Generation of Wood-waste Vinegar and Its Effectiveness as a Plant Growth Regulator and Pest Insect Repellent

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Wood vinegar (WV) was obtained from charcoal production byproducts. The increase in demand for WV as an alternative pesticide requires more production of WV independent of conventional charcoal production. This research was intended to commence the production of WV from available furniture wood waste. The study included the following: (i) the preparation and performance of a pyrolysis kiln; and (ii) the application of the produced WV as a plant growth regulator of papaya plants in the nursery and as a pest insect repellent during maize storage. These experiments were arranged in a randomized block design. The observed variables included pyrolysis rate, the effect of WV on papaya growth in nursery, and the effect of WV in controlling infestation of maize weevils. The data were analyzed using analysis of variance and continued with Duncan's multiple difference test. The results showed that while the production of WV continuously occurred until the 90th min, the maximum (139 mL) was reached at the 10th min. Pyrolysis of 1,000 g of chips of wood-planer's waste yielded WV, tar, bio-oil, and char in quantities of 487.67 mL, 41.76 g, 2.93 mL, and 222 g respectively. The treatment using WV (50 mL/L) increased the diameter of papaya stems in the nursery. Mixing and fuming application of 5 mL of WV as a pest insect repellent on 200 g of maize on the storage could increase the number of the dead maize weevil and reduce the damage maize kernel.

Keywords: Wood vinegar; Wood waste; Pyrolysis; Plant growth regulator; Fumigant

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INTRODUCTION

The protection of plants from various pests using pesticide is often necessary. However, the negative effects of synthetic pesticides need to be considered. In particular, the employed pesticide should meet the requirements for sustainable agriculture and environmental safety. Pesticides derived from plants (plant-based pesticides) are the extraction products of plants with bioactive compounds. They have gained more attention and are considered to be able to fulfill the requirements (Bhat *et al.* 2012; Hagner 2013).

Subsequently, efforts to initialize botanical pesticides commonly meet the problem of practicality on the level of the farmer. For example, farmers need time and effort for the preparation, and a huge amount of extract is required. These conditions inhibit the willingness of farmers to change to botanical pesticides (Tiilikkala *et al.* 2010).

Another way to obtain botanical pesticides is by using the pyrolysis technique, *i.e.*, thermal decomposition of biomass to obtain wood vinegar (WV) or liquid smoke. The alternative raw material is locally available, and the farmer does not need to cultivate the plant. This technique could be integrated into the production of wood charcoal and/or tar as wood and rubber preservatives (Budijanto *et al.* 2008; Tiilikkala *et al*. 2011). An alternative botanical pesticide should be developed that is both based on raw material and locally available. The one-way process together with other processes or the byproducts of other processes should also be developed so that there will be no additional cost and time. Nurhayati and Adalina (2009) stated that the sawdust from the sawmill industry could be technically employed as a raw material in the production of charcoal and wood vinegar, and that the quality of the products meets the national and Japanese standards.

Budijanto *et al.* (2008) and Burnette (2010) stated that the pyrolysis producing the wood vinegar could also produce wood charcoal using an uncomplicated tool. These facts support the innovation of this technology and its adoption by society.

The creative idea in this study is the production of WV from the pyrolysis of teak (*Tectona grandis*) wood chips, a waste material of the furniture industry. The reason to utilize this material is that it is usually not used and is currently removed only by burning. This removal process could cause environmental problems, such as water and air pollution, as well as an increase in greenhouse gas emissions to the atmosphere. This idea is supported by the efforts to meet the present requirements, namely (i) the creation of food safety and security, (ii) the provision of an environmentally friendly pesticide, and (iii) the reduction of wood waste from the wood-based industries.

The aim of this study was to determine the potential of wood vinegar production from waste teak shavings and its effectiveness as a plant growth regulator (PGR) and pest insect repellent (PIR).

EXPERIMENTAL

Materials

Preparation of sample feedstock

Teak-wood chip waste was obtained from four different locations (10 kg from each) representing home industries that prepare furniture in the industrial center of the Mangkubumi subdistrict, Tasikmalaya. The waste was mixed homogeneously and then dried until it reached a humidity of 20% while the feedstock for the pyrolysis was processed in a kiln.

