



Laboratory evaluation of four types of biochar to manage some stored product insects

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Abstract

Four types of biochars were prepared from rice husk as farm waste, sugarcane bagasse as sugar cane juice store waste, residues of *Leucaena leucocephala* tree as horticulture waste and chicken manure as chicken farm reduce at 700°C, then evaluated as a alternative to control *Tribolium castaneum*, *Rhyzopertha dominica*, *Oryzaephilus surinamensis* and *Sitophilus oryzae*. The character of each type has been defined using Scanning Electron Microscopy (SEM) with an Energy Dispersive X-Ray Analysis (EDX) and Fourier transform infrared spectroscopy (FTIR) were used to identify the elemental composition and functional groups distributed on biochars surface. The elemental compositions refer to the chicken manure biochar exhibited a decrease in Carbon concentration and increase Oxygen content; there is a negative correlation between C and O contents. On the other hand, the chicken manure biochar is the only tested biochar that contains Ca, P, and Cl. The chicken manure biochar has the largest number of functional groups on its surface, the mortality of insects was recorded after 10 days which showed that the chicken manure biochar was the most effective which contains more different elements and functional groups on its surface. The most affected insects were *O. surinamensis* and *R. dominica* with mortality percentages 86.66 and 73.33. Smaller particles of chicken manure biochar were more effective than larger particles against both *R. dominica* and *O. surinamensis*, the smaller particles (1.80–0.94 µm) recorded LC₅₀ 1.29 and 0.56 g/kg against *R. dominica* and *O. surinamensis*. SEM images for the affected insects showed the adhesion of biochar particles on insect's body parts, also, the sensilla were disappeared as a result of the friction between biochar particles and insect cuticle. Our results may indicate the promising features of biochar as an alternative method to control some stored product insects with considering the source of biochar which affect its elemental and functional groups contents. Biochar had different efficacy depending upon its moisture contents, with increased moisture the toxicity of biochar decreased.

Keywords Biochar · Particle size · Stored product insects · *Oryzaephilus surinamensis* · *Rhyzopertha dominica* · *Leucaena leucocephala*

Introduction

The rust red flour beetle, *Tribolium castaneum*, the lesser grain borer, *Rhyzopertha dominica*, the saw-toothed grain beetle, *Oryzaephilus surinamensis* and the rice weevil,

Sitophilus oryzae are classified as polyphagous, global pests in stored products throughout the world (Bell 2000). Globally, *R. dominica* is considered the main pest of rice, wheat and millets (Edde 2012), and it can attack a broad range of various stored products such as cereals, dried fruit, and nearly all grains and more especially wheat, barley, sorghum and rice. likewise, another cosmopolitan pest is *T. castaneum*, which mainly infest the products of milled grain, for example, flour and cereals, which is considered a secondary pest as it mainly attacks broken grains and grain dust (Odeyemi et al. 2005). One of the main insect pests that cause primary infestation for stored grain is the rice weevil, *Sitophilus oryzae* which is spread widely around the world causing massive destruction of stored products (Benzi et al. 2009). In comparison to other insect pests of stored products, the species, *Oryzaephilus surinamensis*

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does not seriously cause damage. Because it lives in the bottom layers of infected products, it is most difficult to detect (Kłyś and Przystupińska 2015). It primarily attacks milled grain products, and also feeds on dried fruit, sugar, yeasts, tobacco, nuts, dried meat, but the foodstuffs are the least food that attacked for this type. (Madkour et al. 2013).

To control stored product insects, it is necessary to find more safe and eco-friendly alternatives to the traditional methods as the use of inert dust (Nukenine 2010; Obeng-Ofori 2007; Obeng-Ofori and Boateng 2008). Due to its low mammalian toxicity, inert dust can provide a safe method to control stored product insects by mixing with the produce. During 1960, the activated Kaolin clay was used in the treatment of about 70% of the grain in India. Also, rock phosphate was used in Egypt as a protectant. In addition, lime, ashes and sand dust were used in the protection of grains in West Africa by some local farmers (Obeng-Ofori 2007).

The lignocellulosic materials are the main components of agricultural wastes. In Egypt, these wastes ranged annually between 22 and 26 million tons, and this large quantity of wastes could be transformed into an eco-friendly product such as biochar (Taher and Nasr 2018).

Biochar is a highly porous and adsorbent carbon-rich material that is produced by the heating of organic materials under low oxygen conditions (pyrolysis), it has a similar appearance to different carbon-rich materials e.g., charcoal. But it is mainly developed as a soil conditioner, almost any type of biomass feedstock can be used in the production of biochar (Aly 2016). Its production significantly benefits in the sequestration of carbon by locking it which with abundant in the biomass of the plant. The source nature, production temperature and residence time all are factors that affect the element content and the structure formation of produced biochar (Narzari et al. 2015). There is little information available on the direct effects of biochar on insect survival and or performance. The physical properties of biochar porous structure, high surface area, and abundant oxygen-containing functional groups such as hydroxyl and carboxyl on its surface) as well as the low cost of production makes it a suitable material for controlling insects (Cook and Andrade 2018; Wang et al. 2021). One of the possible alternative solutions to overcome the use of some alternative applications of conventional insecticides to control mites and insects use some alternative natural amendments like biochar that have no risk to humans and the surrounding environment (Bakhat et al. 2020; Chen et al. 2019a, b).

