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Original Article

Production of wood vinegars from coconut shells and additional materials for control of termite workers, *Odontotermes* sp. and striped mealy bugs, *Ferrisia virgata*

Sunan Wititsiri*

Chemistry Program, Faculty of Science and Technology,
Nakhon Sawan Rajabhat University. Nakhon Sawan, 60000 Thailand

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Abstract

Coconut shells and coir are considered as wastes of coconut based products that have not been utilized efficiently. By using these abundant bioresources, which are widely available in Thailand, as raw materials, we were able to produce wood vinegars that may be alternatives to termiticides and pesticides. The wood vinegars were obtained from carbonization process using a 200-liter fuel tank as charcoal brazier under temperatures of 300-400°C. In this study, termiticidal and pesticidal activities of wood vinegars were evaluated against termite workers, *Odontotermes* sp., and striped mealy bugs, *Ferrisia virgata*, using direct contact application. Percent mortalities in the experiments were recorded after 24 hours and corrected for control mortality with Abbott's formula. Wood vinegars of 850, 696, and 898 milliliters were produced from coconut shell (wood vinegar A) and the mixture of coconut shell and coir (wood vinegar B) and the mixture of coconut shell, coir and holy basil (wood vinegar C), respectively. Wood vinegar A exhibited high termiticidal activity against termite workers at a dilution of 1:50, wood vinegar: sterile water (v/v). By this way, 85% (81.71% corrected mortality) of termite workers were killed after the 24 hours of test. At a dilution of 1:10, both wood vinegar A and B had exhibited high pesticidal activities against mealy bugs, 96% (95.12% corrected mortality) of striped mealy bugs were killed by those wood vinegars. In the weakest termiticidal and pesticidal activities, wood vinegar C was able to kill 60% (51.22% corrected mortality) of termite workers at a dilution of 1:50 within 24 hours. Also it killed 93% (91.89% corrected mortality) of striped mealy bugs with a dilution of 1:10 (v/v) within the same amount of time. Post-hoc comparisons (Tukey test) revealed that wood vinegar A possessed the most effective termiticidal activity against termite workers. However, a similarity in high pesticidal activity was found among three wood vinegars against striped mealy bugs. The termiticidal and pesticidal properties of these wood vinegars can be attributed to the mode of action of their active components.

Keywords: wood vinegar, coconut shell and coir, termiticide, pesticide, bioresource

1. Introduction

Termites cause damages of plant materials and wood structures, for example buildings, bridges, household furniture, and paper products. Evidences of termite damages are easily recognized as infested wood materials or a sight of termites themselves. In the United States alone, every year, termites cause an economic loss of approximately 3 billion dollars and more than 1 billion dollars is expensed for the management of the problems (United Nations Environment Program, 2000). An increase of world population is an exertion of rising demand for more constructions. The problem of termites will likely to continue, as we are expanding establishment into lands and forests of termite habitats.

* Corresponding author.
Email address: sunan_w@yahoo.com, sunan.sw@gmail.com

In many parts of the world, termite control is strictly regulated, especially the use of chemicals and insecticides in termite management. However, termite control and prevention with chemical insecticides is a common practice in many countries, especially in developing ones. In Thailand, hundreds of tons of chemical insecticides such as organophosphates, organochlorines, carbamates and pyrethroids are imported every year (Poblap and Silkavute, 2001). This is for termite control required by people in the construction businesses. These wood preservatives and anti-termite chemicals have a great benefit; however, because of toxicity and risk of human health, the uses of these chemicals have also been restricted.

The striped mealy bug, *Ferrisia virgata* (Cockerell), can be found throughout the tropical and subtropical parts of the world. The pest is covered with powdery white wax and has two stripes on it back. It causes serious problems in a wide variety of crops including sweet potato, cassava, and coffee, and can also transmit plant viruses (Schreiner, 2000). However, very little is known about the control and management of striped mealy bugs.

