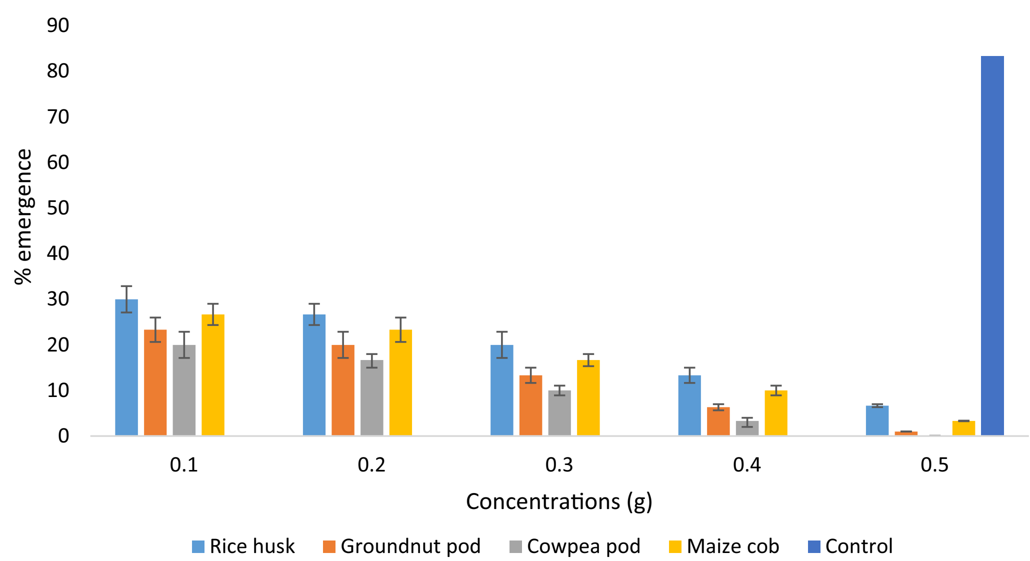

Fig. 1 Adult emergence of *Sitotroga cerealella* treated with agricultural waste powder

Effect of agro wastes powders treatment on Adult emergence

Figure 1 shows the adult emergence of *S. cerealella* in paddy treated with agricultural waste powders (rice husk, cowpea pod, maize cob and groundnut pod). The adult emergence reduced with increase in dosage across the table for each of the agro waste treatments. Cowpea pod powder significantly reduced the development of *S. cerealella* compared with other treatment powders and control. At rate 0.5 g, cowpea pod powder completely inhibited the development of paddy moth. A low adult emergence (30.00) of adult *S. cerealella* was discovered in paddy treated with rice husk powder at dose 0.1 g/20 g of paddy and its effect compared to the control which was 83.67. This was followed by groundnut pod powder that highly inhibited the development (1.00) of *S. cerealella* at concentration 0.5 g/20 g of paddy.

Table 3 Survival of *S. cerealella* eggs treated with agro waste powders

Treatment powders	Conc. (g)	Number of egg incubated	% adult emergence
Rice husk	0.1	20	40.00 ± 3.88^{f}
Groundnut pod		20	30.00 ± 2.88^{ef}
Cowpea pod		20	26.67 ± 2.67^{de}
Maize cob		20	36.67 ± 2.67^{f}
Rice husk	0.2	20	36.67 ± 2.67^{f}
Groundnut pod		20	26.67 ± 2.67^{de}
Cowpea pod		20	20.00 ± 2.88^{de}
Maize cob		20	30.00 ± 2.88^{ef}
Rice husk	0.3	20	26.67 ± 2.67^{de}
Groundnut pod		20	16.67 ± 1.67^{cd}
Cowpea pod		20	10.00 ± 1.08^{bc}
Maize cob		20	20.00 ± 2.88^{de}
Rice husk	0.4	20	16.67 ± 1.67^{cd}
Groundnut pod		20	6.67 ± 0.04^{bc}
Cowpea pod		20	5.00 ± 0.04^{b}
Maize cob		20	10.00 ± 1.08^{bc}
Rice husk	0.5	20	10.00 ± 1.04^{bc}
Groundnut pod		20	1.00 ± 0.01^{a}
Cowpea pod		20	0.00 ± 0.00^{a}
Maize cob		20	5.00 ± 0.05^{b}
Control	0.0	20	90.00 ± 3.88^{c}

