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Comparative study of individual and co-application of pyrolysis products of *Leucaena Leucocephala* tree wastes as natural resources to control the rice weevil *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae)

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ABSTRACT: In this study, the insecticidal activity of individual and co-applications of bio-oil and biochar produced from the residues of the *Leucaena Leucocephala* (Lamark) deWit (Fabales: Fabaceae) tree by pyrolysis was evaluated against the rice weevil, *Sitophilus oryzae*. Bio-oil exhibited high insecticidal activity, of 93% mortality at 30% after 7 days, while biochar did not exhibit insecticidal activity, mortality was 32.5% at 3 g kg^{-1} after 7 days of exposure. An enhancement was recorded for the co-application of 5% of bio-oil at different concentrations of the biochar, and the highest synergistic effect was obtained for 5% of bio-oil + 0.5 g kg-1 of biochar (co-toxicity factor = 30.11-fold). The co-application was re-investigated regarding the mortality and wheat germination percentage after different storage periods, and the results showed no significant changes in the mortality up to 30 days but significantly decreased after 45 days, while the germination percentage was not significantly affected up to 45 days of storage. The gas chromatography-mass spectrometry revealed the prevalence of phenolic compounds and organic acids in approximately 68.19% of the total components in the bio-oil, and the pH was recorded to be highly acidic (pH = 1.5). Additionally, many functional groups were observed on the biochar surface by FTIR, which may have interacted with the chemical components of bio-oil to induce the enhancement action. This study provides information regarding the utilization of the pyrolysis products of lignocellulosic wastes as natural resources to control *S. oryzae* and protect stored wheat from infestation for up to 30 days.

Keywords: *L. Leucocephala tree, Bio-oil, Biochar, Pyrolysis process, Sitophilus oryzae*

INTRODUCTION

Currently, the most important issue affecting the world is climate change. According to the Intergovernmental Panel on Climate Change (IPCC) report, the concentrations of greenhouse gases (GHGs) have continued to increase in the atmosphere. Owing to various agricultural activities, a considerable amount of waste is produced, such as animal waste, agricultural crop residues, and forest waste. In Egypt, the annual volume of waste is approximately 35 million tons. Farmers use the burning method to discard these residues, which causes economic losses and damages human health due to the increase in GHG emissions. Thus, the earth's surface experiences pollution and global warming, and consequently, climate change and its negative impacts on the environment are expected (Abou Hussein and Sawan, 2010; Masson-Delmotte *et al*., 2021). Therefore, it is extremely necessary to utilize these wastes in other ways to convert them into useful products. The most important of these methods is the process of pyrolysis, in which biomass materials are exposed to thermal decomposition at a high temperature in the range of 400°C-800°C under conditions limited to or free of oxygen (Al-Haj Ibrahim, 2020). Under different conditions of the pyrolysis process, different products with different properties can be obtained (Aly, 2016). Depending on the biomass source used during the pyrolysis process and the temperature, different products can be obtained. Liquid bio-oil can be produced approximately within the range of 60-75 wt%. Solid char can be produced within 15–25 wt%, and non-condensable gases are produced at a percentage within 10–20 wt% (Mohan *et al*., 2006). A solid product obtained from the pyrolysis process is called biochar, a material that is highly porous and rich in carbon (Aly, 2016). Biochar is well-known to have many advantages, such as its role in soil improvement, carbon sequestration, and a significant role in environmental remediation (Ahmad *et al*., 2014). In addition, it can be mixed with other materials, such as clay, to improve the uptake of nutrients. such as K, for a long period without reapplication (Farrar *et al*., 2022). Many bio-oil pers have discussed the effect of soil amended with biochar on the development and reproduction of different insect species, such as *Polyphagotarsonemus latus* (Banks), *Laodelphax striatellus,* and *Nilaparvata lugens* (Stål) (Elad *et al*., 2010; Hou *et al*., 2015, 2017; Fu *et al*., 2018). This effect may have been related to the improvement in plant growth and health, which reflected the enhancement of plant defence mechanisms (Fu *et al*., 2018; Chen *et al*., 2019). However, the direct effect of biochar when in contact with insects remains unexplored. Recently, Hassan *et al*. (2022) evaluated the effectiveness of four types of biochar against different stored-product insects and observed that the biochar derived from chicken manure was the most effective. *Oryzaephlius surinamensis* and *Rhyzopertha dominica* were the two most affected insects. Additionally, the difference in particle size of biochar was studied, and the results showed that mortality increased with a decrease in particle size *(Hassan et al*., 2022).