In this research, we did a survey of biochar prepared at 700 °C from various agricultural wastes such as rice husk collected from (Rice), *Oryza sativa*, sugarcane bagasse collected from (Sugar cane) *Saccharin officinarum* and residues of Leucaena tree (*Leucaena leucocephala*) tree in

addition to chicken manure collected from (Egyptian domestic fowls) *Gallus gallus domesticus* for the control of four types of stored grain insects: *R. dominica*, *O. surinamensis*, *T. castaneum*, and *S. oryzae*. The effect of particle size on the insecticidal efficacy of the tested chicken manure biochar was also examined against both *R. dominica* and *O. surinamensis*.

Materials and methods

Tested insects

Four species of insects were used in this study: *Sitophilus oryzae* (Rice weevil), *Tribolium castaneum* (Herbst) (red flour beetle), *Rhyzopertha dominica* (Fabricius), (the lesser grain borer) and *Oryzaephilus surinamensis* (Linnaeus) (the saw toothed grain beetle) were cultured in the laboratory at 28 °C ± 1, Rh. 70 ± 10 and photoperiod L/D 12:12 h. at the Faculty of Agriculture, Alexandria University. *Sitophilus oryzae* were reared on whole wheat as described by (Strong et al. 1967). *T. castaneum* was reared on a mixture of (10:1) whole wheat: brewer's yeast according to the methods of (Beeman et al. 2009). *Rhyzopertha dominica* were reared on whole wheat using the method explained by (Kavallieratos et al. 2005). *Oryzaephilus surinamensis* were reared on whole wheat flour, rolled oats and yeast (5:5:1) according to (Watson and Barson 1996).

Preparation of biochars

About six kilograms of four Four lignocellulosic waste materials were collected from rice husk, sugarcane bagasse, *Leucaena leucocephala*, and chicken manure and used as feedstock for producing biochar. chicken manure was collected from Alex university's experimental farm, rice husk was collected from the rice mill, sugarcane bagasse was collected from sugarcane juice store and *L.leucocephala* branches were collected from trees grown in the forestry research sector of Antoniadis botanical garden, Alexandria, Egypt. The samples were air-dried at room temperature and ground to the.

Ground samples were placed in crucibles, covered with a tightly fitting lid, and pyrolyzed under oxygen-limited conditions in two steps. First, the pyrolysis temperature was raised to 300 °C at approximately 10 °C/min and held for 60 min. Then, the biochars were allowed to cool to room temperature overnight, after that the pyrolysis temperature was raised to 700 °C at approximately 20 °C/min in a muffle furnace and held for 60 min. Then, the biochars were allowed to cool to room temperature overnight and ground to pass through a 0.051-mm sieve before further experiments.

Characterization of biochars

Elemental analysis

The elemental composition and diameter of biochars were analyzed using the technique of Scanning Electron Microscopy (SEM) with an Energy Dispersive X-Ray Analysis (EDX) and performed in a Jeol JSM- 5300 scanning electron microscope at acceleration voltage between 15 and 20 keV.

Fourier transform infrared (FT-IR)

The spectroscopic characterization of biochar was conducted using the FT-IR technique to identify the functional groups that was distributed on the biochar surface. Burkert tensor 37 spectrometers were used in this identification in the range of $400\text{--}4000\text{ cm}^{-1}$ using the technique of KBr pellet as 1.0 mg of samples was added to 100 mg KBr pressed, then exposed to infrared radiation (Wu et al. 2012; Guo and Chen 2014).

Data analysis

Analyses of variance (ANOVA) $p < 0.05$ were conducted with Co-Stat 6.400 program software, and then the homogeneous means were grouped using Tukey's HSD test.

Insecticidal activity of biochars

Four types of biochar were ground and pass through a sieve (0.125–0.56 mm) and applied at 5 g/kg with 20 g sterilized wheat in a 250 ml glass jar and lids were fitted. Jars were tilled up and down (10x) and rotated by hand for 2 min., with a brief period of shaking at 120 s. The jars were kept closed for 15 min after shaking to allow any free dust to settle. Twenty adults of each insect were separately placed in each treated jar. Each treatment was replicated three times. All of the procedures of the experiment were carried out under the same conditions as the rearing. Mortality percentages were recorded after 10 days of exposure for the four types of biochar.

The three different particle sizes of chicken manure biochar were ground to pass through three different sieves, largest size (0.500–0.250 mm), medium size (0.250–0.125 mm), smallest size (0.125–0.56 mm) before assay. Insecticidal activity of three different particle sizes of chicken manure biochar was assessed against adults of *R. dominica* and *O. surinamensis*. Average particle size distribution between (3.96–5.40, 4.02–4.23, 1.80–0.94 μm) was measured by Scanning electron microscope (SEM) (Fig. 1). Samples of wheat were mixed with different doses of biochar each at 0.5, 1, 3 and 5 g/kg. The biochars were applied as described in the previous experiment. Mortality percentage (M%) was determined after 10 days. The LC_{50} values, and their upper