Mean followed by the same letters within the same column are not significantly different ($p > 0.05$)

Effect of Agro waste powders on percentage egg hatchability and adult emergence of *S. cerealella*

Cowpea pod powder applied at concentration 0.5 g/10 g of paddy completely prevented hatchability of moth eggs (Table 3). The percentage adult emergence of paddy treated with cowpea pod powder at dosage 0.2 g, 0.3 g, 0.4 g and 0.5 g/10 g of paddy grains were 26.67%, 20.00%, 10.00% and 5.00%, respectively. Groundnut pod powder also significantly prevented hatchability of *S. cerealella* eggs, causing 30.00%, 26.67%, 16.67%%, 6.67% and 1.00% adult emergence of paddy moth at concentrations 0.1 g, 0.2 g, 0.3 g, 0.4 g and 0.5 g/10 g of paddy grains. Adult emergence was significantly higher ($p < 0.05$) in untreated than agro wastes treated powders. The results obtained from the percentage hatchability of eggs and adult emergence significantly showed that agro waste powders (rice husk, cowpea pod, maize cob and groundnut pod) were efficacious in the eggs deterrence of *S. cerealella.*

Mortality of adult *S. cerealella* in treated paddy with agricultural waste extracts

Paddy treated with agro waste extracts (rice husk, cowpea pod, maize cob and groundnut pod) significantly reduced the population of *S. cerealella* (Table 4). The mortality of paddy moth is concentration and exposure time dependent, that is the higher the concentration, the higher the mortality rate. Cowpea pod extract was the most toxic to paddy moth that caused 46.67%, 50.00%, 53.67%, 63.33% and 83.33% mortality of *S. cerealella* at concentrations 0.1 ml, 0.2 ml, 0.3 ml, 0.4 ml and 0.5 ml/20 g of paddy grains after 24 h of exposure, respectively. Cowpea pod extract evoked 100% adult mortality of *S. cerealella* at concentration 0.4 ml/20 g of paddy grains after 96 h of exposure. This was followed by groundnut pod extract that caused 40.00%, 46.33%, 50.00%, 53.33% and 73.33% mortality of *S. cerealella* at concentrations of 0.1 ml, 0.2 ml, 0.3 ml, 0.4 ml and 0.5 ml/20 g of paddy grains after 24 h of exposure, respectively. Groundnut pod evoked 100% of mortality of paddy moth at concentration of 0.5 ml/20 g of paddy after 72 h of treatment. The least toxic agro waste powder was rice husk that caused 33.67%, 66.33%, 43.33%, 46.67% and 66.67% mortality of *S. cerealella* at concentrations 0.1 ml, 0.2 ml, 0.3 ml, 0.4 ml and 0.5 ml/20 g of paddy after 24 h of treatment, respectively. Cowpea pod, groundnut pod and maize cob extracts caused 100.00% mortality of *S. cerealella* at concentration of 0.5 ml/20 g of paddy grains after 96 h of exposure, respectively.

Lethal Concentration (LC) of agro waste extracts against *S. cerealella*

The lethal concentrations of the agro wastes extracts against *S. cerealella* are given in Table 5. The calculated concentrations required for the rice husk, groundnut pod, cowpea pod and maize cob extract to cause 50% (LC_{50}) and 90% (LC_{90}) mortality against the test organism calculated after 24 h were 0.34 and 0.81 ml, 0.22 and 0.74 ml, 0.16 and 0.64 ml, and 0.28 and 0.78 ml, respectively. However, it was observed that these values continued to reduce after 48, 72 and 96 h of exposure. From the calculation, cowpea pod powder was observed to have the lowest lethal dose across all periods of exposure. All these values have different confidence limits that might be effective aside from the calculated values.

