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Research article

Entomotoxicity of some agro-wastes against cowpea bruchid, *Callosobruchus maculatus* (Fab.) [Coleoptera: Chrysomelidae] infesting cowpea seeds in storage

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ABSTRACT

Cowpea, *Vigna unguiculata* is a popular agricultural produce known as poor man's meat among Africans because it is very cheap and affordable. In spite of its importance, its infestation by cowpea seed bruchid, *Callosobruchus maculatus* has been a major constrain hindering its storage. Considering the high level of infestation of cowpea by *C. maculatus* and the high level of pollution caused by agricultural products, this research investigated the entomotoxicant effectiveness of rice husk, wheat husk and groundnut pod ash and powder in the control of cowpea beetle in storage. This study was carried out under laboratory condition of ambient temperature 28 ± 2 °C and 70 ± 5% relative humidity. The wastes (rice husk, groundnut pod and wheat husk) were pulverized separately and another portion was burnt to ashes at 525 °C. The powders and the ashes were analyzed for their proximate composition, phytochemical content (powders) and silica content (ashes). The powders and the ashes were tested at 0.1, 0.2, 0.3, 0.4 and 0.5 g/20 g of cowpea. Rice husk ash resulted in the highest mortality of 100% of adult beetles at dosage of 0.5g/20g cowpea after 96 h post-application. Wheat husk ash at 0.4 and 0.5 g per 20 g cowpea seed had the highest protectant ability on cowpea as it reduced fecundity to 4.67% and prevented adult emergence, seed damage and weight loss. The ash of the wastes caused more mortality of the adult beetles than their powders. The results obtained showed that the wastes caused high mortality of *C. maculatus*. It was also found that the wastes had some phytochemicals which might be responsible for the recorded high mortality. The findings showed that the tested agro-wastes have a promising insecticidal potential against *C. maculatus*, and can be used as possible alternatives to synthetic chemical insecticides for the control of stored product insects.

1. Introduction

Climate change has become a major source of concern all over the world because its effects are harming many facets of life, including agriculture and human health. Indeed, the world's food security is in jeopardy because many crops have low yields year after year due to climatic change, and the little that was produced is being infested by insect pests right from the farm level (FAO, 2015). The control of these insect pests is becoming more difficult every day as many of them are developing resistance to many of the insecticides on markets. Climate change has been identified as one of the primary factors aggravating insect resistance to insecticides, and many of these insecticides have been banned by governments for adversely contributing significantly to the problem of climate change (Isman, 2000). Also, pollution has been noted for its contribution to climate change (Heald et al., 2006; UNICE, 2007; Jacob and Winner, 2009). Agricultural pollution (wastes) in Nigeria is becoming a major concern, especially in her cities. Therefore, it is necessary to find ways through which these wastes can be recycled and incorporated into pest management systems to avoid the use of chemical insecticides (Obi et al., 2016; Akowuah et al., 2018; Babarinde et al., 2020).

Agriculture is one of the oldest practices known to man and it has been the major backbone of human existence and development of many countries (Ashamo and Ogungbite 2014; Ileke, 2019; Ileke et al., 2020a; b; Obembe et al., 2020). Adeyemo et al. (2013) opined that the backwardness in the agricultural sector of any country amounts to backwardness in the economic growth of such a country. Despite its relevance to human life, it has been facing a lot of challenges among which the

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infestation of its products by weevils and moths appears most prominent (Obembe and Ogungbite 2016; Idoko and Ileke 2020; Ileke et al., 2020b; Obembe et al., 2020). The menace of these insect pests inhibits the agricultural growth of some developing countries where insect pest management practices and government intervention in terms of efficient storage facilities are still low (Ashamo and Ogungbite 2014; Ileke et al., 2021).

Cowpea, *V. unguiculata* is one of the most popular agricultural products known as poor man's meat among Africans because it is very cheap and affordable (Ileke 2014, 2019; Idoko and Ileke 2020; Obembe et al., 2020). The crop plays an integral role in reducing food insecurity in many developing countries (Ileke and Olotuah 2012; Ashamo et al., 2013; Oyeniyi et al., 2015; Idoko and Ileke 2020). Despite the importance of this crop, infestation by *C. maculatus* has been a major constraint hindering its large-scale production and storage. The damage due to insect infestation is not only restricted to the field but also extended to the storage where they can cause more than 60% seed damage (Oni 2014; Ileke 2015, 2019; Ileke et al., 2021). The multivoltine type of reproduction of the insect is a factor that compounds the problem of its infestation compared to other insect pests of cowpea (Obembe and Ogungbite 2016; Idoko and Ileke, 2020; Ileke et al., 2020b; Obembe et al., 2020).

The discovery of synthetic chemical insecticides in the early 1930s brought about a new thoroughfare of insect control until the early 1990s when the problems associated with many of the past advocated chemical insecticides become unbearable (Isman 2006). These chemicals have adverse effects on both human and environmental pollution (Akanji et al., 1993; Bamisaye et al., 2013; Ileke et al., 2014; Ileke and Adesina, 2018). Some countries in Europe and America have banned the use of synthetic chemical insecticides as well as the importation of commodities protected with such chemicals (Isman, 2006).