During the pyrolysis process to produce biochar, bio-oil is obtained because of the condensation of gases. Bio-oil, also known as wood distillate (WD) or bio-oil , is a green biomass that is environment-friendly with insecticidal activity (Tiilikkala *et al*., 2010; Zhang *et al*., 2012; Grewal *et al*., 2018) and comprises mainly organic acids, phenols, aldehydes, and ketones (Souza *et al*., 2012). Certain studies have investigated the effect of the co-application of bio-oil and biochar on certain crop seeds and observed enhancements in the seed germination and plant growth bio-oil parameters (Pan *et al*., 2017; Luo *et al*., 2019; Ju *et al*., 2021). In Egypt, many crops are planted, but grains are the most dominant staple crop. Wheat is the most planted grain (Abdelaal and Thilmany, 2019). Like all grains, wheat is attacked by many stored grain insects, which cause losses in quality and production.

The rice weevil *S. oryzae* is a primary insect that attacks cereal grains in storage. The infestation of stored grains with this insect pest causes quantitative damage due to grain weight loss (owing to insect feeding) and qualitative damage, such as loss in nutritional, aesthetic, and industrial value, respectively. The insect also decreases germination by feeding on seed embryos. *S. oryzae* can cause cereal loss of 12: 20% and may reach up to 80% under favorable conditions (Gad *et al*., 2020). Here, we aimed to 1) produce bio-oil and biochar through the pyrolysis of *Leucaena Leucocephala* tree residues, 2) evaluate the efficiency of bio-oil and biochar as individual treatments against *S. oryzae*, 3) evaluate the co-application of bio-oil and biochar against *S. oryzae*, 4) study the effect of the co-application of bio-oil on the mortality percentages of *S. oryzae* and germination percentages of wheat grain after different storage periods, and 5) determine the chemical characterization of bio-oil and biochar through gas chromatography-mass spectrometry (GC-MS) and Fourier transform infrared (FTIR) analysis.

2.MATERIALS AND METHODS

2.1. Tested insects.

Sitophilus oryzae (L.) (Coleoptera: Curculionidae) had been cultured in the laboratory for virtually ten years at the Faculty of Agriculture, Alexandria University. The insects were raised in total darkness on sterilized whole wheat at a constant temperature of 27°C ± 1°C and 65% ± 5%. RH. adult insects were used in toxicity tests during 2–3 weeks of emergence. All the experiments were conducted under these conditions.

2.2. Preparation of biochar and bio-oil from Leucaena wood

Bio-oil and biochar were prepared from the pruning residue of *L. leucocephala* trees grown in the forestry research sector of the Antoniades botanical garden, Alexandria governorate, Egypt. The pruned branches were air-dried in the open air for approximately 6 months. Afterward, the branches were stored in the lab at room temperature. The branches were sawn into suitable pieces.

A stainless-steel reactor with a dimension of 150 × 110 × 50 mm was equipped with temperature control and an electrically heated furnace. In this experiment, 150 g of the wood sample underwent heating in the reactor from room temperature to a target pyrolysis temperature (400°C) at a heating rate of nearly 5°C/min. The holding time at the target temperature was 1 h. The pyrolysis vapors went through a cooled condenser to separate the bio-oils. After the pyrolysis experiment, the bio-oil was stored in the refrigerator during storage periods, and the crude bio-oil was gradually split into three distinct layers. The superstratum was thin oil, the middle was high-quality liquid, and the bottom was viscose wood tar with several other substances. The liquid in the middle fraction (feasible bio-oils) was isolated. After pyrolysis, the reactor was allowed to cool to room temperature, and the biochar remaining was extracted and stored in a sealed bag until use.