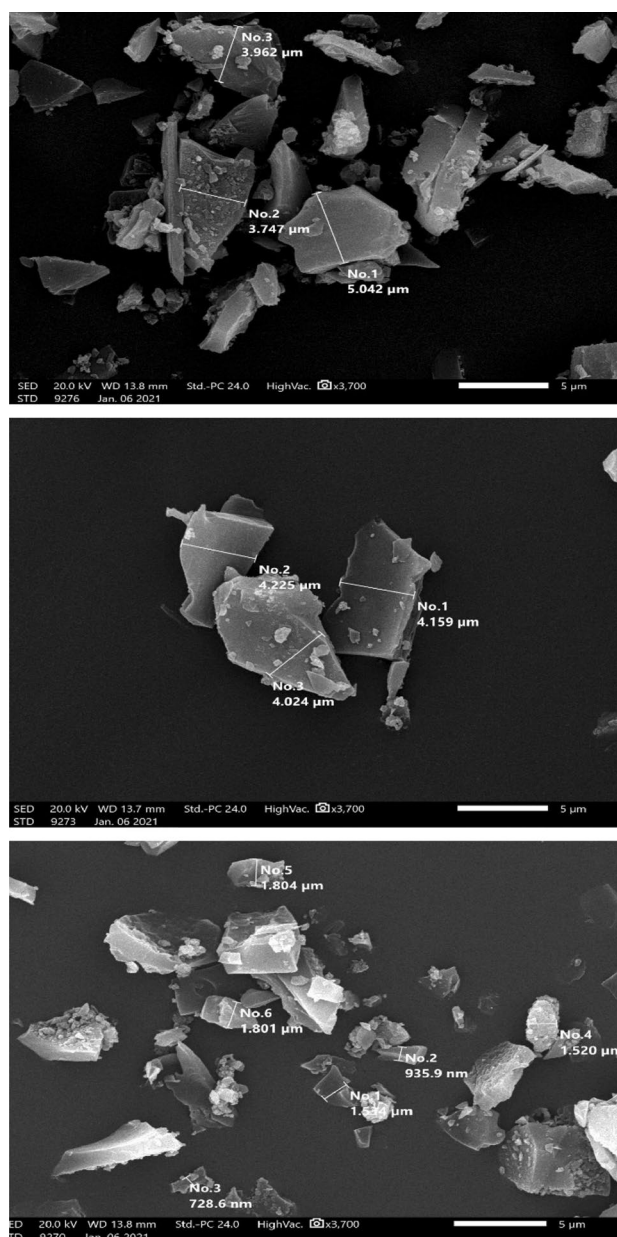


Fig. 1 Average particles diameter of three different particles types of chicken manure biochar

and lower confidence interval limits, as well as intercept, were estimated by probit analysis were calculated according to (Finney 1971) using LdP line software (Ehab Soft, Cairo, Egypt). Non-overlapping, 95% fiducially limits were used to determine significant differences among treatments ($P < 0.05$).

Insects scanning electron microscopy

The most affected adults were *R. dominica* and *O. surinamensis* treated with chicken manure biochar after 10 days

of exposure to biochar as compared with unexposed insects. The samples were fixed by immersing them immediately in 4F1G (Fixative, phosphate buffer solution) PH=7.4 at 4 °C for 3 h according to the methods of (Tahmasebi et al. 2015). Specimens were then postfixed in 2% OsO₄ in the same buffer at 4 °C for 2 h. Samples were washed in the buffer and dehydrated at 4 °C through a graded series of ethanol. Insects were dried using a critical point method, mounted using carbon paste on an AL- stub and coated with gold up to a thickness of 400 Å in a sputter-coating unit (JFC-1100 E). Observations of *R. dominica* and *O. surinamensis* morphology in the coded specimens were performed in a Jeol JSM- 5300 scanning electron microscope operated between 15 and 20 keV.

Role of biochar moisture content on its toxicity

the performance of two more effective tested biochar chicken manure and *L. leucocephala* against the most susceptible tested insect *O. surinamensis* was examined, mixing 5 g/g biochar with different concentrations of distilled water 0, 25, 50, 100, 150 (w/w) and applied on 20 gm wheat grain in a 250 ml glass jar in the same way mentioned above. Twenty adults of *O. surinamensis* were added into each jar. Mortality were recorded after 10 days.

Results

The elemental composition

To identify the elemental composition and diameter of the four biochar types, the technique of electron dispersive X-ray analysis (EDX) was used. The results for each type of biochar were presented in (Fig. 2a–d), respectively. To compare the four types. The results were summarized in (Table 1) as presented by the mass percent and atomic percent. The most abundant elements were carbon and oxygen with the difference in their ratio. In the first three types *L. leucocephala*, sugarcane bagasse and rice husk the carbon percentages were higher than that of oxygen with a mass % of 89.48 ± 0.52 , 83.24 ± 0.57 and 48.36 ± 0.77 , the least carbon with percentage was noticed is for rice husk biochar. The second element in its percentage in these three types is oxygen with mass % of 9.04 ± 0.64 , 14.16 ± 0.82 and 35.26 ± 1.01 , respectively. potassium is common in all types with different percentages, and it is the last element found in *L. leucocephala* type with a mass % of 1.48 ± 0.12 while its mass% in the types of sugarcane bagasse and rice husk were 1.94 ± 0.15 and 1.15 ± 0.12 with the presence of silicon in both types but with a higher percentage in rice husk (15.23 ± 0.37) compared with that of sugarcane