Effect of agro waste powders treatment on Adult emergence

Cowpea pod extract completely inhibited the development of *S. cerealella* on paddy at concentrations 0.3 ml, 0.4 ml and 0.5 ml/20 g of paddy grains (Fig. 2). This was followed by groundnut pod extract that significantly inhibited the development (0.00) of *S. cerealella* at concentrations 0.4 ml and 0.5 ml/20 g of paddy. The adult

Table 4 Dose–response of adult *S. cerealella* treated with agro waste extracts

Agro waste treatments extracts	Conc. (ml/20 g paddy)	Mean % mortality ± SE after			
		24 h	48 h	72 h	96 h
Rice husk	0.1	33.67 ± 2.33[b]	43.33 ± 3.67[bc]	43.33 ± 3.67[bc]	50.00 ± 3.88[b]
Groundnut pod		40.00 ± 3.88[de]	50.00 ± 3.88[cd]	56.33 ± 3.67[bc]	60.67 ± 3.33[c]
Cowpea pod		46.67 ± 2.33[cd]	56.67 ± 3.33[cde]	63.67 ± 3.33[cd]	66.33 ± 3.67[cd]
Maize cob		36.33 ± 2.67[bc]	46.67 ± 3.33[b]	53.33 ± 3.33[b]	56.67 ± 3.33[b]
Rice husk	0.2	36.67 ± 2.33[bc]	46.67 ± 3.33[cde]	53.67 ± 3.33[bc]	56.67 ± 3.33[cde]
Groundnut pod		46.33 ± 3.67[def]	56.33 ± 3.67[def]	60.00 ± 3.88[cd]	66.33 ± 3.67[cde]
Cowpea pod		50.00 ± 3.88[cde]	60.00 ± 3.88[def]	66.33 ± 3.67[de]	70.00 ± 3.88[def]
Maize cob		40.00 ± 3.88[bcd]	50.00 ± 3.88[cde]	56.67 ± 3.33[bc]	60.00 ± 3.88[bcd]
Rice husk	0.3	43.33 ± 3.67[def]	50.00 ± 3.88[def]	56.33 ± 3.67[cde]	63.67 ± 3.33[cde]
Groundnut pod		50.00 ± 3.88[efg]	60.00 ± 3.88[efg]	66.67 ± 3.33[efg]	70.00 ± 3.88[def]
Cowpea pod		53.67 ± 3.33[fgh]	63.67 ± 3.33[efg]	70.00 ± 3.88[efg]	73.67 ± 3.33[efg]
Maize cob		46.33 ± 3.67[efg]	56.67 ± 3.33[efg]	60.00 ± 0.88[def]	66.67 ± 3.67[cde]
Rice husk	0.4	46.67 ± 3.33[fgh]	53.67 ± 3.33[fgh]	63.67 ± 3.33[fg]	73.33 ± 3.67[fgh]
Groundnut pod		53.33 ± 3.67[fgh]	63.33 ± 3.67[fgh]	73.33 ± 3.67[gh]	90.00 ± 3.88[hi]
Cowpea pod		63.33 ± 3.67[gh]	76.67 ± 3.33[ghi]	90.00 ± 3.88[ghi]	100.00 ± 0.00[i]
Maize cob		50.00 ± 3.88[gh]	60.00 ± 3.88[fgh]	66.33 ± 3.67[fg]	76.33 ± 3.67[fg]
Rice husk	0.5	66.67 ± 3.33[h]	80.00 ± 3.88[ij]	86.67 ± 3.33[hi]	96.67 ± 3.33[hi]
Groundnut pod		73.33 ± 3.67[hi]	93.67 ± 3.33[jk]	100.00 ± 0.00[i]	100.00 ± 0.00[i]
Cowpea pod		83.33 ± 3.67[i]	100.00 ± 0.00[k]	100.00 ± 0.00[i]	100.00 ± 0.00[i]
Maize cob		70.00 ± 3.88[h]	83.67 ± 3.33[j]	93.33 ± 3.67[hi]	100.00 ± 0.00[i]
Control		0.00 ± 0.00[a]	0.00 ± 0.00[a]	0.00 ± 0.00[a]	0.00 ± 0.00[a]