2.3. FTIR

FTIR performed the spectroscopic characterization of biochar to identify the function groups distributed on its surface. Bruker Tensor 37 spectrometers were used in the range of 400-4000 cm^{-1} utilizing KBr pellets, as 1.0 mg of the samples was added to 100 mg of pressed KBr and exposed to IR radiation (Wu *et al*., 2012; Guo and Chen, 2014).

2.4. Chemical component analysis of the bio-oil of *L. leucocephala*

The analysis of the chemical components of the bio-oil of *L. leucocephala* was performed using a GC-TSQ mass spectrometer (Thermo Scientific, Austin, TX, USA) with a direct capillary column TG-5MS (30 m × 0.25 mm film thickness). The column oven temperature was initially set at 50°C and increased at a rate of 5°C/min to 250°C, maintained for 2 min, and increased to the final temperature (300°C) at 30°C/min and maintained for 2 min. The injector and MS transfer line temperature were maintained at 270°C and 260°C, respectively. Helium was used as a carrier gas at a constant flow rate of 1 ml/min. The solvent delay was 4 min, and diluted samples of 1 µL were automatically injected using an Autosampler AS1300 coupled with GC in split mode. Electron ionization mass spectra were collected at an ionization voltage of 70 eV over a range of m/z 50-60 in the full-scan mode. The ion source temperature was set at 200°C. The bio-oil chemical components were identified based on their retention time, with the mass spectra with those of Wiley 09 and NIST 14 mass spectral databases. The percentage of components was calculated using the GC peak area. The pH of the bio-oil was measured using a pH meter (Crison™ pH-metro PH 25+).

2.5. Bioassay procedures

2.2.1. Biochar toxicity bioassays

In a 250-mL glass jar, the requisite quantities of biochar (0.5, 1 and 3 g kg^{-1}) were combined with 20 g of wheat. Each biochar concentration and wheat were mixed. The jars were snugly sealed with lids and rotated, overturned for 30 seconds, vigorously shaken for 10 seconds, and rotated and overturned again for another 30 seconds. Each jar contained 20 adult insects gathered during 2-3 weeks of emergence. Four replicates constituted each treatment and control group. The mortality percentages were recorded after 7 days.

2.5.2. bio-oil toxicity bioassay

Different concentrations of bio-oil were obtained by diluting it with acetone (5%, 10%, 20%, and 30%). In addition, 1 mL of each diluted concentration (as a control treatment) was distributed on 20 g of wheat in 250-mL jars. Thereafter, all the jars containing wheat and bio-oil were physically shaken. The treatments were allowed to evaporate. Twenty adult insects were placed individually in each jar. Four replicates constituted each treatment. All experiments were maintained at 27 ± 2 ^{O}C and 75 ± 5% R.H. After 7 days of adding insects, the mortality percentages were recorded.

2.5.3. Co-application of biochar and bio-oil from Leucaena wood

Here, 20 g of wheat was pretreated with 5% bio-oil and allowed to evaporate. Thereafter, different concentrations of biochar (0.5, 1, and 3 g kg^{-1}) were applied to wheat as previously stated, and 20 adults were added immediately to each replicate. The mortality percentages were recorded after 7 days of treatment. Wheat grain treated with the co-application of 5% bio-oil+ 3 g kg-1of biochar had been stored for different storage periods (7, 15, 30, and 45 days). After each storage period, the insects were added, and the mortality was recorded.

2.6. Germination test

After each storage period, the germination test was conducted according to a previous study (Liu *et al*., 2006). Approximately 20 wheat seeds were immersed in water for 24 h. The swollen seeds were filtered prior to distribution on a moistened-thin sheet of cotton placed in a 9-cm Petri dish and incubated at room temperature in the dark. Water was applied as needed. After 4 days, the number of seedlings was counted, and the germination percentages were calculated.

2.7. Statistical analysis

The data are expressed as means of the replicates ± standard error and cumbered using analysis of variance, followed by Tukey's multiple range test to determine the differences between the means of treatment. The co-toxicity factors were calculated using Mansour *et al*. (1966).