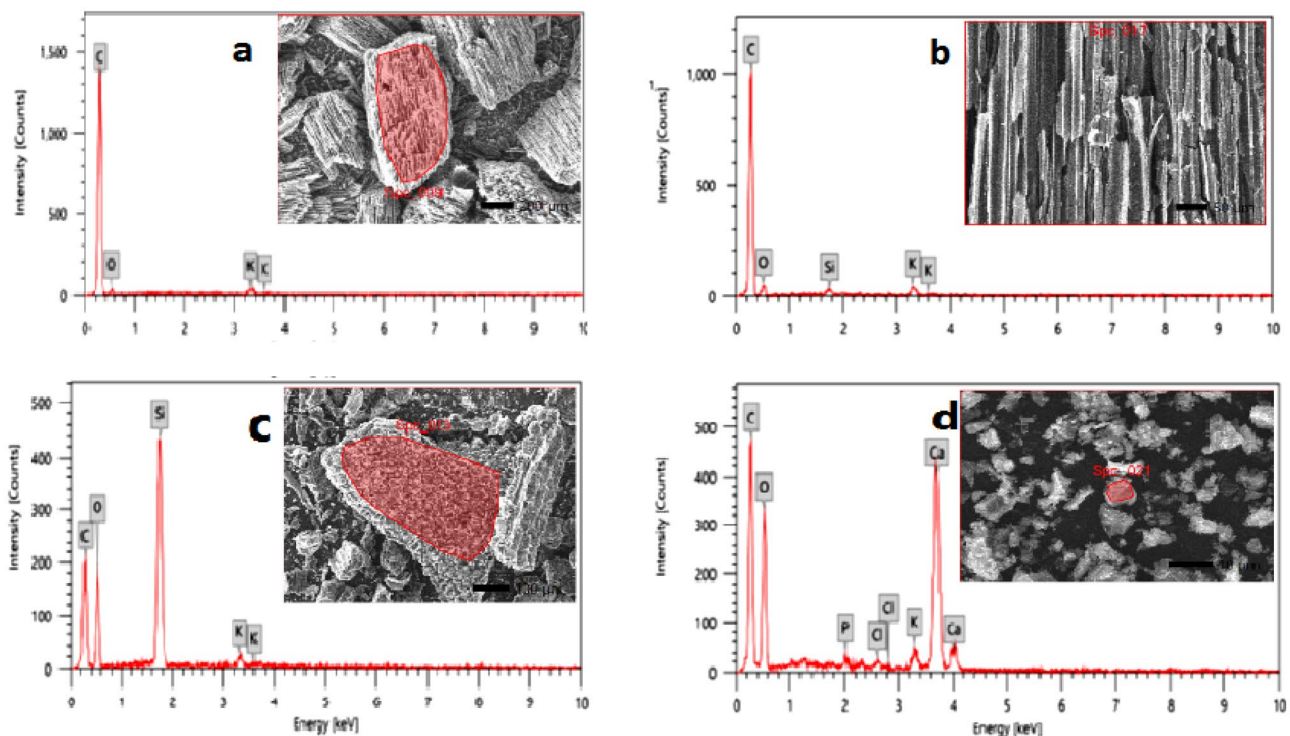


Fig. 2 Scanning electron microscope (SEM) images and corresponding SEM/EDX graph of the types *Leucaena leucocephala*, (a) sugarcane bagasse, (b) rice husk (c) and chicken manure (d)

Table 1 The elemental composition of biochar prepared from different sources

Element	Biochar source $\pm$ (SD)							
	Rice husk		Sugarcane bagasse		<i>Leucaena leucocephala</i>		Chicken manure	
	Mass%	Atomic%	Mass%	Atomic%	Mass%	Atomic%	Mass%	Atomic%
C	48.36 $\pm$ 0.77	59.19 $\pm$ 0.94	83.24 $\pm$ 0.57	87.85 $\pm$ 0.60	89.48 $\pm$ 0.52	92.51 $\pm$ 0.53	35.51 $\pm$ 0.36	47.14 $\pm$ 0.48
O	35.26 $\pm$ 1.01	32.40 $\pm$ 0.93	14.16 $\pm$ 0.82	11.22 $\pm$ 0.65	9.04 $\pm$ 0.64	7.02 $\pm$ 0.50	45.24 $\pm$ 0.96	45.09 $\pm$ 0.96
K	1.15 $\pm$ 0.12	0.43 $\pm$ 0.05	1.94 $\pm$ 0.15	0.63 $\pm$ 0.05	1.48 $\pm$ 0.12	0.47 $\pm$ 0.04	1.44 $\pm$ 0.10	0.59 $\pm$ 0.04
Ca	-	-	-	-	-	-	16.80 $\pm$ 0.33	6.68 $\pm$ 0.13
Si	15.23 $\pm$ 0.37	7.97 $\pm$ 0.19	0.67 $\pm$ 0.09	0.30 $\pm$ 0.04	-	-	-	-
P	-	-	-	-	-	-	0.62 $\pm$ 0.06	0.32 $\pm$ 0.03
Cl	-	-	-	-	-	-	0.40 $\pm$ 0.05	0.18 $\pm$ 0.02

bagasse (0.67 ± 0.09). Many other elements were found in the fourth type, chicken manure rather than carbon, oxygen and potassium which were common in the first three types. These elements were Ca, P, and Cl with mass% of 16.80 ± 0.33 , 0.62 ± 0.06 and 0.40 ± 0.05 respectively. Another difference, that the percentage of oxygen was higher than that of carbon, the mass% of both 35.51 ± 0.36 and 45.24 ± 0.96 for C and O respectively. Finally, the potassium was present in mass percentage closer to that of the first three types which were 1.44 ± 0.10 .