Fabrication of kiln

The kiln (Fig. 1) was made from an iron steel drum (diameter = 23 cm and height = 32 cm) as the pyrolysis chamber. In this apparatus there were (i) the sealed lid inlet feedstock that can tolerate high temperature, (ii) the outlet that pipelines the pyrolysis product to the condenser, and (iii) a metal cylinder as a heat insulator jacket around the kiln, which contains a chimney pipe on the upside. All of the parts were connected with metal welding and were checked to avoid gas leaks.

Methods

Generation of WV and monitoring of parameters

Wood chip waste (1000 g) with a water content of 20%, used as feedstock per unit of WV produced, was heated to 450 °C for 90 min and the experiment conducted three repetitions. The observed WV production parameters were the production rate of WV during the process and the final quantity of the products (WV, tar, bio-oil, and biochar). The crude distillate contained WV, bio-oil, and the remaining tar. The biochar was weighed after the end of the process and the kiln was cooled.

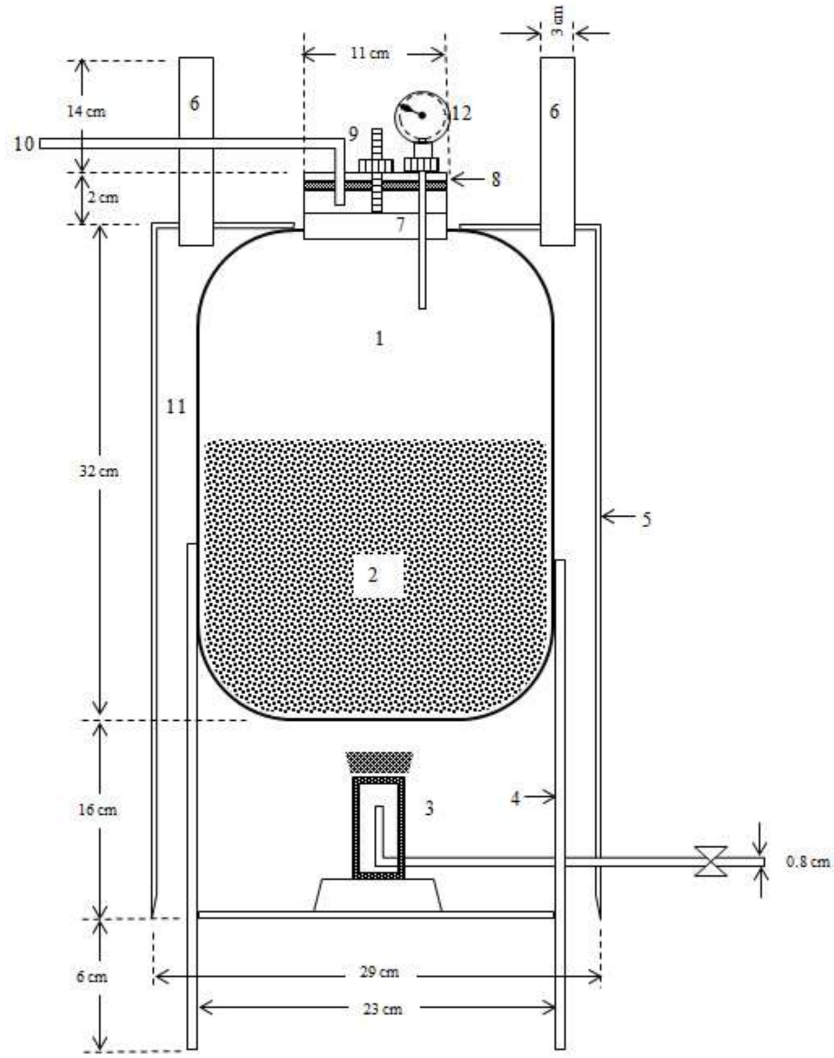

Fig. 1. Design of wood vinegar kiln. Description: (1) pyrolization chamber; (2) wood waste/feedstock; (3) LPG stove; (4) supporting tripod; (5) heat insulator; (6) chimney of flame; (7) feed hole; (8) sealed lid; (9) bolt and nut; (10) gas pipeline connected to condenser; (11) insulating space; (12) thermometer

Experimental setup for effective test of WV

The experiment to determine the effectiveness of WV as a PGR and PIR was arranged in randomized block design. The data were analyzed using analysis of variance (ANOVA) and continued with the Duncan's multiple different test (Gomez and Gomez 1983).