3. RESULTS AND DISCUSSION

3.1. Chemical components of bio-oil from Leucaena wood

The GC–MS analysis results of the preboiled bio-oil in 24 compounds under different chemical classes are listed in Table 1. The phenolic compounds were the major component in the bio-oil composition by approximately 68.19% of the total components, including cresol; 2-methoxy phenol; phenol-2,6 dimethoxy (syringe); gauiacol-4ethyl; and phenol-2,4 dimethoxy 2-methyl which were the most phenolic compounds by percentages of 18.11%, 17.32%, 16.40%, 13.48%, and 7.81%, respectively. Phenol; o-cresol; and phenol 2, 4 dimethyl were the least abundant phenolics by approximately 1.04%, 0.9%, and 0.88%, respectively. The following components in the composition of bio-oil are the carboxylic acids, which constituted approximately 6.34%, represented by benzoic acid, 4-hydroxy (2.15%); 1-cyclooctene-1-carboxylic acid (1.38%); 1, 2-benzenedicarboxylic acid, diethyl ester (1.14%); benzene acetic acid, 4-hydroxy-3-methoxy (0.79%); and benzoic acid, 2-hydroxy-, phenylmethyl ester (0.88%). Benzene derivatives comprised approximately 6.31%, represented by benzene,1,2,5-trimethoxy-3-methyl. Other organic compounds were observed under different classes, including ketones, amines, diamides, alkenes, and aldehydes, which represented a percentage of 11.29%.

The GC–MS analysis results showed the highest abundance of phenolic compounds, resulting from the thermal degradation of lignin (Yang *et al*., 2007), and carboxylic acids, which are believed to be produced from the hemicellulose that mainly contains acetyl groups in its composition (Kartal *et al*., 2004). The composition of the bio-oil prepared from *L. leucocephala* correlated with a previous report that the chemical composition of bio-oil prepared from Toona sinensis wood mainly contained carboxylic acids, phenolic compounds, and other compounds belonging to different chemical groups, such as ketones, amides, aldehydes, esters, and alcohols (Adfa *et al*., 2017). Similarly, another study reported the chemical composition of bio-oil prepared from acacia bark, which mainly contained acetic acids and phenolic compounds (Prianto *et al*., 2020). The GC–MS of bio-oil prepared from Cinnamomum parthenoxylon wood showed that the main components were organic acids and phenols (Adfa *et al*., 2020). The pH of the *L. leucocephala* bio-oil was 1.5. The bio-oil in this study exhibited a good insecticidal effect, which may have been the result of its high acidity. Adfa *et al*. (2020) discovered that the criterion for the good quality of the bio-oil was a pH of approximately 3.

Table (1) Chemical component (%) of bio-oil prepared from *L. Leucocephala* analyzed by GC-MS

Components	Retention time (min)	Peak area%	Molecular formula	Molecular weight
Benzoic acid, 4-hydroxy-	4.79	2.15	C7H6O3	138
2-cyclopenten-1-one,2-hydroxy-3-methyl	5.26	2.02	C6H8O2	112
O-cresol	5.92	0.96	C7H8O	108
2-methoxyphenol	6.25	17.32	C7H8O2	124
1-ethoxy-2,4-hexadiene	6.92	0.94	C8H14O	126
Phenol, 2,4-dimethyl-	7.72	0.88	C8H10O	122
Creosol	8.30	18.11	C8H10O2	138
2-cyclohexen-1-one,	9.13	0.49	C10H16O3	184
Guaiacol, 4-ethyl	10.09	13.48	C9H12O2	152
Phenol, 2,6-dimethoxy	11.77	16.40	C8H10O3	154
1-cyclooctene-1-carboxylic acid,	11.93	1.38	C10H14O2	166
Phenol	12.83	1.04	C10H12O2	164
Phenol-4,5 ,dimethoxy-2-methyl	13.70	7.81	C9H12O3	168
2,5,5,8a-tetramethyl-3,5,6,7,8,8a-hexahydro-2H-naphthalen-1-one	14.08	0.82	C14H22O	206
Phosphonic diamide, N-(1,1-dimethylethyl)-N',p-bis(1 methylethyl)-	14.74	0.74	C13H16O3	220
2(3H)-Naphthalenone, 4,4a,5,6,7,8-hexahydro-1-ethoxy	14.88	0.37	C11H16O2	180
Lilial	15.08	0.74	C14H20O	204
Benzene,1,2,5-trimethoxy-3-methyl	15.24	6.31	C10H14O3	182
Benzene acetic acid,4-hydroxy-3-methoxy	15.52	0.79	C9H10O4	182
1,2-Benzenedicarboxylic acid, diethyl ester	16.44	1.14	C12H14O4	222
4-(2'-Methyl-3' Butenyl) Azulene	16.82	1.37	C9H7ClN2O	194
Methyl (-3 oxo-2-pentyl cyclo pentyl) acetate	17.54	2.57	C13H22O3	226
[1,2,4]Triazolo[1,5-A] [1,3,5]Triazin-7-Amine	20.99	1.28	C12H14N6O	258
Benzoic acid, 2-hydroxy,- phenylmethyl ester	21.45	0.88	C14H12O3	228