Fourier transforms infrared (FT-IR) analysis

The FTIR spectra of all types, (a) *Leucaena leucocephala*, (b) chicken manure, (c) rice husk and (d) sugarcane bagasse respectively in the region of 4000–500 cm^{-1} were shown in (Fig. 3), and summarized in (Table 2). The results of FTIR analysis shows that the four types are relatively different in their functional groups also the chicken manure biochar shows the largest number of functional group on its surface.

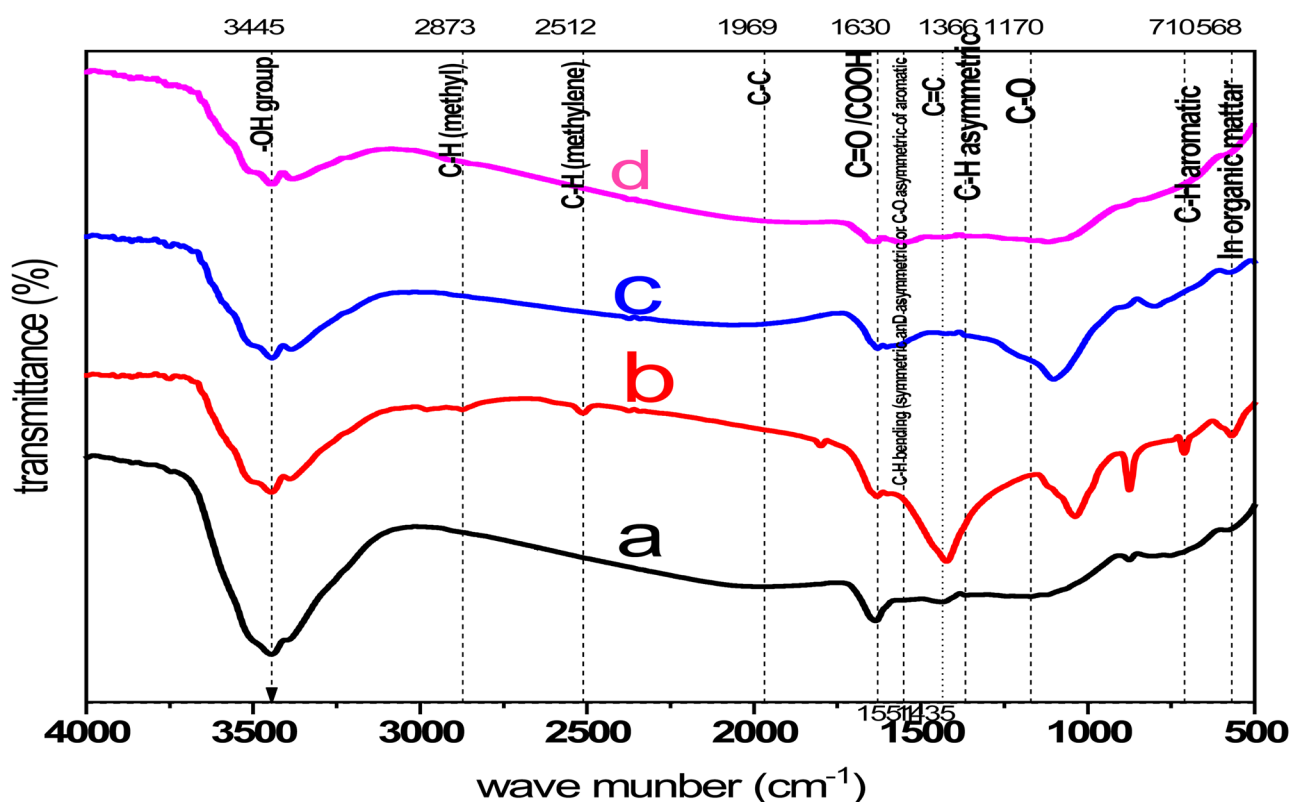


Fig. 3 FTIR spectra for biochar types, **a** *Leucaena leucocephala*, **b** chicken manure, **c** rice husk and **d** sugarcane bagasse

Table 2 FTIR bands and corresponding functional groups observed in the spectrum for each biochar type

Wavenumber (cm ⁻¹)	Assignments	Rice husk	Sugarcane bagasse	<i>Leucaena leucocephala</i>	Chicken manure
3000–3700	-OH group	3443.6052–3387.6462	3443.4734–3381.6227	3445.2587	3445.2067–3390.6020
2800–3000	C-H (methyl)	-	-	-	2873.6437–2979.8946
2512	C-H (methylene)	-	-	-	2512.7511
2000	C–C	2066.6876	-	1969.8942	-
1600–1800	C=O /COOH	1629.4875–1601.6461	1633.1786	1634.5845	1799.7296–1630.8493
1560	C=C	-	1551.4758	-	-
1420–1450	C-H asymmetric	-	-	1435.6404	1422.8044
1317–1375	C-H bending (symmetric and asymmetric or C-O asymmetric of aromatic	-	-	1366.7821	-
1000–1260	C-O	1102.9053	1119.6352–1162.2830–1240.9596	1170.4790	1038.0334
700–900	C-H aromatic (out of plane)	799.6459	-	753.2122–875.7330	710.6338–874.9179
400–700	In organic matter	467.6012–576.9556	-	583.0563	568.5260