Mean followed by the same letters within the same column are not significantly different ($p > 0.05$)

Table 5 Lethal concentrations (LC) of adult *S. cerealella* treated with agro waste extracts

Agro wastes	Slope ± SE	Intercept ± SE	χ^2	Exposure period (h)	LC_{50} (LCL-UCL) (ml)	LC_{90} (LCL-UCL) (ml)	p-value
Rice husk	1.02 ± 0.23	0.48 ± 0.15	7.88	24	0.34 (0.15–4.33)	0.81 (0.71–1.03)	0.05
	1.04 ± 0.23	0.73 ± 0.15	15.80	48	0.20 (0.13–3.04)	0.67 (0.5–2.31)	0.00
	1.25 ± 0.25	1.03 ± 0.15	14.58	72	0.15 (0.10–2.52)	0.58 (0.52–1.23)	0.00
	1.66 ± 0.25	1.48 ± 0.16	22.52	96	0.12 (0.08–2.16)	0.50 (0.46–0.75)	0.00
Groundnut Pod	1.00 ± 0.23	0.64 ± 0.15	7.61	24	0.22 (0.16–0.29)	0.74 (0.62–0.94)	0.06
	1.32 ± 0.24	1.17 ± 0.16	25.45	48	0.13 (0.11–0.45)	0.55 (0.41–1.02)	0.00
	1.55 ± 0.25	1.50 ± 0.16	30.86	72	0.11 (0.09–0.31)	0.49 (0.37–0.85)	0.00
	1.86 ± 0.26	1.92 ± 0.18	26.55	96	0.09 (0.06–0.12)	0.44 (0.41–0.50)	0.00
Cowpea Pod	1.15 ± 0.23	0.92 ± 0.15	12.76	24	0.16 (0.14–1.14)	0.64 (0.55–1.46)	0.00
	1.59 ± 0.25	1.53 ± 0.18	32.30	48	0.11 (0.09–0.92)	0.50 (0.42–1.27)	0.00
	1.74 ± 0.26	1.86 ± 0.18	28.45	72	0.09 (0.06–0.84)	0.44 (0.41–0.50)	0.00
	2.07 ± 0.29	2.25 ± 0.21	40.68	96	0.08 (0.07–0.94)	0.38 (0.24–0.41)	0.00
Maize cob	1.03 ± 0.23	0.56 ± 0.15	7.98	24	0.28 (0.18–0.32)	0.78 (0.65–1.02)	0.05
	1.13 ± 0.23	0.91 ± 0.15	13.50	48	0.16 (0.13–0.49)	0.67 (0.56–0.98)	0.00
	1.25 ± 0.24	1.16 ± 0.16	23.83	72	0.12 (0.10–0.39)	0.58 (0.32–0.56)	0.00
	1.61 ± 0.25	1.57 ± 0.17	29.24	96	0.11 (0.07–0.24)	0.48 (0.34–0.63)	0.00

χ^2 = Chi-square value, S.E = Standard error, LCL = Lower confidence limit and UCL = Upper confidence limit