The PGR effectiveness experiment aimed to test the effectiveness of 5 concentration treatments of WV on the growth of papaya (*Carica papaya*) with five conducted repetitions. The concentration of WV was varied as A (0 mL), B (25 mL), C (50 mL), D (75 mL), and E (100 mL) in 1 L of water. Response variables were measured based on: (i) shoot length, the distance between the top leaf to the root boundary; (ii) leaf area, calculated from the total leaf area projected on paper and measured; and (iii) stem diameter, measured at a stem height of 1 cm from the root boundary. Measurements were taken from five 60 day-old plants and averaged.

The PIR effectiveness experiment aimed to test the effectiveness of 5 treatments on 10 pairs of maize weevils (*Sitophilus zeamais*) cultivated in a jar containing 200 g of maize with five conducted repetitions. The treatments included P (without WV as the control), Q (5 mL of WV was mixed with maize kernel), R (10 mL of WV was mixed with maize kernel), S (5 mL of WV placed in a glass cup as fumigant), and T(10 mL of WV placed in a glass cup as fumigant). The experiment was performed for 50 days in the dark at 25 °C. The measured response variables were the number of the dead maize weevils and the weight of residual maize kernels.

RESULTS AND DISCUSSION

Generation of WV

The measured rates included (i) volume of tar from the outlet of heavy fraction and (ii) the volume of crude distillate measured a 5-min period during the process (Fig. 2).

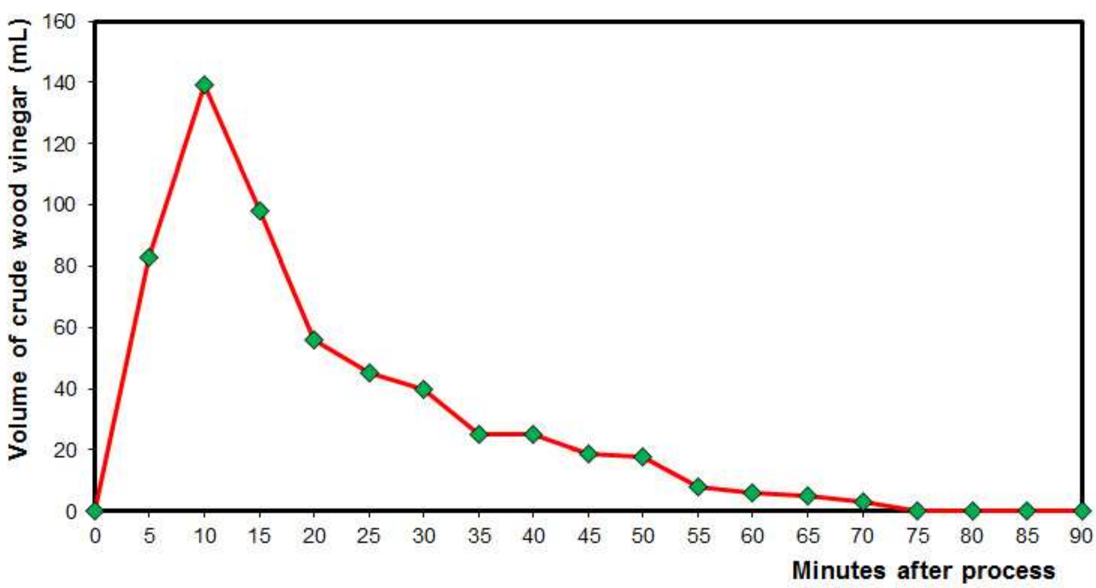

Fig. 2. Generation of crude wood vinegar with time

In the first phase, the condensate containing WV was produced and reached maximum production at the 10th min (139 mL). Then, the yield decreased and ended at the 90th min. The increase of distillate in the initial period was because a temperature of 100 °C had been reached and the water started to evaporate (Fig. 3). The temperature of the kiln was gradually increased and led to the degradation of organic compounds in the feedstock. As stated by Sjostrom in Budijanto *et al.* (2008), the pyrolysis of wood was initialized with the degradation of hemicellulose at 200 to 260 °C, then cellulose at 240 to 350 °C and lignin at 280 to 500 °C.