3.2. FTIR analysis of biochar prepared from *L. leucocephala*

The FTIR analysis results of the biochar prepared from *L. leucocephala* are shown in (Table 2), confirming the presence of different functional groups distributed on the biochar surface. Peaks observed at 2922.5484 and 2852.5356 cm^{-1} represent methyl groups substituted on the aromatic rings. According to a previous study, the presence of triple bonds in alkyne was confirmed at peaks near 2200 cm^{-1}, which was observed in the current analysis at 2196.6186 cm^{-1} (Coates, 2006). Peaks recorded between 1600 and 1800 cm^{-1} may be attributed to C=O for lactones or carboxyl carbonate or may represent the vibration of C=C in aromatic compounds (Morterra *et al*., 1988; Zawadzki, 1989). C=C stretching in the rings was confirmed near 1560 cm^{-1}, as observed in the *L. leucocephala* biochar at 1558.4762 cm^{-1} (Abdulrazzaq *et al*., 2014). The absorbance at 1436 cm^{-1} represents aliphatic C–H groups (Tatzber *et al*., 2007; Cantrell *et al*., 2012). The peak at 1351.2175 cm−1 may be attributed to the C–H bending in-plane, which may have resulted from cellulose or hemicellulose (Fan *et al*., 2012). A band assigned to the stretching C–O group was observed at 1215.4094 cm^{-1}, resulting from phenols, alcohols, and carboxylic acids (Varsányi, 2012). The bands in the range of 700–900 cm^{-1} were assigned to binding C–H groups out of the plane of aromatic rings, indicating the presence of rings with more substitutions (Gómez-Serrano *et al*., 1999; Keiluweit *et al*., 2010). The absorbance at 570.4183 cm^{-1} may have resulted from the presence of inorganic matter, such as carbonate and silicates (Tong *et al*., 2013).

Table 2: FTIR bands and corresponding functional groups observed in the spectrum of *L. Leucocephala* biochar.

Wavenumber (cm^{-1})	Assignments	Biochar of *L. leucocephala*
2800-3000	C-H (methyl)	2922.5484 2852.5356
2000-2200	C≡C (disubstituted)	2196.6186
1600-1800	C=O /COOH	1747.4829 1696.9197
1560	C=C	1558.4762
1420-1450	Asymmetric C-H	1436.0098
1317-1375	C-H bending (symmetric and asymmetric or C-O asymmetric of aromatic	1351.2175
1000-1260	C-O	1215.4094
700-900	C-H aromatic (out of plane)	876.6303 825.8728 758.1046
400-700	Inorganic matter	570.4183

3.3. Insecticidal activity of the bio-oil of *L. leucocephala* against *S. oryzae*

Here, the insecticidal activity of the bio-oil of *L. leucocephala* was evaluated against the adults of *S. oryzae* at various concentrations. The mortality percentages are shown in Table 3. The bio-oil of *L. leucocephala* exhibited relatively high mortality, which increased with an increase in concentration. Mortality percentages were recorded at concentrations 5%, 10%, 20%, and 30% to be 41.66%, 63.3%, 70.46%, and 92.93%, respectively. The activity of the bio-oil of *L. leucocephala* bio-oil may have been due to its composition, mainly its high content of phenolic compounds, which included cresol, syringol, 2-methoxy phenol, guaiacol-4-methyl, phenol 4,5 dimethoxy-2-methyl, phenol, o-cresol, and phenol 2,4 dimethyl, in addition to the presence of carboxylic acids and other organic compounds.