Recently, there have been reports on wood vinegars, which are dark brown condensed liquids from smoke obtained from dry distillation of wood under high temperature conditions (Yoshimoto, 1994). Wood vinegars have been used as soil improvement materials, pesticides and also termiticides (Yatagai and Unrinin, 1989; Kim *et al*., 2000; Kim *et al*., 2001; Lee and Huh, 2002; Mu *et al*., 2003; Rico *et al*., 2007). They have been obtained from many different sources of raw materials, such as wood and bamboo. These wood vinegars have been reported to have more than 200 chemical components of organic compounds, alcohols, and aldehydes (Kim *et al*., 2008). Uses of wood vinegar produced from wood and bamboo against bacteria, fungi, and termites have been investigated. Several studies reported wood vinegars contain organic chemicals of bactericidal, fungicidal, and termiticidal activity (Seo *et al*., 2000; Radhakrishnan *et al*., 2002; Yatagai *et al*., 2002). Wood vinegar made from bamboo contains chemical compounds that also exhibit termiticidal activities (Yatagai *et al*., 2002).

Waste materials, such as coconut shell and coir, are produced daily in a large amount from coconut factories. In many parts of Thailand abundant coconut trees are planted and utilized. Coconut shell and coir are among wastes in landfills. In this study wood vinegar from coconut shell and coir are obtained by the carbonization process similar to that of other wood vinegars. Coconut shell is composed of cellulose, lignin, and hemicellulose as wood (Child, 1943). Therefore, coconut shells were used to produce wood vinegars. The wood vinegars produced from coconut shell and coir can be considered as environmentally friendly products because they are made from bio-renewable resources. Herein, coconut shell and coir were used as raw materials to produce wood vinegars and then its termiticidal activity were investigated against termite worker, *Odontotermes* sp., and pesticidal activity against striped mealy bugs, *Ferrisia virgata*. Moreover, the termiticidal and pesticidal activities of wood vinegar produced from coconut shell and coir were studied. As well, holy basil substances have been reported to have activities against pests and parasites (Maunwongyathi, 1994). For this reason, holy basil is combined as a part of the recipe while producing wood vinegars. Lastly, mortalities of termite workers and striped mealy bugs were investigated in order to study the effectiveness of these wood vinegars.

2. Materials and Methods

Thirty kilograms of coconut shell, 15 kg of each coconut shell and coir (1:1 w/w), and 10 kg of each coconut shell, coconut coir and holy basil (1:1:1 w/w) were ingredients to produce wood vinegar A, B, and C, respectively (Table 1). All three wood vinegars were obtained from the carbonization process using a 200-liter fuel tank as charcoal brazier with the wood vinegar collected under temperatures of 300-400°C. The system was set in air-closed condition and wood vinegars were collected from the vapors and left for ninety days for precipitation. A siphon was used to release crude wood vinegars from the metal barrel. Determination of pH of crude wood vinegar was performed by pH meter (MP 120FK, Mettler Toledo). Specific gravity was measured using standard hydrometer. Boiling points were measured from wood vinegars by simple distillation.

The termite workers, *Odontotermes* sp., which were widely found in Thailand (Ahmad, 1965) were employed

Table 1. Details of wood vinegars used in investigations of their termiticidal and pesticidal activity*.

Wood vinegar	Sources and amount	No. of pest exposed	Dilution (wood vinegar per pure water, v/v) used against	
			Termite workers	Striped mealy bugs
A	Coconut shell (30 kg)	100	1:50	1:10
B	Coconut shell and coir (15:15 kg)	100	1:50	1:10
C	Coconut shell, coconut coir and holy basil (10:10:10 kg)	100	1:50	1:10
Sterile water	Sterile water	100	-	-

*Each experiment was performed in 5 replicates.

throughout this study. Tested termite workers with a body length of approximately 0.6 cm were used. Termiticidal activity was investigated according to that of Lewis *et al*. (1978) with slight modification. For each single experiment, the termiticidal activities of each of the three crude wood vinegars against termite workers were examined by placing 20 randomly selected termite workers in a 10-cm diameter petri dish containing soil on a filter paper. The termite workers were treated with 0.5 ml of sterile water (a control group) and 1:50, wood vinegar: sterile water (v/v), diluted wood vinegar and then incubated at 25°C. Termite worker activity was recorded by counting the moribund termite workers treated with wood vinegars and sterile water. After 24 hours, percent mortalities of termite workers in all experiments were recorded. These concentrations were performed with five replicates. The concentration is limited as Lunjak (2006) showed that at a dilution of 1:50, wood vinegar: sterile water (v/v), can control termite and 1:200, wood vinegar: sterile water (v/v), can be used to repel insects. In this study, a minimum concentration of wood vinegars is applicable with mortalities of pests at least from 50% or more after a treatment with wood vinegars.