Insecticidal activity of biochars

The toxicity of the four biochars to the target insect species was represented in (Table 3). The obtained results showed that the chicken manure biochar exhibited the highest effectiveness. The obtained results showed that the chicken manure biochar exhibited the highest effectiveness against both *O. surinamensis* and *R. dominica* with mortality percentages 86.66 and 73.33% followed by *Leucaena leucocephala* biochar 50.00 and 30.00%, respectively at tested concentration 5 g/kg. Nevertheless, rice husk and sugarcane bagasse biochar presented lower toxicity on *O. surinamensis* and *R. dominica*. Moreover, there was no toxicity effect for all of the tested biochars against *S. oryzae* and *T. castaneum*.

Effect of different particle size chicken manure biochar

Different particle size chicken manure biochar was tested for contact toxicity against adults of *R. dominica* and *O. surinamensis* and their LC₅₀ values are shown in (Table 4; Fig. 2). The different particle size of chicken

manure biochar showed significant toxic activity and it was clear that with a decrease in the particle size, the toxicity activity also increases. It was observed that chicken manure biochar was more toxic to *O. surinamensis* adults than to *R. dominica* adults. The lowest particle size (1.80–0.94 µm) of the biochar resulted in strong activity against *R. dominica* and *O. surinamensis* adults with LC₅₀ values of 1.29 and 0.56 g/kg, respectively. Whereas in the case of particle size (4.02–4.23 µm) the LC₅₀ value was 11.25 and 12.33 g/kg respectively. But the largest particle size (3.96–5.40 µm) showed the lowest toxicity. These results also revealed that an increase in mortality with decreased biochar particular size to (1.80–0.94 µm) was observed in both tested insects.

Insects scanning electron microscopy

Scanning electron micrographs of *O. surinamensis* and *R. dominica* (most affected by biochar) shows the adhesion of biochar particles on insect's body parts compared with

Table 3 Toxicity of four types of biochar *Leucaena leucocephala*, sugarcane bagasse, rice husk and chicken manure against some stored product insects after 10 days exposure periods

Type of biochar	Mean of mortality ± (SE) after 10 days exposure periods *			
	<i>S. oryzae</i>	<i>R. dominica</i>	<i>O. surinamensis</i>	<i>T. castaneum</i>
<i>Leucaena leucocephala</i>	18.33 ± 4.4	30.00 ± 2.00	50.00 ± 0.0	6.66 ± 3.3
sugarcane bagasse	1.66 ± 1.66	23.33 ± 3.3	20.00 ± 5.7	13.33 ± 4.4
rice husk	3.33 ± 3.3	31.33 ± 6.00	26.66 ± 9.2	13.33 ± 4.4
chicken manure	1.66 ± 1.6	73.33 ± 1.6	86.66 ± 1.6	13.33 ± 4.4
interactions LSD _{0.05}	9.37			

*Mean ± Standard Error (SE)

Table 4 Comparative toxicity of chicken manure biochar particle size against *R. dominica* and *O. surinamensis* after 10 days exposure periods

Insects	Chicken manure biochar particle size (μm)	LC_{50} (g/kg)	Confidence limits		Slope $\pm$ variance	ch^2	df	P-value
			lower	upper				
<i>R. dominica</i>	3.96–5.40	>20	-	-	-	-	-	-
	4.02–4.23	11.25	6.37	37.30	0.94 ± 0.19	1.47	4	0.48
	1.80–0.94	1.29	1.10	1.48	2.31 ± 0.20	3.54	4	0.17
<i>O. surinamensis</i>	3.96–5.40	>20	-	-	-	-	-	-
	4.02–4.23	13.22	7.50	42.36	1.07 ± 0.21	2.90	4	0.26
	1.80–0.94	0.56	0.47	0.66	1.98 ± 0.21	5.78	4	0.06

Upper and lower limits of the confidence interval of 95% are indicated between parentheses

untreated ones. (Fig. 4) shows no scarification of adult's cuticle was observed after exposure. Biochar particles were seen heavily clustered on the whole body of *O. surinamensis* more than *R. dominica*. The sensilla were not seen in different body parts which may result from the friction between biochar particles and cuticles during the insect's movement.

The impact of biochar moisture content on its toxic efficiency

We examined the efficacy of the two most effective biochar chicken manure and *L. leucocephala* with moisture

content 0, 25, 50, 100, 150% against *O. surinamensis* after an exposure period 10 days (Table 5). Types of biochar had different efficacy. Depending upon its moisture contents, with increased moisture the toxicity of biochar decreased. Dry biochar caused significant highest toxicity effect 93.33 ± 6.66 and 43.33 ± 8.81 , toxicity decreased gradually upon 36.66 ± 6.66 and 6.66 ± 3.33 at 150% moisture content (w/w) with chicken manure and *L. leucocephala* biochar. Moreover, chicken manure biochar remained more toxic than *L. leucocephala* biochar with all examined moisture content.