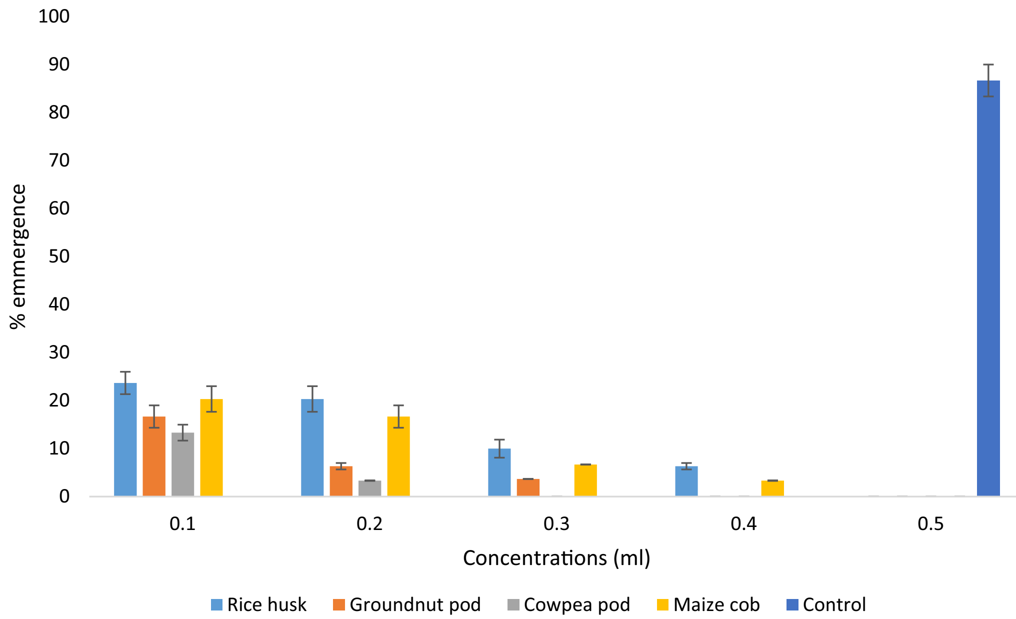

Fig. 2 Adult emergence of *Sitotroga cerealella* treated with agricultural waste extracts

emergence reduced significantly with an increase in concentration across the table for each of the agro waste extract treatments. A low adult emergence (23.67) of *S. cerealella* was discovered in paddy treated with rice husk extract at dose 0.1 ml/20 g of paddy and its effect compared to that of the control which was 86.67.

Effect of Agro waste extracts on percentage egg hatchability and adult emergence of *S. cerealella*

All the agro waste extracts applied at concentration 0.5 ml/10 g of paddy completely prevented hatchability of moth eggs (Table 6). Cowpea and groundnut pod extracts at concentration of 0.4 ml completely prevented the hatchability of paddy moth. Adult emergence was significantly higher ($p < 0.05$) in untreated than agro waste treated extracts. The results obtained from the percentage hatchability of eggs and adult emergence significantly showed that rice husk, cowpea pod, maize cob and groundnut pod extracts were effective in the eggs deterrence of *S. cerealella.*

Mean followed by the same letters within the same column are not significantly different ($p > 0.05$).

Chemical compounds present in cowpea pod extract

The result of chromatogram of the chemical compounds is presented in Fig. 3. Nineteen compounds were isolated from cowpea pod extract representing 100% of its constituents (Table 7). Cowpea pod extract was the most effective of all the agricultural wastes with

Table 6 Survival of *S. cerealella* eggs treated with agro waste powders

Treatment powders	Conc. (ml)	Number of egg incubated	% adult emergence
Rice husk	0.1	20	25.33 ± 3.33^{f}
Groundnut pod		20	20.00 ± 2.88^{ef}
Cowpea pod		20	10.00 ± 0.88^{de}
Maize cob		20	15.67 ± 0.67^{f}
Rice husk	0.2	20	26.67 ± 2.33^{f}
Groundnut pod		20	15.67 ± 0.67^{de}
Cowpea pod		20	5.00 ± 0.04^{de}
Maize cob		20	20.00 ± 2.88^{ef}
Rice husk	0.3	20	16.67 ± 1.33^{de}
Groundnut pod		20	0.00 ± 0.00^{cd}
Cowpea pod		20	0.00 ± 0.00^{a}
Maize cob		20	5.00 ± 0.04^{de}
Rice husk	0.4	20	15.67 ± 0.67^{cd}
Groundnut pod		20	0.00 ± 0.00^{a}
Cowpea pod		20	0.00 ± 0.00^{a}
Maize cob		20	10.00 ± 1.08^{bc}
Rice husk	0.5	20	0.00 ± 0.0^{a}
Groundnut pod		20	0.00 ± 0.00^{a}
Cowpea pod		20	0.00 ± 0.00^{a}
Maize cob		20	0.00 ± 0.00^{a}
Control	0.0	20	90.00 ± 3.88^{c}