To obviate the problem of chemical insecticides, different control methods have been advocated across the globe. However, botanical insecticides are gaining more attention than other control measures because of availability and ease of application compared to other control measures (Ashamo et al., 2013; Idoko and Ileke 2020; Obembe et al., 2020). However, despite several researches on the use of botanical insecticides, very few are useful because the researchers failed to consider the availability of the botanicals to resource-poor farmers who have little knowledge of how to extract oils and active compounds from pesticidal plants. Due to this reason, there is the need to search for other readily available botanical materials that could be useful in insect control.

Agriculture has contributed to environmental pollution especially in developing countries where there is no equipment to recycle the agricultural wastes (Chomchalow, 2003; Babarinde et al., 2020). Chomchalow (2003); Babarinde et al. (2020) reported that some agricultural wastes like rice husk, maize cob, cowpea husk, groundnut pod and many others have insecticidal potentials. Also, Laing et al. (2006); Obi et al. (2016); Akowuah et al. (2018) reported that the ash of agricultural wastes is effective in insect control.

Rice, wheat and groundnut are cultivated in Nigeria. A lot of rice waste (rice husk), wheat waste (wheat husk) and groundnut waste (groundnut pod) are being generated without their secondary utilization. Considering the high level of infestation of cowpea by *C. maculatus* and the high level of pollution caused by agricultural wastes, this research investigated the effectiveness of rice husk, wheat husk and groundnut pod ash and powder as entomotoxicants in the control of cowpea beetles in storage.

2. Materials and methods

2.1. Insect rearing

The insects used in this research were collected from infested cowpea grains from the Food Storage Technology Laboratory, Biology Department, Federal University of Technology, Akure. The insects were reared on cleaned uninfested cowpea (Ife Brown Variety) and they were placed inside plastic containers with cover perforated and covered with muslin cloth to prevent the escape of the insects, prevent other intruders and to allow for ventilation. These containers were placed inside an insect rearing cage at ambient temperature of 28 ± 2 °C and 70 ± 5% relative humidity.

2.2. Collection of plant materials

The agricultural wastes used included rice husk (RH), wheat husk (WH) and groundnut pod (GP). The RH and WH were collected from the Grain Processing Unit of Agricultural Development Project (ADP), Akure, Ondo State, Nigeria while the GP was collected from a farm in Akure. The wastes were dried and milled into fine powder using an electric milling machine. The powders were kept inside separate plastic containers until further use.

2.3. Preparation of plant ashes

The ash of RH, WH and GP was prepared by burning the dried sample into ashes using muffle furnace at 550 °C. The ashes were sieved to remove the charcoal and stones and were later kept inside airtight plastic containers until use.

2.4. Proximate analysis of RH, WH and GP

The moisture content, ash content, fat content, crude fibre and crude protein were analyzed using the method of AOAC (2000).

2.5. Determination of phytochemicals

The alkaloid and saponin content of RH, WH and GP were determined using the method of Obadoni and Ochuko (2001) while tannin and phytate content were determined using the method of Makkar et al. (1993).

2.6. Determination of total alkaloids

Five grams (5g) of each of the sample was weighed into 250 ml beaker and 200 ml of 10% acetic acid in ethanol was added, covered and allowed to stand for 4 h. This was filtered and the extract was concentrated on a water bath to one-quarter of the original volume. Concentrated ammonium hydroxide was added dropwise to the extract until the precipitation was complete. The whole solution was allowed to settle and the precipitate was collected and washed with dilute ammonium hydroxide and then filtered. The residue is the alkaloid, which was dried and weighed.

2.7. Determination of total saponins

Twenty grams (20 g) of each of the sample was placed in a conical flask and 100 cm^3 of 20% aqueous ethanol was added. The samples were put in hot water bath (55 °C) for 4 h and constantly stirred. The mixture was filtered and 200 ml of 20% ethanol was added again. The solution of the sample was reduced to 40 ml over water bath (90 °C). The concentrate was transferred into a 250 ml separation funnel and 20 ml of diethyl ether was added and shaken vigorously. The aqueous layer was recovered while the ether layer was discarded. The purification process was repeated, after which 60 ml of n-butanol was added to the purified extracted sample. The combined solution of n-butanol and extracts were washed twice with 10 ml of 5% aqueous sodium chloride. The remaining solution was heated in a water bath. After evaporation the samples were dried in the oven to a constant weight; the saponin content was calculated.

Table 1. Percentage mortality of parental adult *C. maculatus* on cowpea seeds treated with powder and ash of groundnut pod, rice husk and wheat husk.