For pesticidal activities of wood vinegar A, B, and C against striped mealy bugs, *Ferrisia virgata*, the investigations were carried out similar to the above experiment. In brief, 20 striped mealy bugs were placed on leaves of gardenia jasmine (*Gardenia augusta*), on which they normally live, in a petri dish. The mealy bugs were treated with 1 ml of sterile water, 1:200, 1:100, 1:50, 1:20, and 1:10 diluted wood vinegar A, B, and C. This assay was repeated with five replicates for each concentration and pesticidal activity was defined by the count of survivor after 24 hours of exposure. The data of all mortalities was converted to percentage.

Percent mortalities of the insects were calculated percent corrected mortality in all experiments using Abbott's formula (Abbott, 1925). Therefore, in cases that the control mortality ranged from 5 to 20%, the mortalities of treated groups would be corrected according to following equation:

$$\frac{\text{\% mortalities in treated group - \% mortalities in untreated control group x 100}}{\text{100 - \% mortalities in untreated control group}} \quad (1)$$

Statistical analysis of mean mortalities of the insects was then calculated by using a one-way analysis of variance, one-way ANOVA with Tukey's comparison procedure as post hoc test. The data were considered significant at $P= 0.005$ and $P=0.001$.

3. Termite resistance of plywood coated with tar extracted from the wood vinegars

The resistance of plywood treated with tar extracted from the wood vinegars was studied in a field test. In brief, the plywood specimens (5×10×2.5 cm) dried at 70°C for 10 hours were coated with tar produced from different wood vinegars (wood vinegar A, B, and C) and left at room temperature for two weeks. Later, tar coated plywood was placed on the termite worker *Odontotermes* sp. mound in an outdoor condition for a month. Controls were uncoated-tar plywood specimens.

4. Results and Discussion

4.1 Production of wood vinegars

The wood vinegar from coconut shells (wood vinegar A), from coconut shells and coir (wood vinegar B), and produced from a combination of coconut shells, coconut coir and holy basil (wood vinegar C) were collected at the exit of a vapor funnel during the process of carbonization. The wood vinegar A, B, and C separated from the middle layer had smoke odor and transparent brown color and had distillation temperature at 70°C. The pH values of wood vinegar A, B, and C were 2.9, 2.5, and 3.4, and specific gravities were 1.02, 1.03, and 1.01, respectively. From sources of the raw materials of wood vinegar A, B, and C, 850, 696 and 898 ml of wood vinegars were produced. Leaks of vapor from funnel maybe a cause of less amount of wood vinegar B.

In this study, wood vinegars A, B and C were obtained in an amount of 2,444 ml. Usually, the wood vinegar amount obtained should be 4,846 ml (Appropriate Technology Association, 2006). The reason for this is that, the substance compositions in coconut shells and coir were different from general wood. The wood vinegars A and B obtained from this experiment were more acidic than that of wood vinegar C. It might be ocimol, eugenol, methyl chavicol and linalool in holy basil that enhanced the base properties in the wood vinegar C (Bunyapraphat, 1996). Studies investigated wood vinegars produced by several woods such as *Eucalyptus* (Amen-Chen *et al*., 1997; Pimenta *et al*., 2000), oak (Guillen and Manzanos, 2002), bamboo (Mu *et al*., 2004) and mangrove (Loo *et al*., 2007; Loo *et al*., 2008); however, such studies did not produce wood vinegars from coconut shell and coir. Although, recently the wood vinegar produced from coconut shell were studied for antifungal activity (Baimark and Niamsa, 2009), it has not been studied for termiticidal or pesticidal activities as in this study.