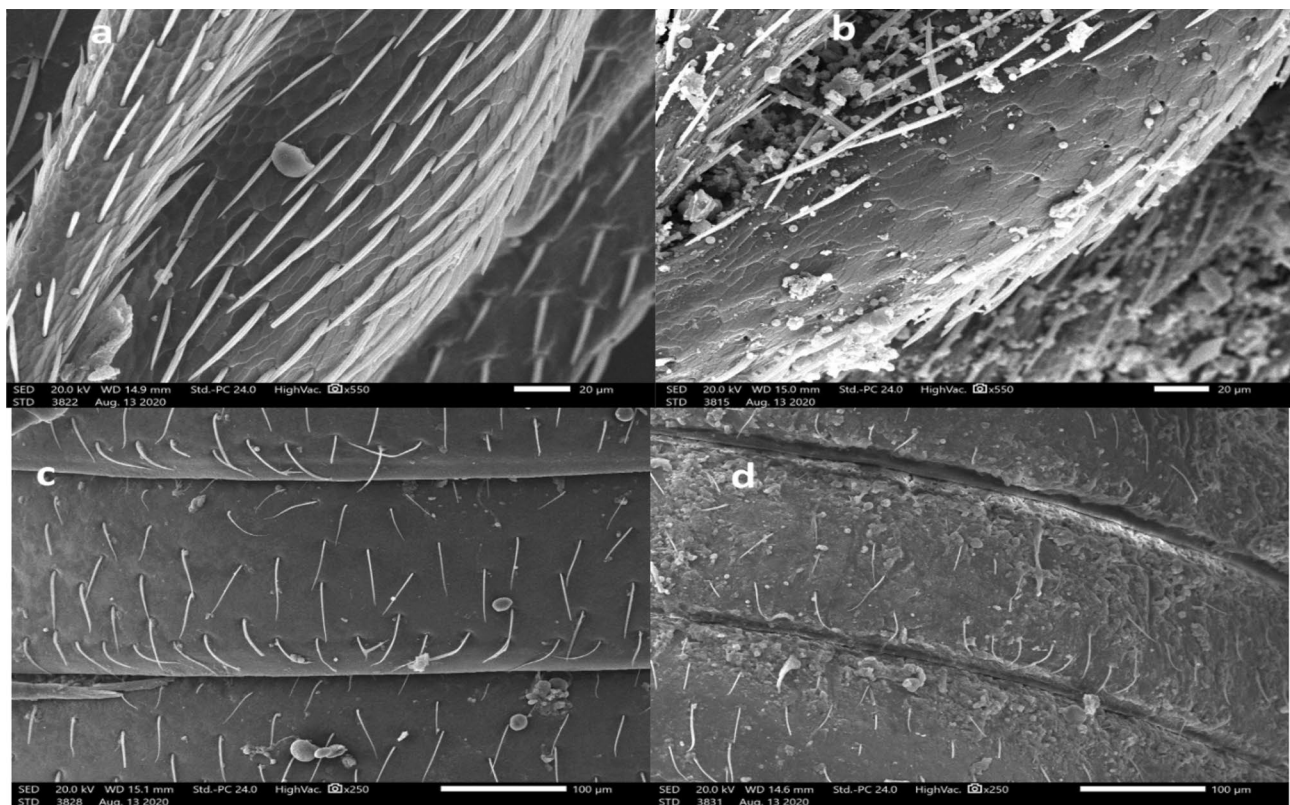


Fig. 4 Micrographs of scanning electron microscope of untreated and treated stored product insect with chicken manure biochar: **a&b** untreated and treated *O. surinamensis*, **c&d** untreated and treated *R. dominica*

Table 5 The impact of biochar moisture content on its toxic efficiency against *O. surinamensis*

Type of biochar	Mean of mortality $\pm$ (SE) after 10 days exposer periods *				
	Moisture content (%) of biochar				
	0	25	50	100	150
chicken manure	93.33 $\pm$ 6.66a	80.00 $\pm$ 11.54ab	63.33 $\pm$ 3.33 abc	60.00 $\pm$ 0.00 bc	36.66 $\pm$ 6.66 c
<i>Leucaena leucocephala</i>	43.33 $\pm$ 8.81a	33.33 $\pm$ 3.33ab	26.66 $\pm$ 3.33abc	10.00 $\pm$ 5.77bc	6.66 $\pm$ 3.33c
interactions LSD _{0.05}	18.17				

*Mean $\pm$ Standard Error (SE)