Agricultural wastes	Formulations used	Dosage (g)	Mortality in hours			
			24	48	72	96
Groundnut pod	Powder	0.1	10.00 ± 5.77^{bc}	16.67 ± 0.33^{bc}	40.00 ± 1.15^{fg}	43.33 ± 0.67^{f}
		0.2	13.33 ± 3.33^{bc}	20.00 ± 1.00^{cd}	46.67 ± 0.88^{gh}	60.00 ± 0.00^{h}
		0.3	16.67 ± 3.33^{cd}	23.33 ± 0.33^{cd}	63.33 ± 0.67^{j}	66.67 ± 0.33^{hi}
		0.4	20.00 ± 5.77^{de}	36.67 ± 0.88^{f}	66.67 ± 0.33^{jk}	73.33 ± 0.67^{ij}
		0.5	23.33 ± 0.81^{de}	50.00 ± 0.58^{hi}	70.00 ± 0.00^{k}	80.00 ± 1.00^{j}
	Ash	0.1	13.33 ± 3.33^{bc}	23.33 ± 0.81^{cd}	43.33 ± 3.33^{f}	50.00 ± 0.58^{g}
		0.2	13.33 ± 3.33^{bc}	30.00 ± 0.58^{ef}	56.67 ± 3.33^{ij}	63.33 ± 0.67^{h}
		0.3	16.67 ± 3.33^{cd}	43.33 ± 0.67^{gh}	73.33 ± 1.33^{k}	76.67 ± 0.33^{j}
		0.4	26.67 ± 2.02^{ef}	46.67 ± 0.88^{h}	76.67 ± 0.33^{kl}	86.67 ± 0.33^{kl}
		0.5	36.67 ± 3.33^{g}	56.67 ± 0.33^{i}	86.67 ± 0.33^{l}	93.33 ± 0.33^{l}
Rice husk	Powder	0.1	3.33 ± 0.33^{a}	13.33 ± 0.33^{b}	16.67 ± 0.33^{b}	33.33 ± 0.33^{b}
		0.2	10.00 ± 1.00^{bc}	30.00 ± 0.58^{ef}	33.33 ± 0.67^{de}	60.00 ± 1.00^{h}
		0.3	23.33 ± 0.33^{de}	36.67 ± 0.88^{f}	40.00 ± 1.15^{fg}	66.67 ± 0.33^{hi}
		0.4	23.33 ± 0.33^{de}	46.67 ± 0.88^{h}	50.00 ± 0.00^{hi}	76.67 ± 0.33^{j}
		0.5	23.33 ± 0.88^{de}	46.67 ± 0.33^{h}	60.00 ± 0.58^{j}	86.67 ± 0.66^{k}
	Ash	0.1	33.33 ± 0.66^{fg}	60.00 ± 0.58^{i}	73.33 ± 0.66^{k}	80.00 ± 0.57^{jk}
		0.2	40.00 ± 0.58^{g}	63.33 ± 1.20^{i}	83.33 ± 0.33^{l}	83.33 ± 0.33^{jk}
		0.3	50.00 ± 0.58^{h}	73.33 ± 0.66^{j}	86.67 ± 0.33^{lm}	90.00 ± 0.00^{l}
		0.4	66.67 ± 0.88^{i}	83.33 ± 0.66^{k}	90.00 ± 0.00^{m}	96.67 ± 0.33^{l}
		0.5	73.33 ± 0.88^{i}	86.33 ± 0.33^{k}	90.00 ± 0.00^{m}	100.00 ± 0.00^{l}
Wheat husk	Powder	0.1	0.00 ± 0.00^{a}	6.67 ± 0.33^{a}	16.17 ± 0.33^{b}	16.67 ± 0.33^{b}
		0.2	3.33 ± 0.33^{a}	16.67 ± 0.33^{bc}	23.33 ± 0.33^{c}	23.33 ± 0.33^{c}
		0.3	6.67 ± 0.53^{ab}	16.67 ± 0.33^{bc}	26.67 ± 0.33^{cd}	26.67 ± 0.67^{cd}
		0.4	6.67 ± 0.33^{ab}	20.00 ± 0.00^{cd}	26.67 ± 0.33^{cd}	30.00 ± 0.58^{de}
		0.5	10.00 ± 0.58^{bc}	20.00 ± 0.00^{cd}	26.67 ± 0.33^{cd}	36.67 ± 0.33^{ef}
	Ash	0.1	3.33 ± 0.33^{a}	6.67 ± 0.33^{a}	13.33 ± 0.33^{b}	23.33 ± 0.33^{c}
		0.2	3.33 ± 0.33^{a}	16.67 ± 0.33^{bc}	23.33 ± 0.33^{c}	33.33 ± 0.33^{e}
		0.3	16.67 ± 0.33^{cd}	26.67 ± 0.33^{de}	36.67 ± 0.88^{ef}	43.33 ± 0.88^{f}
		0.4	23.33 ± 0.33^{de}	33.33 ± 0.67^{ef}	40.00 ± 0.58^{fg}	50.00 ± 1.17^{g}
		0.5	33.33 ± 0.33^{fg}	43.33 ± 0.33^{gh}	56.67 ± 0.33^{ij}	60.00 ± 0.00^{h}
	Control	0.0	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	3.33 ± 3.33^{a}	6.67 ± 6.67^{a}

Each value is the mean ± standard error of 3 replicates. Means with the same alphabet within the column are not significantly ($p > 0.05$) different using New Duncan's Multiple Range Test.