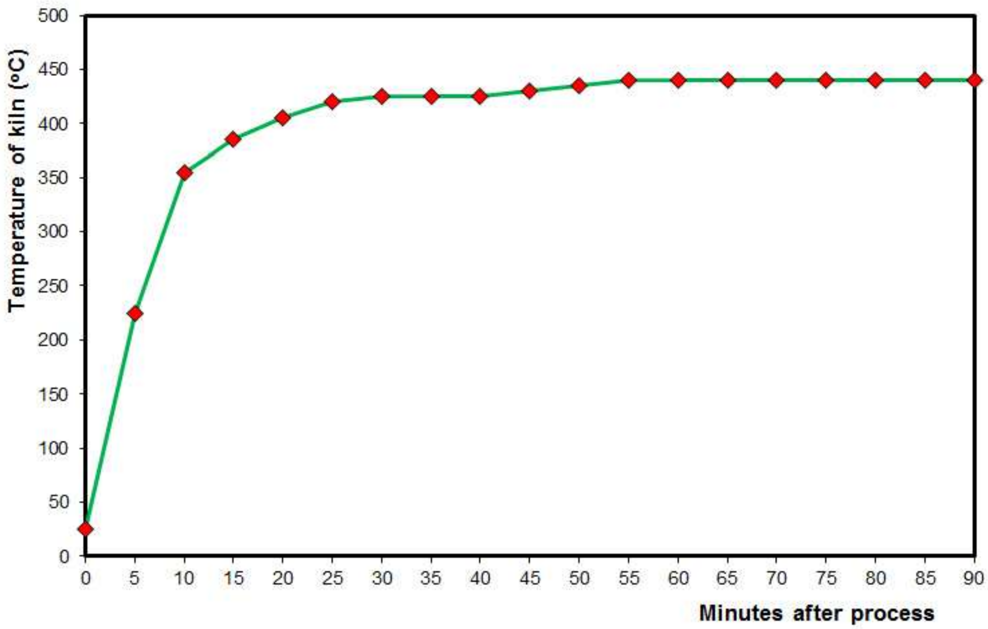

Fig. 3. Temperature of kiln during the process

Danarto *et al.* (2010) stated that pyrolysis can be defined as the thermal decomposition of organic material in its inert condition (without the presence of oxygen), which may induce the formation of volatile compounds. Generally, pyrolysis was started at 200 °C and remained at a temperature of 450 to 500 °C. Pyrolysis of biomass will produce three products: gas, liquid, and solid (char) (Danarto *et al.* 2010). Bridgwater (2005) stated that the quantity of the products depends on the process. Therefore, in order to obtain the optimal results, the temperature should be maintained at the carbonation range (not exceeding 500 °C) and the time should be lengthened. Furthermore, Bridgwater (2005) reported that the composition of the carbonization products were as follows: gas (35%), liquid (30%), and solid (35%). If the temperature exceeds 500 °C or even reaches 800 °C, gasification will occur and yield gas (85%), liquid (tar, 5%), and solid (10%).

Quantities and Properties of Components

Carbonization of 1,000 g of wood chip waste produced WV, bio-oil, tar, and charcoal with average quantities of 482.67 mL, 2.93 mL, 41.76 g, and 222 g, respectively (Table 1).

Table 1. Yield of Pyrolysis Products from 1,000 g of Teak-wood Waste

Batch	Yield of components			
	Biochar (g)	Wood vinegar (mL)	Tar (g)	Bio-oil (mL)
1	231	494	39.3	2.1
2	229	462	41.5	3.1
3	206	492	44.5	3.6
Average	222	482.67	41.76	2.93
%-w	22.2	49.28	3.34	0.37

The quantity of components was determined by type and by water content of biomass, temperature, and process time. Nurhayati and Adalina (2009) showed that pyrolysis of bark waste in a brick kiln equipped with a water condenser produced WV (40.6%) and charcoal (33.6%). Identification of the WV component of palm bunches showed that most of the phenol and acetic acid existed at all pyrolysis temperatures (350, 400, and 450 °C). The quantity of phenol and acid was increased with increasing temperature (Indrayani *et al.* 2011). The composition of WV from the teak wood was 2.70% phenol, 13.80% carbonyl, and 7.21% acid (Tranggono *et al*. 1996).

Fig. 4. (1) Chips of wood waste; (2) crude WV; (3) tar; and (4) char

The amount of obtained bio-oil increased in the range 300 to 350 °C and slightly decreased in the range 350 to 500 °C. On the other hand, charcoal yield was reduced with increasing temperature. These results showed that bio-oil yield was inversely correlated with that of charcoal. In the range of 300 to 350 °C, the effect of thermal cracking led the forward reaction rate higher. Pyrolysis is an endothermic reaction that occurs at temperatures higher than 350 °C. The decrease in bio-oil yield was caused by the occurrence of continuous secondary thermal cracking. In the secondary thermal cracking, several solids such as charcoal were continuously pyrolyzed into non-condensed gas, leading to a reduction of bio-oil and charcoal yields and an increase in gas yield (Chaiya, 2011) .