Table 3: Insecticidal activity of *L. Leucocephala* bio-oil against *S. oryzae* adults

Material	conc. (%)	Mortality %± (SE)
bio-oil	5	41.66±8.82c
	10	63.33±6.00bc
	20	70.46±0.46b
	30	92.93±3.55a

Means in the same column within a treatment, followed by the same letter(s), are not significantly different at P = 0.05; Turkey's test.

Our results correlated with those of many studies that reported the insecticidal activity of bio-oil against different insect species. A previous study investigated the termiticidal activity of the bio-oil derived from *Cinnamomum parthenoxylon* wood against *Coptotermes curvignathus* and showed high mortality, which increased with an increase in the bio-oil concentration (Adfa *et al*., 2020). In another study, the termiticidal activity of bio-oil obtained from *Vitex pubescens* wood was evaluated and exhibited activity against *Reticulitermes speratus* and *C. formosanus* (Oramahi and Yoshimura, 2013). A study reported the bioactivity of bio-oil derived from sunflower seed hulls waste against *S. oryzae*, *L. serricorne*, *and T. castaneum* and showed insecticidal activity (Urrutia *et al*., 2021). According to these studies, the bio-oil activity may be attributed to the high content of phenolic compounds and total acids. (Homayoonzadeh *et al*., 2022) investigated the effects of bio-oil on two prominent stored-product moths, *Ephestia kuehniella* (Zeller) (Lepidoptera: Pyralidae) and *Plodia interpunctella* (Hübner) (Lepidoptera: Pyralidae) and concluded that the consumption of bio-oil inhibited the activities of enzymes of detoxification and digestion. The induction of the antioxidant system and reduced levels of energy reserves were also recorded.

Cumulatively, a reduction in longevity and fecundity was reported, compared with those of the untreated insects. Both phenolics and organic acids were the most prevalent in the bio-oil when analyzed by GC–MS (Homayoonzadeh *et al*., 2022).

3.4. Insecticidal activity of the co-application of *L. leucocephala* bio-oil and biochar

The insecticidal activities of biochar and the mixture of biochar with bio-oil are shown in Table 4. Biochar alone exhibited extremely low activity against *S. oryzae* even at a high concentration, as the mortality percentage was recorded to be 32.5% at 3 g kg^{-1}.

The same concentrations of biochar were mixed with the lower concentration of 5% bio-oil, and the mortality was greatly increased for biochar and bio-oil as the bio-oil mortality recorded at 5% was only 41.66%. However, after mixing with biochar, the mortality increased to 69.3%, 77.7%, and 89.6% with concentrations of biochar at 0.5, 1, and 3 g kg^{-1}, respectively.

Table 4: Insecticidal activity of the mixture of bio-oil and biochar prepared from *L. leucocephala* against *S. oryzea* adults

Material	Mortality percentage±(SE) at conc.(g/kg)		
	0.5	**1**	**3**
biochar	11.6±1.6b	20.0±2.8b	32.5±1.4a
biochar +5% bio-oil	69.3±5.7b	77.4±3.4ab	89.62±0.2a
Co-toxicity Factor	30.11	25.52	20.03

Means in the same row within a treatment, followed by the same letter(s), are not significantly different at P = 0.05; Turkey's test.

The co-toxicity factor of the co-application exceeded 20-fold and produced significant synergism ratios for all treatments. The synergizing effect of the bio-oil increased with a decrease in the concentration of biochar, and the co-toxicity factor was highly synergistic (30.11-fold at the lowest dose of 0.5 g kg^{-1} biochar). This implied that bio-oil is a good synergizing additive to biochar, which may result from the interaction between the chemical components of bio-oil and the functional groups distributed on the biochar surface originating from the chemical composition of biochar. The bio-oil addition significantly augmented the action of biochar. The co-application of 5% bio-oil +3000 mg/kg biochar was reevaluated after different storage periods in terms of its influence on insect mortality and germination percentages of wheat grain. The results are shown in Figure 1; no significant change was observed in the mortality percentages recorded after 7 days of adding insects to stored wheat. were 91.6% and 83%, but the mortality significantly decreased to 63% after 45 days of storage. Many bio-oil producers have discussed the compatibility between dust and other controlling agents, such as chemical pesticides or biopesticides, to increase the efficiency of both treatments and prolong the protection period of stored products.