2.8. Determination of total tannins

0.5 g of each of the sample was weighed into a plastic bottle of 50 ml. Distilled water (50ml) was added to the sample and shaken for 1 h using mechanical shaker. The solution was filtered into a 50 ml glass flask. Then 5 ml of the filtrates was pipetted into a test tube and mixed with 2ml of 0.1 M $FeCl_3$ in 0.I N HCl and 0.008 M potassium ferrocyanide. The absorbance was measured at 120 nm within 10 min.

2.9. Determination of total phytates

Two grams (2 g) of each sample was weighed and soaked in 100 ml of 2% hydrochloric acid in conical flask for a period of 3 h. The mixed solution was filtered through a double layer Whatman filter paper. Distilled water (100 ml) was added to 50 ml to the filtrate of each sample in 250 ml beaker to give proper acidity. Ten milliliters (10 ml) of 0.3% ammonium thiocyanate solution was added into each solution as indicator. This was titrated with standard iron (III) chloride solution which contained 0.00495 g iron per ml. The end point was slightly brownish-yellow which persisted for 5 min.

2.10. Determination of silica content

The silica content from the ash was determined by using the modified method described by Walsh (1977). Ash obtained from the method described above was digested with 5 ml of 6M HCl. The sample was weighed. Then addition of another 5 ml of 6M HCl to the residue was followed by heating, and then the solution was diluted with 20 ml of distilled water. Hot distilled water was used to wash the residue on ash free filter paper. After sufficient washing to remove chloride, the filter paper along with residue was placed in the crucible and ignited at 525 °C. After cooling, the silica mass using electronic weighing balance (Model KD-CN) was taken. The amount is determined by means of atomic absorption spectrophotometry.

2.11. Entomological bioassay

Twenty grams of the cowpea seeds were weighed into 250 ml plastic containers. The powders of RH, WH and GP weighing 0.1, 0.2, 0.3, 0.4 and 0.5 g were separately thoroughly mixed with the cowpea seeds inside the plastic containers while cowpea seeds not treated with powder were used as control. Ten pairs of 0- to 24-h old adults of *C. maculatus* were introduced into those treated cowpea seeds at different dosages and beetle mortality was assessed at 24, 48, 72, and 96 h after treatments (Equation 1). The test was set up in a factorial experiment laid out in Completely Randomized Design and each treatment was replicated three times. Dead and live insects were removed on the 5th day and fecundity was noted. Also, percentage adult emergence (Equation 2), percentage seeds damage (Equation 3), weight loss (Equation 4) and beetle perforation index (Equation 5) were calculated using the formulae below:

Table 2. Interactive effect of the three agricultural wastes (groundnut pod, rice husk and wheat husk), formulation used (powder and ash) and the dosages on the survival of parental adult *C. maculatus*.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Agricultural wastes * formulation used	1162.222	2	581.111	7.164	0.002
Agricultural wastes * dosages	453.333	8	56.667	0.699	0.691
Formulation used * dosages	140.000	4	35.000	0.432	0.785
Agricultural wastes * formulation used*dosages	1826.667	8	228.333	2.815	0.010
Error	4866.667	60	81.111		

The dependent variable = Mortality 96 h.

$$\% \text{ parental adult mortality} = \frac{\text{number of dead parental adult}}{\text{total number of parental adult}} \text{x} 100 \quad (1)$$

$$\% \text{ adult emergence} = \frac{\text{number of emerged insects}}{\text{total number of egg laid}} \text{x} 100 \quad (2)$$

$$\% \text{ damaged seed} = \frac{\text{number of holed seed}}{\text{total number of seed}} \text{x} 100 \quad (3)$$

$$\% \text{ weight loss} = \frac{\text{initial weight} - \text{final weight}}{\text{intial weight}} \text{x} 100 \quad (4)$$

Beetle Perforation Index (BPI) was expressed as described by Fatope et al. (1995).

$$\text{BPI} = \frac{\% \text{ treated maize grains perforated}}{\% \text{ control maize grains perforated}} \times 100 \quad (5)$$

The ash of each of the three agricultural wastes was also assayed for its insecticidal potentials, following the same procedure used for the powder bioassay.

2.12. Statistical analysis

All data were subjected to general linear models (GLMs). The data collected for parental adult mortality, seed damage, beetle perforation index and seed weight loss were subjected to analysis of variance (ANOVA), their means separated using Duncan's Multiple Range Test at 0.05 significant level. The interaction between the agricultural wastes, the formulation used (powder/ash) and dosages at 96 h post-application was determined using Linear regression analysis. Data analysis was done using statistical package for social sciences (SPSS) version 20 and the charts were plotted using Microsoft office Excel 2016.