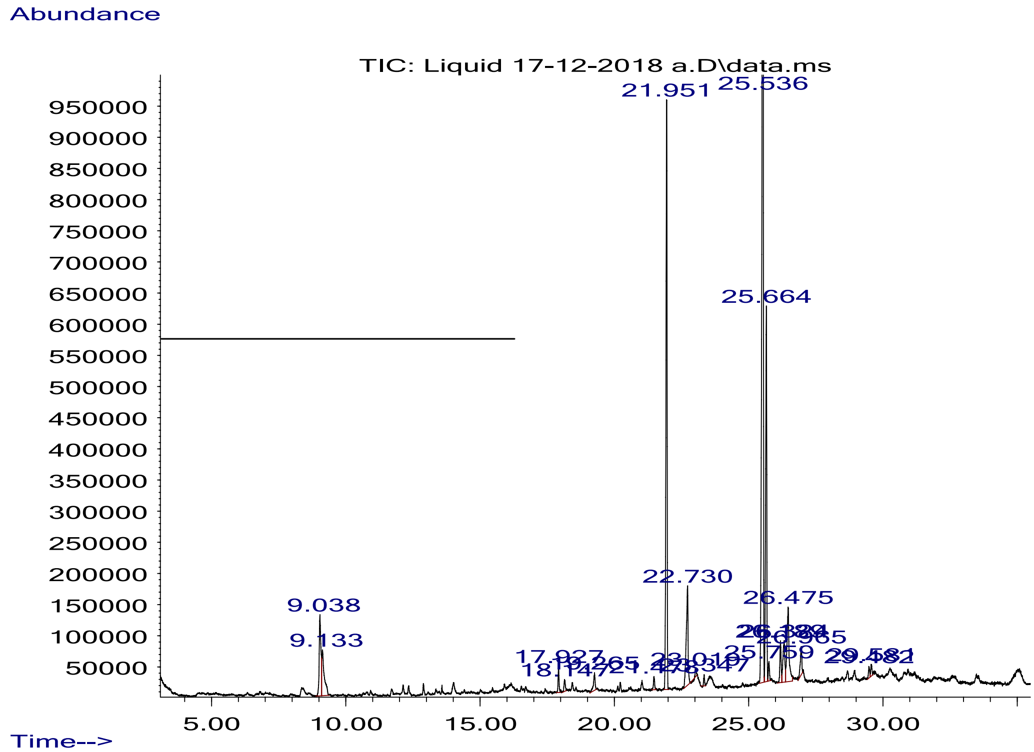

Fig. 3 Chromatogram of the chemical compounds present in cowpea pod extract

Table 7 Chemical compounds present in cowpea pod extract

RT (mins)	Compound Name	Cas no.	% Total
9.038	Benzaldehyde, 2-methyl-	000529-20-4	4.245
9.133	5-Amino-2H-pyrazole-3-carboxamide	1000387-89-6	3.336
17.927	Undecanoic acid, methyl ester	001731-86-8	0.771
18.147	Acetamide, N-isoxazolo[5,4-b]pyrid in-3-yl-	1000362-63-0	0.469
19.265	4,5-Dimethyl-2-pyrimidone	034939-17-8	0.872
21.478	7-Hexadecenoic acid, methyl ester, (Z)-	056875-67-3	0.478
21.952	Pentadecanoic acid, 14-methyl-, methyl ester	005129-60-2	20.399
22.730	n-Hexadecanoic acid	000057-10-3	5.390
23.017	4-Pentenal, 2-methylene-	017854-46-5	0.119
23.348	Hexadecanoic acid, ethyl ester	000628-97-7	0.273
25.534	9,12-Octadecadienoic acid, methyl ester	002462-85-3	39.571
25.666	9-Octadecenoic acid (Z)-, methyl ester	000112-62-9	12.710
25.757	trans-2-Dodecen-1-ol, trifluoroacetate	1000352-26-2	0.666
26.186	Methyl stearate	000112-61-8	1.524
26.324	9,12-Octadecadienoic acid (Z,Z)- methyl ester	000060-33-3	2.346
26.473	9,17-Octadecadienal, (Z)-	056554-35-9	4.728
26.965	Octadecanoic acid	000057-11-4	1.2685
29.482	6,9,12-Octadecatrienoic acid, methyl ester	002676-41-7	0.405
29.581	Methyl 6-cis,9-cis,11-trans-octade catrienoate	1000336-37-7	0.431%

* *RT* retention time; **CAS no* Chemical Abstract Service Registry Number

9, 12-Octadecadienoic acid, methyl ester having the highest percentage total of 39.57%, followed by pentadecanoic acid, 14-methyl-, methyl ester (20.39%) with 4-Pentenal, 2-methylene- (0.12%) having the least percentage. The identified compounds have many biological properties.

Discussion

The agro wastes-derived insecticidal screening test revealed the promising insecticidal potential of rice husk, cowpea pod, maize cob and groundnut pod against paddy moth (*S. ceralella*). Insecticidal activities of rice husk, cowpea pod, maize cob and groundnut pod against Angoumois grain moth (*S. ceralella*) are scarce in the literature, which motivated this study in the first place.