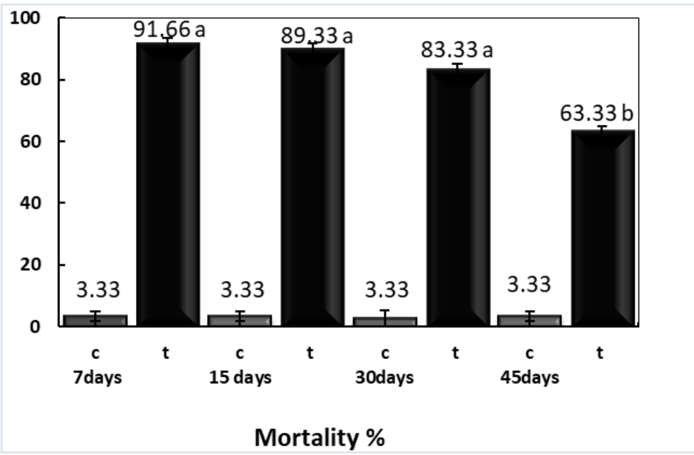

Fig (1): The mortality percentage ± (SE) of *S. oryzae* after co-application of wood vinegar at 5% +3000 mg/kg biochar at different storage periods

Wakil *et al*. (2021) reported that four stored-product insects, i.e., *Cryptolestes ferrugineus* (Stephens) (Coleoptera: Laemophloeidae), *T. castaneum*, the stored-product psocid *Liposcelis paeta* and *R. dominica* could be effectively controlled over 180 days through the combination of a diatomaceous earth formulation enhanced with the sesquiterpene polyol ester bitterbarkomycin

(DEBBM), *Beauveria bassiana*, and imidacloprid. The mortality of the insect species decreased, and the progeny production increased over a storage period of 6 months (Wakil *et al*., 2021). Another study demonstrated that the combination of spinosad at a dose of 0.5 mg kg^{-1} with different doses of DE and *Trichoderma harzianum* effectively reduced the wheat damage and weight loss caused by *S. oryzae* for 90 days. Additionally, no significant effects were recorded on the seed germination compared with that of the control (Gad *et al*., 2020). (Figure 2) shows the germination percentages recorded after each storage period, with no significant differences between all the periods of storage and the control group. This correlated with a previous study that observed the positive effect of the co-application of biochar and bio-oil on the plant growth of cucumber. These positive effects were related to an increase in nutrient supply and plant growth stimulation (Pan *et al*., 2017).

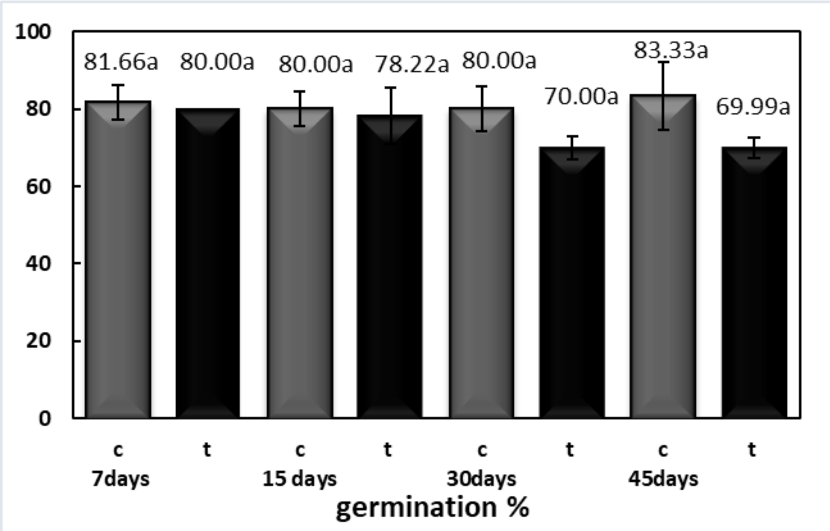

Fig (2): Effect of wood vinegar at 5% +3000 mg/kg biochar on germination ± (SE) of wheat after different storage periods