4.2 Termiticidal activities of wood vinegars

In comparison to the control group, which had a percent mortality during the experiment of 18%, wood vinegar A, B, and C were able to kill termite workers at 85, 61 and 60% (81.7, 52.4, and 51.2% corrected mortality) after the 24 hours, respectively. Post-hoc comparisons (Tukey test) showed that the differences between mean mortalities of control groups and termite workers were significant ($P< 0.001$). In this case, termite workers were treated with wood vinegar A, B, and C at 1:50 (v/v) (Table 1). It also revealed significant differences between the mean mortalities of termite workers treated with wood vinegar A and B, and between termite workers treated with wood vinegar A and C (*P<0.005*) (Table 2 and 3). However, statically significant differences in the mean mortalities were not found between termite workers treated with wood vinegar B and C indicating similar termiticidal property in both wood vinegars. It was demonstrated that after direct contract application of wood vinegar A, B, and C using a dilution of 1:50 (v/v) to test termite workers the orders of effectiveness of termiticidal activities are: wood vinegar A > B and A > C. Although the order of percent corrected mortalities of termites treated with the wood vinegar was A > B > C, the activities were not different significant between B and C.

The activity of wood vinegar A exhibited the strongest termiticidal activity than that of wood vinegar B and C. Statistically significant differences in mean mortalities were observed between termite workers treated with wood vinegars A and B, and A and C. The termiticidal property of wood vinegars A, B and C may due to their components. Reports indicated that formaldehyde and phenol in wood vinegar should be the major causes of mortality of pests (Lunchak, 2006). Those of pests show spasmodic body after they were treated with wood vinegar. The wood vinegar contains formaldehyde, which includes a carbonyl (C=O) group, similar to that of carbamate. The carbamate can affect the nervous system of insects and cause inactiveness of the nervous system (Pimsamarn, 1994). Also, acetic acid, which accounts for more than 50% in the wood vinegar, should make a contribution to termiticidal activity (Yatagai *et al*., 2002). It might be possible that termite workers were more susceptible to components of wood vinegar A, indicating wood vinegar from coconut shell possess compounds of termiticidal activity more than that of the other wood vinegars B or C.

This study shows that coconut shells may be a worthy source of wood vinegar that could be utilized as a termiticide capable of excluding termites from wood constructions and other wood products. The broad use of organophosphates and organochlorides for management of termites has been appointed as human health concern as reports indicating chemical insecticides related illnesses (Poblap and Silkavute, 2001). Wood vinegar from coconut shell and coir may offer an alternative to the current reliance upon insecticidal application. The present study represents the first description of the utilization of plant wastes as raw materials for the manu-

Table 2. Termiticidal and pesticidal activities of three different wood vinegars against termite workers and striped mealy bugs after 24 hours of direct contact application*.

Wood vinegars	Mortality rate of termite workers			Mortality rate of striped mealy bugs		
	Means	Percentage	%Corrected mortality	Means	Percentage	%Corrected mortality
A	17	85	81.71	19.2	96	95.12
B	12.2	61	52.44	19.2	96	95.12
C	12	60	51.22	18.6	93	91.89
Sterile water	3.6	18	-	0	0	-

* Five replicates of 20 termite workers and striped mealy bugs were tested for each wood vinegar.

Table 3. Post-hoc comparisons (Tukey test) of mean mortalities of termite workers and striped mealy bugs between the experiments and control groups.