The decanted wood vinegar had the physical properties shown in Table 2.

Table 2. Physical Properties of Wood Vinegar from Teak-wood Waste

Parameter	Results
pH	3.6
Density (ρ)	1.021 g/mL
Color	Yellowish-brown

These physical properties of WV from teak-wood were almost the same as those found by Nurhayati and Adalina (2009) and Yashimoto (1994). Hence. the first research priority was to test the effectiveness of WV in the agrochemical application.

Effectiveness of Wood Vinegar

Wood vinegar as a plant growth regulator

Application of WV as PGR affected the stem diameter of papaya in the nursery (Table 3). It is believed that WV gave stimulus to the cambium cell division, thus increasing the diameter. The results were similar to those of Siarudin and Suhaendah (2007), which applied the WV in growing media (concentration of 2%) on the stems and leaves of albizia (*Paraserianthes falcataria*) in a nursery. It was applied three times every two weeks. The treatments gave positive results for the increase of albizia growth in the nursery.

Table 3. Effect of WV on Papaya Growth at 60 Days

Treatments	Growth parameters		
	Length of shoot (cm)	Leaf area (cm^2)	Diameter of stem (cm)
A	24.92 a	8.00 a	0.54 a
B	25.13 a	8.17 a	0.63 ab
C	23.35 a	8.20 a	0.80 b
D	20.89 a	8.20 a	0.48 a
E	21.98 a	7.83 a	0.49 a

Note: Numbers followed by the same letter indicate no significant differences according to the Duncan's multiple range test at a confidence level of 5%

Based on Table 3, the treatment of WV concentration only affected the diameter of the stem and did not have a significant effect on shoot length or leaf area. As stated by Yashimoto (1994) and Burnette (2010), the composition of WV included phenol, carbonyl, alcohol, and acid. The content of an alcohol of low concentration induced the growth of plants such as a synthetic PGR effect. Widhi *et al*. (2000) suggested that the aliphatic alcohol increases the rate of photosynthesis because it can increase the turbidity of stomatal cells, thus increasing CO_2 fixation. For example, a low concentration of triacontanol can increase vegetative growth and yield of several annual crops, including cucumbers, sweet corn, carrots, tomatoes, and radish.

The original vinegar, distilled vinegar, and ether-extracted vinegar were diluted with distilled water 10^2 to 10^7 times. These diluted vinegar solutions were used to investigate the effect of bamboo vinegar on the germination and radicle growth of seed plants. High concentrations of all types of treated bamboo vinegar (*e.g.*, 10^2 of original vinegar and 10^3 of ether-extracted vinegar) showed strong inhibition of the germination of the seed. However, an appropriate dilution of bamboo vinegar showed a promotional effect on germination and radicle growth of lettuce, watercress, honewort, and chrysanthemum tested seeds (Mu *et al.* 2003).

Wood vinegar as a pest insect repellent

Treatment R of 10 mL WV mixed with 200 g maize kernel resulted in the highest mortality compared to other treatments at 10 and 20 days after incubation (Table 4). These data indicated that, at the dose, WV was effective as an insect repellent, so the weevil did not find suitable food and eventually starved. However, its function as food storage fumigant was relatively low, as indicated by treatments S and T, although significantly different from the control.

Table 4. Effect of WV on Controlling Maize Weevils (*Sitophilus zeamais)*

Treatments	Number of dead weevils		
	10 Dai.	**20 Dai.**	**30 Dai.**
P	0.2±0.44 [a]	0.8±0.40 [a]	12.4±2.07 [a]
Q	3.8±0.83 [c]	12.8±0.98 [c]	19.2±0.83 [b]
R	7.2±0.83 [d]	18.2±0.75 [d]	18.8±1.09 [b]
S	1.8±0.83 [b]	9.0±1.41 [b]	18.4±1.51 [b]
T	1.8±0.44 [b]	9.2±1.32 [b]	18.4±1.67 [b]

Note: Numbers followed by the same letter indicate no significant differences according to the Duncan's multiple range test at a confidence level of 5%.
Dai. = day after incubation

Based on observation 30 days after incubation, the cumulative mortality rates among all treatments were equally close, except for the control, because time almost reached the end of the adult stage of the insect's life cycle, so the mortality was close to 100%.