3. Results

3.1. Mortality of parental adult C. maculatus exposed to powder and ash of three agricultural wastes

The effects of powder and ash of groundnut pod, rice husk and wheat husk on the survival of *C. maculatus* are presented in Table 1. Significant variation existed between and within treatments which was directly proportional to the increase in the period of application. Within 24 h of application, RH ash applied at 0.4 and 0.5 g per 20 g cowpea seeds resulted in the highest adult beetle mortality and was significantly different from other treatments ($F_{30, 62} = 13.364$, $p < 0.001$). Rice husk ash applied at 0.5 g per 20 g seeds caused the highest parental adult mortality within 48, 72 and 96 h post-application and was significantly different from other treatments ($F_{30, 62} = 14.208$, $p < 0.001$; $F_{30, 62} = 21.500$, $p < 0.001$ and $F_{30, 62} = 25.137$, $p < 0.001$, respectively). Regardless of the type of formulations used (powder or ash), RH appeared most effective among other agricultural wastes as it inflicted the highest adult mortality within 96 h of exposure. Also, irrespective of

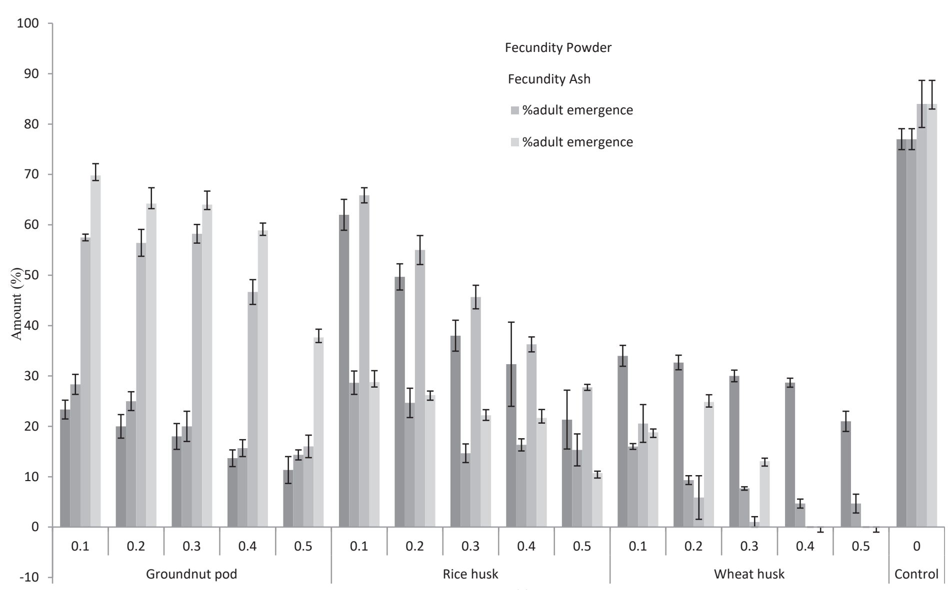

Figure 1. Fecundity (oviposition) and adult emergence of *C. maculatus* exposed to different agricultural wastes. Note: Fecundity value is the actual number of eggs laid and not in percentage. The values are means of three replicates.

Table 3. Seed damage, weight loss and beetle perforation index caused by *C. maculatus* infestation on cowpea treated with agricultural wastes powders and ash.