Discussion

In this research, we examined the toxicity of four types biochar rice husk, sugarcane bagasse, *L. leucocephala*, and chicken manure of biochar against *Tribolium castaneum*, *Rhyzopertha dominica*, *Oryzaephilus surinamensis* and *Sitophilus oryzae*. we found that chicken manure biochar was the most effective one biochar against *R. dominica* and *O. surinamensis*. Other studies have found that biochar was an effective material that can be used to control insects. (Chen et al. 2019b) examined the effect of three types of biochar (derived from the straw of corn, wheat, or rice) on the reproduction of English grain aphid *Sitobion avenae*. On wheat, biochar caused decreased in aphid lifetime fertility and population growth. Also, biochar application to paddy fields may play a role in suppressing the *Cnaphalocrocis medinalis* population (Chen et al. 2019a). To explain the mechanism for the chicken manure biochar effect on insects. Following characterization, a notable difference between rice husk, sugarcane bagasse, *L. leucocephala*, and chicken manure biochar. Elemental compositions refer to the chicken manure biochar exhibited a decrease in Carbon concentration and increase Oxygen content; there was a negative correlation between C and O contents. Moreover, the chicken manure biochar is the only tested biochar that contains Ca, P, and Cl (Ahmad et al. 2014; Pan et al. 2019). The results of FTIR analysis showed that the chicken manure biochar has the largest number of a functional group on its surface compared with other tested biochars, which were -OH group stretching (3000–3700 cm⁻¹), C-H methyl (2800–3000 cm⁻¹), C-H methylene (2512 cm⁻¹), C=O /HCOO (1600–1800 cm⁻¹), C-H asymmetric (1420–1450 cm⁻¹), C-O (1000–1260 cm⁻¹), C-H aromatic (700–900 cm⁻¹) and inorganic matter stretching (400–700 cm⁻¹). Insect cuticle is a layered, fibrous composite of chitin, water, protein, catechol, lipid and occasionally metal and mineral. Chitin (N-acetylglucosamines) has many C-H, N-H, and O-H groups (Chapman 1998; Vincent and Wegst 2004). So that, biochars may be adhered on the insect's surface functional groups causing death.

The skeletal structure of biochar that looks like a carbon sponge, and its ability to retain H₂O, material may be

abrasive to an insect's cuticle leading to an increased potential for dehydration (Cook and de Andrade 2018), while the mineral structure is hardly biodegradable, the re-condensed vapor that can be joined in the biochar pores and its surfaces or less aromatic and more biodegradable and can be considered organic phase, the biochar to be more toxic than other which does not enough mineral groups (Wilson 2014).

There were substantial variations in the effectiveness of various particle sizes of measured chicken manure biochar and their fractions, the smallest particles (1.80 to 0.94 μ m) were shown to be extremely effective in controlling all tested insects, indicating that particle size was a biochar property that can influence its toxicity. According to the current findings, inert dust particles with diameters ranging from (1.80 to 0.94 μ m) showed greater insecticidal effects than bigger particles. Also, substantiate was a considerably favorable association between the effectiveness of the tested biochars and its particles size. Biochar small particles have a greater surface area than the other biochar containing larger particles. Hence, the larger was the surface it covers and the greater the toxicity it produces, as the contact area between the insect's body and the particles increases. Our studies were in agreement with those optioned by (Cook and de Andrade 2018) who found the ants in contact with biochar particles (< 150 μ m) had the lowest mean survival, followed by the survival of ants exposed to the coarse material (> 1.0 mm). The particles of inert dust with sizes of < 45 μ m were strongly influencing the insecticidal action than larger particles against *R. dominica*, *S. oryzae* and *C. ferruginous* (Vayias et al. 2009; Baliota and Athanassiou 2020). Our results showed that the mortality of *Oryzaephilus surinamensis* decreased from 80% at 25% to 36.66 at 150% chicken manure biochar moisture content. This means that biochar becomes ineffective when saturated with water. Some of the findings were similar to those of previous studies. this is one of the disadvantages of using biochar to control stored material insects. There are numerous examples of inert dust's effectiveness being affected by increasing moisture content the lower the moisture content, the greater the mortality increase. Moreover, the increased grain moisture content causes a decrease in the toxicity of diatomaceous earth

against *S. oryzae* and *R. dominica*. grain moisture content 11.8% moisture content caused 95 and 72% mortality but grain moisture content 15.0% caused 53 and 17% mortality of *S. oryzae* and *R. dominica*, respectively. (Fields and Korunic 2000). The possible mechanism of action of biochar can be explained by different suppositions such as (1) biochar particles known to degrade hydrocarbons in nature so they therefore possibly degrade alkanes which present in insect cuticles (Ahmad et al. 2014). (2) The degradation of the peritrophic membrane was further accelerated by the biochar which is known for its capability to degrade hydrocarbons and aromatic structures in nature (Ahmad et al. 2014). (3) Reduced efficiency in converting consumed food into a growth and energy source associated with possible energy diversion from growth to the detoxification process (Wang et al. 2021). (4) The SEM of treated insects indicted that biochar is material that may be abrasive to an insect's cuticle leading to an increased potential for dehydration (Cook and de Andrade 2018). The SEM of treated insects indicted that biochar is material that may be abrasive to an insect's cuticle leading to an increased potential for dehydration (Cook and de Andrade 2018). May be entering on insect's spiracles and effect or interfering on respiration process.

Conclusion

Our results refer to the insecticidal activity of biochar may be chemical or physical effect. As shown by SEM image, the physical effect observed by desiccation that happened to the insect also the inverse relationship between the moisture content of biochar and its toxicity which may reflect the mechanism of moisture absorption from the insect body. On the other hand, the chemical effect observed by the FTIR analysis that shows the large number of active groups that distributed on the surface of manure type that gave the higher insecticidal activity. Finally, more studies are needed to explain the mode of insecticidal activity of biochar.

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Declarations

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

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