Table 5. Effect of WV on Preventing from Maize Weevils (*Sitophilus zeamais)* Infestation

Treatments	Weight of residual maize kernel (g)	
	40 Dai.	**50 Dai.**
P	154.76±1.76 [a]	153.94±1.88 [a]
Q	179.84±4.31 [b]	178.68±4.65 [b]
R	191.46±2.15 [c]	189.48±3.02 [c]
S	180.70±1.14 [b]	179.18±1.34 [b]
T	182.88±1.46 [b]	181.22±1.79 [b]

Note: Numbers followed by the same letter indicate no significant differences according to the Duncan's multiple range test at a confidence level of 5%.
Dai. = day after incubation

The highest weight of residual maize grain was achieved in the treatment R (Table 5). This is because treatment R at least was consumed by *S. zeamais*. This means that the treatment gave best protection on maize storage. As previously stated, WV is an effective pest insect repellent for maize storage.

Respectively, treatment Q, S, and T were found to provide a protective effect significantly different compared to the control, although lower than the treatment R.

The application of WV as PIR could decrease the amount of damaged maize grain, because it would repress the appetite of the *S. zeamais* pest. This indicates that WV has a mode of action as an antifeedant or a repellent to the insect; hence it would not pursue the treated maize. Surtikanti studied (2004) to determine the repellent effect of some type of plant leave on maize weevil. Maize kernels as cultivation media were mixed with lemon grass leaves, red onion leaves, clove leaves, dringo (*Acorus calamus*) leaves, and control, respectively. The listed treatments gave the intensity of pest infestation of 4.15%, 16.12%, 6.65%, 3.37% and 17.21%; and gave number of dead weevil of 27.11, 8.14, 19.27, 31.12, and 6.22. According to Chalermsan and Peerapan (2009), WV had potencies for post-harvest applications in reducing egg-laying and the number of damaged seeds by the cowpea beetle (*Collosobruchus maculates*).

Indrayani *et al.* (2011) suggested that WV displayed an ability to kill subterranean termites at concentrations of 1, 2, 3, and 4%. The pyrolysis temperature and the concentration of WV affected the mortality of the termites and the loss of paper eaten. The higher the pyrolysis temperature and the higher the concentration of WV, the higher the mortality and the lower the loss of paper weight. The results were in line with those of Prawira *et al.* (2013) on the evaluation of the application of WV from *Vitex pubescens* wood as the pesticide inhibiting the attack of a subterranean termite (*Coptotermes curvignathus*) on rubber wood. The optimal concentration was also determined. The research parameters were the WV's retention on rubber wood, the mortality of the termite, and the loss of rubber wood weight. The results showed that the highest retention (0.0245 g/cm^3) was obtained when a WV concentration of 15% and a pyrolysis temperature of 400 °C were employed. A mortality rate of 100% was achieved at a WV concentration of 10% and a pyrolysis temperature of 400 °C.

Hagner's (2013) studies provide strong evidence for the potential of birch-derived pyrolysis liquids as an effective, non-costly, and environmentally friendly method against mollusks. More studies are needed to investigate the effective compounds behind the observed repellent effect. As WV is only slightly toxic or non-toxic to most non-target aquatic and soil organisms, the environmental risk of synthetic pesticides could be diminished by including WV as part of pest control protocol.

CONCLUSIONS

1. Pyrolysis for 90 min on 1,000 g of wood-planers furniture waste yielded wood vinegar (WV), tar, bio-oil, and char in quantities of 487.67 mL, 41.76 g, 2.93 mL, and 222 g, respectively. The produced WV had the following physical properties: a pH of 3.6, a specific gravity of 1.021 g/mL, yellowish-brown color, and met the requirements for the national standards.
2. The WV was produced and reached its peak capacity (139 mL) at the 10th min. The production continuously decreased and then stopped at the 90th min. The increase of distillate occurred at the initial time because the evaporation of water had commenced. Then, the increase in the kiln's temperature degraded the organic compound on the feedstock.
3. Treatment with a WV concentration of 50 mL/L increased the stem diameter of papaya in the nursery.
4. Mixing and fuming application of 5 mL of WV as a pest insect repellent on 200 g of maize on the storage could increase the number of the dead maize weevil (*Sitophilus zeamais*) and reduce the damage maize kernel.

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