Agricultural wastes	Plant formulation	Dosage	Percentage		
			Weight loss	Damage	BPI
Groundnut pod	Powder	0.1	20.37 ± 0.95^{f}	11.53 ± 1.33^{c}	41.52 ± 1.79^{g}
		0.2	14.25 ± 1.76^{de}	10.45 ± 1.65^{c}	28.79 ± 2.24^{e}
		0.3	9.39 ± 1.32^{bc}	5.50 ± 3.69^{ab}	18.96 ± 1.88^{d}
		0.4	5.70 ± 0.96^{ab}	8.32 ± 3.48^{b}	11.88 ± 2.21^{c}
		0.5	1.62 ± 0.81^{a}	9.48 ± 1.33^{b}	3.45 ± 1.73^{ab}
	Ash	0.1	11.31 ± 1.12^{cd}	13.48 ± 3.19^{c}	23.30 ± 3.19^{d}
		0.2	8.48 ± 0.88^{bc}	13.20 ± 3.19^{c}	17.27 ± 1.71^{d}
		0.3	5.09 ± 0.29^{ab}	12.50 ± 3.47^{c}	10.44 ± 1.04^{c}
		0.4	3.12 ± 0.44^{a}	11.88 ± 3.72^{c}	6.30 ± 0.71^{b}
		0.5	1.17 ± 0.66^{a}	11.28 ± 3.19^{bc}	2.51 ± 1.44^{ab}
Rice husk	Powder	0.1	18.33 ± 0.73^{f}	34.20 ± 1.15^{f}	67.57 ± 0.78^{h}
		0.2	13.53 ± 0.33^{de}	31.43 ± 1.99^{f}	62.40 ± 0.81^{h}
		0.3	10.23 ± 0.24^{cd}	23.90 ± 1.10^{e}	47.23 ± 2.26^{g}
		0.4	9.40 ± 0.29^{bc}	21.30 ± 0.80^{e}	42.27 ± 0.94^{g}
		0.5	7.27 ± 0.35^{bc}	16.07 ± 1.92^{d}	31.63 ± 2.17^{ef}
	Ash	0.1	15.57 ± 1.34^{e}	17.43 ± 1.79^{d}	34.33 ± 1.93^{f}
		0.2	13.05 ± 0.71^{de}	14.57 ± 0.92^{cd}	28.80 ± 0.47^{e}
		0.3	7.67 ± 0.87^{bc}	10.83 ± 0.47^{b}	21.43 ± 0.13^{d}
		0.4	5.20 ± 0.26^{ab}	10.10 ± 1.24^{b}	19.20 ± 1.00^{d}
		0.5	4.77 ± 0.46^{ab}	8.97 ± 1.17^{b}	17.60 ± 1.53^{d}
Wheat husk	Powder	0.1	7.84 ± 1.02^{bc}	2.92 ± 0.21^{a}	17.31 ± 2.14^{d}
		0.2	2.29 ± 1.76^{a}	0.92 ± 0.76^{a}	5.01 ± 3.83^{b}
		0.3	0.39 ± 0.39^{a}	0.11 ± 0.11^{a}	0.87 ± 0.87^{a}
		0.4	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}
		0.5	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}
	Ash	0.1	3.08 ± 0.39^{a}	1.59 ± 0.02^{a}	6.78 ± 0.82^{b}
		0.2	2.74 ± 0.79^{a}	1.18 ± 0.42^{a}	6.06 ± 1.78^{b}
		0.3	2.35 ± 0.68^{a}	1.01 ± 0.36^{a}	5.19 ± 1.51^{b}
		0.4	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}
		0.5	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}
	Control	0.0	31.97 ± 1.14^{g}	50.47 ± 2.44^{g}	100.00 ± 0.00^{i}

Each value is the mean ± standard error of 3 replicates. Means with the same alphabet within the column are not significantly different using New Duncan's Multiple Range Test.

the dosage of the agricultural waste used, the ashes were more effective than the powders. However, none of the treatments achieved complete parental adult mortality throughout the exposure period except rice husk ash. Moreover, the order of effectiveness of the agricultural waste based on the type of formulations used in them could be arranged as WH powder < WH ash < GP powder < GP ash < RH powder < RH ash.

Furthermore, Table 2 shows that the combined effect of the agricultural wastes and the formulations used against the parental adult survival was significant at 96 h post-application ($F_{2,\ 60} = 7.164$, $p < 0.005$). The combined effect of agricultural wastes and dosage as well as formulations used and dosage have no significant effect on the mortality of the adults at 96 h of observation ($p > 0.05$). Moreover, the interactive effect of the agricultural wastes, the formulation used and the dosages on the survival of the adults were significant ($p < 0.005$).

3.2. Effects of ash and powder of groundnut pod, rice husk and wheat husk on the fecundity and adult emergence of C. maculatus

The effects of the three agricultural wastes on the fecundity and adult emergence of the cowpea beetle are presented in Figure 1. The fecundity and adult emergence of the beetle varied with increase in the dosage and the type of agricultural wastes as well as the type of the formulation used (ash and powder). All the wastes significantly reduced the fecundity rate of the beetles when compared to the control in which 77 eggs were laid and 84.27% adult emergence was recorded. The fecundity in the treated cowpea seeds with agro-wastes ranged from 0.00 to 61.00. All the agricultural waste ashes were more effective than their powders except the groundnut pod in which its powder was more effective than its ash. Wheat husk ash was the most effective with only 4.67 fecundity at 0.4 and 0.5 g per 20 g of cowpea seeds. The wheat husk ash was significantly different from other agricultural wastes at 0.4 and 0.5 g per 20 g of cowpea seeds (fecundity: $F_{30,\ 62} = 41.749$, $p < 0.05$). Also, only the ash and powder of wheat husk at 0.4 and 0.5g dosages prevented the emergence of the adult beetle and was statistically significantly different from other treatments at $F_{30,\ 62} = 23.257$, $p < 0.0005$. The order of effectiveness of the three agricultural wastes regardless of the formulations used in them could be arranged as wheat > groundnut > rice husk.