Another study discovered that the individual application of poplar-derived bio-oil or biochar (PBC) enhanced pepper seedling growth, while the co-application of bio-oil and PBC effectively promoted tomato seedling growth over the individual application (Luo *et al*., 2019). Another study investigated the effects of the application of bio-oil on the growth, yield, and quality of rapeseed and concluded that the plant height, total and green leaf number, leaf area, effective branch number, and pod number per plant significantly increased because of the application of a 400-fold bio-oil dilution. It significantly increased the rapeseed's dry matter. In addition, the resistance of rapeseed to diseases and low temperatures improved with the application of bio-oil (Zhu *et al*., 2021).

4. CONCLUSIONS

Waste biomass can be converted into useful and eco-friendly products in several ways. This study employed the pyrolysis process to transform trimmers of the Leucaena tree into bio-oil and biochar, which demonstrated insecticidal activity against the stored-product insect, *S. oryzae*. The results showed that the high insecticidal activity of bio-oil alone at a mortality rate of 30% was approximately 93% after 7 days. The co-toxicity factor of 5% and the 500 mg kg^{-1} biochar had a highly synergistic effect of 30.11-fold. This implied that bio-oil is a good synergizing additive to biochar. The co-application of bio-oil and biochar provided satisfactory protection for the 30-day storage against infestation. This period of protection could be prolonged by a monthly reapplication. The germination percentages indicated that there was no significant effect on the storage periods, implying that there was no negative effect on the vitality of the seeds.

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الملخص العربي

دراسة مقارنة المعاملة الفردية والمشتركة لمنتجات الانحلال الحرارى لبقايا شجرة الليوسينا كمصادر طبيعية لمكافحة حشرة سوسة الارز

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في هذه الدراسة ، تم تقييم نشاط النشاط الإبادى المنفرد والمشترك للزيت الحيوي والفحم الحيوي المنتج من بقايا شجرة الليوسينا *Leucaena Leucocephala* عن طريق الانحلال الحراري ضد حشرة سوسة الأرز ، *Sitophilus oryzae*. أظهر الزيت الحيوي نشاطًا إبادى عاليًا ضد الحشرة بنسبة موت 93 ٪ بتركيز 30 ٪ بعد 7 أيام ، بينما لم يظهر الفحم الحيوي نشاطًا إبادى حشرى ، حيث كان معدل الوفيات 32.5 ٪ عند 3 جم / كجم بعد 7 أيام من فترات التعرض. كذلك تم تسجيل تنشيط للتطبيق المشترك لـ 5٪ من الزيت الحيوي بتركيزات مختلفة من الفحم الحيوي ، وتم الحصول على أعلى تأثير تنشيطى لـ 5٪ من الزيت الحيوي + 0.5 جم/ كجم من الفحم الحيوي (معامل السمية المشتركة = 30.11 ضعف). كما تم إعادة تقييم التطبيق المشترك من حيث نسبة الموت للحشرات ونسبة الإنبات للحبوب بعد فترات تخزين مختلفة،و أظهرت النتائج عدم وجود تغيرات معنوية في نسبة موت الحشرات حتى 30 يومًا ولكنها انخفضت بشكل معنوي بعد 45 يومًا ، بينما لم تتأثر نسبة إنبات الحبوب معنويًا حتى 45 يومًا من التخزين. أظهر تحليل كروماتوجرافى الغاز انتشار المركبات الفينولية والأحماض العضوية في حوالي 68.19٪ من إجمالي المكونات في الزيت الحيوي ، وسجل الأس الهيدروجيني الحموضة العالية (pH = 1.5). بالإضافة إلى ذلك ، تمت ملاحظة العديد من المجموعات الوظيفية على سطح الفحم الحيوي بواسطة FTIR ، والتي ربما تكون قد تفاعلت مع المكونات الكيميائية للزيت الحيوي للحث على إجراء التنشيط. تقدم هذه الدراسة معلومات حول استخدام منتجات الانحلال الحراري للنفايات اللجينية السليلوزية كمصادر طبيعية لمكافحة حشرة *S. oryzae* وحماية القمح المخزن من الإصابة لمدة تصل إلى 30 يومًا.