The results obtained from this research showed that rice husk, cowpea pod, maize cob and groundnut pod powders and extracts had distinct toxicity effects on the survival of *S. cerealella.* Findings from this experiment demonstrated that rice husk, groundnut pod, cowpea pod, and maize cob powders and extracts tested against moth, *S. cerealella*, showed insecticidal activity. This was confirmed in all the treatments with the results showing variations in their effectiveness against the insect pest. This study also reveals the toxicity and reproduction inhibitory effects of the powders, extracts and their ashes. The powders and extracts achieved high moth mortality even at lower concentrations. The toxicity effect of this powders and extracts increased with increase in concentration and period of exposure. The cowpea pod of all the examined agro waste had the lowest lethal dosage and concentration to the adult insect.

The high mortality effect of these agricultural waste powders and extracts may be as a result of agro waste powders and extracts to have disrupted normal respiratory activities of the insect (Adedire et al. 2011; Ileke 2014). The agro wastes might have prevented the movement of the moth within the grains leading to starvation which could also prevent mating of the moth leading to low or no oviposition (Ashamo and Akinnawonu 2012). The results obtained in this research agreed with the observation made by Ashamo and Akinnawonu (2012), Ashamo et al. (2013), Adeyemo et al. (2013), Ileke (2013), Hossien et al. (2018). They all reported on the effectiveness of underutilized indigenous plant in the management of *S. cerealella*. Hossien et al. (2018) observed significant variations in paddy treated with dried leaf powder of neem, bishkatali, marigold and chopped garlic bulb at rate of 2.5 g/kg paddy against rice moth (*S. cerealella*) at 30 and 180 days infestation.