3.3. Seed damage, beetle perforation index and weight loss caused by C. maculatus infestation on cowpea seeds treated with powders and ash of three agricultural wastes

Table 3 shows the effect of the powder and ash of the three agricultural wastes on the ability of *C. maculatus* in causing seed weight loss and damage of the protected cowpea seeds as well as the beetle perforation index (BPI). The ability of the beetle to cause weight loss and damage seed varied with the type of agricultural wastes, formulations used (ash and powder) and the dosage of the formulations. The ash and powder of the wastes significantly reduced seed weight loss, damage and as well as BPI compared to the control. Only the WH ash and powder assayed at 0.4

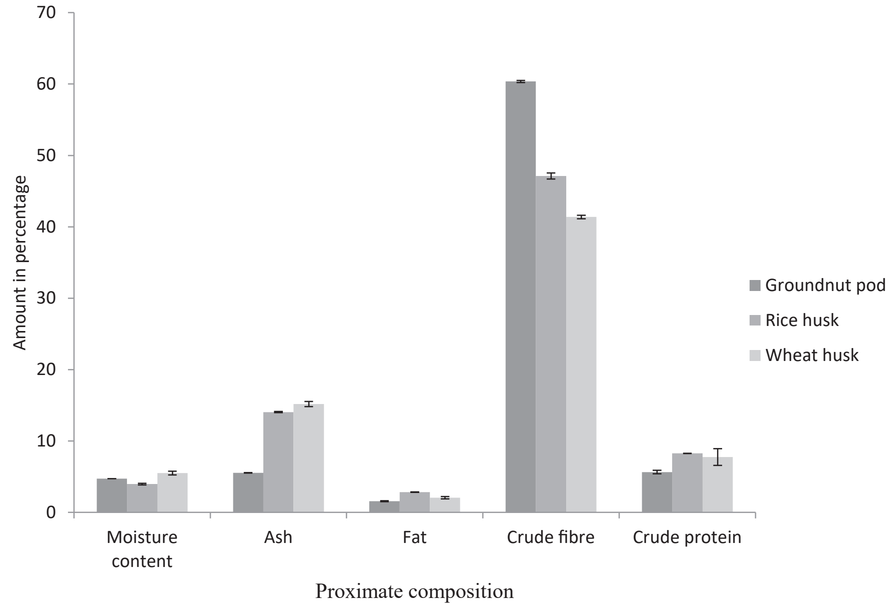

Figure 2. Proximate composition of the three agricultural wastes.

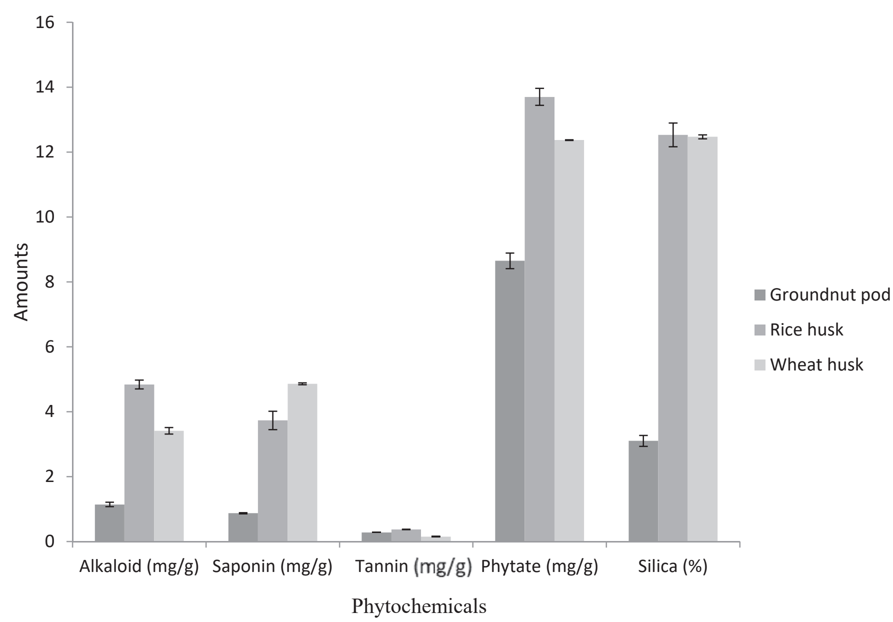

Figure 3. Phytochemical composition of the three agricultural wastes.

and 0.5g per 20 cowpea seed were able to completely prevent the weight loss and damage of the protected cowpea seeds.

3.4. Proximate and phytochemical composition of three agricultural wastes

The proximate and phytochemical content of the three agricultural wastes powder is presented in Figures 2 and 3 respectively. The rice husk powder had the highest crude protein, ash and fat content of 8.25%, 14.04% and 2.82%, respectively. Also, the highest level of tannin content (0.37 mg/g) and phytate content (13.70 mg/g) was recorded in the rice husk powder. The rice husk ash contained the highest silica content of 12.53%. The highest moisture content and saponin content of 5.49% and 4.86 mg/g were respectively recorded in the wheat husk powder. Groundnut pod powder had the highest crude fibre content of 60.36%.

4. Discussion

The results obtained from this work showed that the three agricultural wastes have good insecticidal efficacy. The result showed that the potency of the agricultural wastes varied with the formulations used (ash and powder) and the dosages used. Regardless of the dosage used, it was observed that rice husk ash caused more mortality of adult beetles than the remaining two agricultural wastes. The high mortality rate caused by the agricultural wastes could be due to the ability of their ash and powder to block the breathing spaces (spiracles) of the beetles and thereby leading to asphyxiation (Ofuya, 1986; Adedire and Lajide, 1999; Ogungbite et al., 2014; Ileke, 2015; Ileke et al., 2020a).

It was noted in this research that the ash of the agricultural wastes had a higher lethal effect on the beetles when compared with their powders. The high mortality caused by the ash of the wastes may be due to its toxic properties causing desiccation of the insects' cuticle as suggested by Tadesse and Basedow (2005). Also, the high mortality inflicted by rice husk could be attributed to the high silica content in it because silica has been reported as being insecticidal (Khot et al., 2012). The results obtained in the work acquiesced with the findings of Ogungbite et al. (2014) as well as Rahman and Talukder (2006) in which the ashes of *Newbouldia laevis* and *Acacia arabica* L. (bablah) were found to cause high mortality of *C. maculatus* respectively. Although, the powders of the three agricultural wastes were less effective than their ashes. The powder also caused high beetle mortality as reflected by the probit analysis. Rice husk powder caused more insect mortality than other powders and this agreed with the reports of many works in which the powders of botanical sources have been used in the control of insect pests (Mkenda et al., 2015; Osariyekemwen and Benedicta, 2017; Babarinde and Pitan, 2019; Fouad et al., 2020). The ability of these powders to cause high mortality of the beetles could be due to the phytochemicals present in them. It was found that the wastes contain alkaloid, tannin, saponin and phytate. Yang et al. (2006) reported that these phytochemicals have considerable toxicity towards the survival of insects. However, it was found in this work that only tannin and saponins contributed to the mortality of the beetles as reflected in the regression analysis.

Ash and powder of the wastes notably reduced the fecundity and adult emergence of the beetles as well as their ability to cause damage and weight loss of the cowpea seeds. The fecundity and adult emergence of the beetles as well as the ability to cause damage and weight loss was directly proportional to the increase in dosages. It was observed that none of the wastes was able to completely prevent the fecundity of the beetles. Also, it was observed that only the ash and powder of wheat husk at high dosages (0.4 and 0.5g) was able to prevent the emergence of the adult beetles and as well prevented the damage and weight loss of the protected cowpea, thereby having 0% BPI. The result obtained agreed with the work of Ogungbite et al. (2014) in which the ash of *Newbouldia laevis* prevented the emergence of adult *C. maculatus.* The reduced fecundity rate could be due to the high mortality rate of the adult beetles due to exposure to the powder and ash of the wastes. Ashamo et al. (2013) as well as Oni et al. (2015) opined that a high mortality rate could reduce the frequency of mating and thereby reduce the fecundity rate of insects. Also, the low percentage of adults that emerged from the treated cowpea could be due to the inability of the eggs to develop because the ashes and powders of the wastes must have blocked the chorion of the eggs (Adedire et al., 2011; Ileke et al., 2020a; Obembe et al., 2020).

Furthermore, the powders and the ashes may also cause the inability of the insect larvae to fully cast off their old exoskeleton that typically remained linked to the posterior part of the abdomen (Oigiangbe et al., 2010; Ileke, 2019; Ileke et al., 2020a; b; Obembe et al., 2020). The phytochemicals contained in the powder of the three agricultural wastes could also reduce adult emergence because some of the allelochemicals found in the powder of the wastes had been reported to be capable of disrupting insect life cycle (Yang et al., 2006; Oigiangbe et al., 2010; Ileke, 2019; Ileke et al., 2020a; b; Obembe et al., 2020).

The reduced seed damage and weight loss observed in this study may be attributed to the beetle's low adult emergence. Ashamo and Ogungbite (2014) opined that the number of adult insects that emerged on a protected commodity is directly proportional to the damage and weight loss of such protected commodity. The analyses done showed that there was a significant relationship between agricultural wastes and the formulation used (ash and powder). Also, the analyses showed that there was a significant interactive effect of agricultural wastes, the formulation used and dosage on the survival of *C. maculatus.*

5. Conclusion

It was observed in this work that there was an interaction between the agricultural wastes, the formulations used in them and their dosages. Nevertheless, the rate at which these wastes displayed their insecticidal potency differed. For example, it was noted that rice husk ash and powder inflicted higher mortality of the beetles than the formulations of other wastes while the ash and powder of wheat husk exhibited the greatest protectability against the beetles. The order of effectiveness of the wastes was rice husk > groundnut pod > wheat husk. Therefore, since these agricultural wastes have displayed high insecticidal potency, they could be incorporated into pest management strategies to reduce agricultural pollution, the financial cost of protecting agricultural produce and as well promote food security in the developing countries. However, more researches should be carried out on the safety of the ash and powder of these agricultural wastes to the consumers of the protected commodity.

Declarations

Author contribution statement

Michael Olufemi Ashamo: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.

Kayode David Ileke; Olaniyi Charles Ogungbite: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

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The authors declare no conflict of interest.

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