The agro wastes significantly reduced the development of egg to adulthood most especially cowpea and groundnut pods. This validated the report of Xiaosong and Weston (1995), who carried out oviposition and feeding deterrent from Chinese prickly against Angoumois grain moth and reported that the fraction containing xanthoxylin had significant deterrent effects on ovipositional behaviour and also strong antifeedant properties on larvae of *S. cerealella*. Ashamo and Akinnawonu (2012) observed that adult moth mortality increased as concentration of powder increased. Adult emergence significantly reduced in toxicity of agro wastes against eggs and adult stages bioassay. Cowpea pod was able to effect 100% mortality of the adult moths within 72 h of application at higher concentration. The toxicity effects of the agro waste may be ascribed to physical abrasion of the wings and cuticle of *S. cerealella*, and this could have resulted in loss of body fluid, dehydration and high mortality of *S. cerealella* observed in this study (Ogunwolu et al. 1998; Gemechu et al. 2012). This work is in agreement with the findings of Akinneye and Ogungbite (2013) as well as Ogungbite et al. (2014) where powders of different plant materials successfully prevent emergence of adult insects.

The death of insect larvae as results of agro waste toxicity that might have led to inability of larval to completely cast off their exoskeleton during moulting remained linked to the posterior part of their abdomen which can affect larval and pupa survival as well as growth disruption (Oigiangbe et al. 2010; Ileke 2014). The agro waste powders and extracts had effect on post-embryonic survival of this insect which resulted in prevention of adult emergence at different concentrations. The secondary metabolites present in these agricultural wastes could be responsible for the inability of the emergence of teneral adult (Murdue-huntz and Nisbet 2000). Secondary metabolites in plants had been reported to altered growth, reduced the survival of larvae as well as disruption of insects' life cycle (Yang et al. 2006). Based on the results obtained, cowpea pod was more toxic to paddy moth than other agro wastes (rice husk, groundnut pod and maize cob) evaluated.

The GC–MS analysis of cowpea pod extract revealed the presence of 19 phytochemical compounds of which were reported to possess various bioactivities. For instance, 9, 12-Octadecadienoic acid, methyl ester which had the highest percentage total belongs to the class of organic compounds known as lineolic acids and derivatives, unsaturated fatty acid, abundantly in plant glycosides. An essential fatty acid for mammalian nutrition and biosynthesis of prostaglandins and cell membranes. Hexadecanoic acid and 9-octadecenoic acid (Z), methyl ester—Oleic acid ester were known to be cancer preventive (Simin et al. 2000), anti-inflammatory (Harborne and Baxter 1983) potent antibacterial and antifungal activity (Seidel and Taylor 2004). The observed bioactive compound in cowpea pod may singly or synergy with one another to control lepidopteran insect pest. This observation validated the report of Viuda-Martos et al. (2010) that plant extracts contain bioactive compounds that may act independently or in synergy to insect management. It has been reported that some plant bioactive compounds can be industrialized into products suitable for integrated pest management as a result of their effectiveness, selectivity to pests, have no or little harmful effect against non-target organisms (Jiang et al. 2007).

Conclusion

This study was carried out to determine the toxicity of rice husk, cowpea pod, maize cob and groundnut pod powders and extracts against *Sitotroga cerealella*. There is abundant evidence of poor insecticide education and misuse in Nigeria, farmers apply insecticides at high dosage to effect rapid and immediate killing of stored product insect pests. The treatments significantly achieved high mortality of the adult insects and significantly inhibit oviposition by adult insects and hatchability of oviposited eggs even at low concentration. Cowpea pod was the most effective of all the agricultural wastes, and this might be as a result of the high amount of major bioactive components in it which has been reported to be toxic to coleopterans (weevils and beetles) insect pests. The current results revealed that the selected agricultural wastes have promising insecticidal potential and can be used as an alternative to synthetic chemicals for the control of Angoumois grain moth (*S. ceralella*).

Abbreviations

FUTA: Federal University of Technology, Akure; ANOVA: Analysis of variance; SE: Standard error; GC–MS: Gas chromatography-mass spectrometry; LD: Lethal dose; LC: Lethal concentration; TETFund: Tertiary education trust fund; IBR: Institution based-research.

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Authors' contributions

MO contributed to conceptualization, methodology, formal analysis and writing—reviewing and editing. KD contributed to methodology, data curation, formal analysis and writing—original draft. AI contributed to data curation and investigation. All authors have read and approved the manuscript.

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Availability of data and materials

Data collected and analysed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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