Tested pests	Between groups treated with		Standard error	Mean differences of mortality
Termite workers	Sterile water	Wood vinegar A	0.975	13.4*
	Sterile water	Wood vinegar B	0.975	8.6*
	Sterile water	Wood vinegar C	0.975	8.4*
	Wood vinegar B	Wood vinegar A	0.975	4.8**
	Wood vinegar C	Wood vinegar A	0.975	5.0**
Striped mealy bugs	Sterile water	Wood vinegar A	0.265	19.2*
	Sterile water	Wood vinegar B	0.265	19.2*
	Sterile water	Wood vinegar C	0.265	18.6*

* *P<0.001, *** *P<0.005*, 5 replicates (n = 20 per experiment). Data calculated from one-way ANOVA with Tukey's comparison procedure as post-hoc test. P value of less than 0.005 was considered as the level of significance for all tests.

facture of types of wood vinegars, which may be very useful as revolutionary termiticides. In the future, investigations on the identification of the active components of these wood vinegars should be carried out similar to Yatagai *et al*. (2002) who determined chemical components of some wood vinegars for their termiticidal activities.

4.3 Pesticidal activities of wood vinegars

The pesticidal activities of wood vinegar A, B, and C against striped mealy bugs, were investigated at a dilution of 1:10 (v/v). Percent mortality of mealy bugs in the control group was zero. The mealy bugs that were wood vinegar A, B and C was applied showed percent mortalities of 96, 96, and 93% (95.1, 95.1, and 91.8% corrected mortality), respectively. Post-hoc comparisons showed that the mean mortalities of striped mealy bugs in the tested groups were significantly different ($P<0.001$) from that of the control group (Table 2 and 3). Wood vinegar A, B, and C have a similarity of pesticidal activity against striped mealy bugs, despite the percent corrected mortalities of striped mealy bugs treated with the wood vinegars in the tested groups have some differences.

The successful application of all three wood vinegars in the experiment resulted in the high pesticidal activity against striped mealy bugs. More than 90% of mealy bugs were killed after the 24 hours of the test. Figure 1 shows that the percent corrected mortality of striped mealy bugs treated with three wood vinegars at the same dilution of 1:10 (v/v) comparing to that of the termite workers, 1:50 (v/v).

The diluted wood vinegars with less than 1:10 (v/v) show a low pesticidal activity for striped mealy bugs. When the wood vinegars A, B, and C, concentration less than 1:10 (v/v), were used for treating mealy bugs, the mealy bugs survived, because of the fact that they are protected by a wax back cover (Schreiner, 2000). However, with the treatment of a higher concentration of wood vinegar, mortalities of striped mealy bugs were observed. Formaldehyde, phenol and acetic acid could be active components contributed to this pesticidal activity (Yatagai *et al*., 2002).

In agricultural fields, for example in a coffee plantation, mealy bugs cause a significant damage to the coffee beans (Kucel and Ngabirano, 1997). This study presents the use of wood vinegars of coconut shell and coir that may be used as an alternative to pesticides in order to use against mealy bugs.

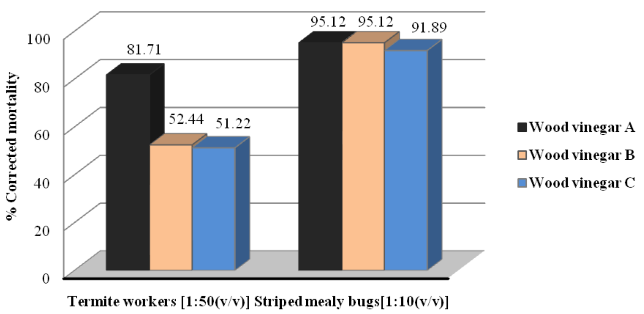

Figure 1. Corrected percent mortality of termite workers and striped mealy bugs treated with three different wood vinegars.

4.4 Resistance of plywood coated with tar extracted from the wood vinegars

After a month of exposure of tar-coated plywood specimens to the termites, *Odontotermes* sp., none of the plywood specimens coated with tar from wood vinegars A, B, and C was damaged. On the other hand, the control plywood specimens, uncoated-tar plywood specimens, were damaged by the termites.

The tar coated plywood specimens proved to be effective against termites. However, if using this tar extracted from the wood vinegars, smoke-like odor and dark brown color of those wood vinegars should be considered. Further experiments are required to be carried out in order to investigate the period of resistance. Tar extracted from wood vinegars could be biological alternatives for termite control (Verma *et al*., 2009).

5. Conclusions

The present work showed the production of three wood vinegars and the effects of these wood vinegars on termite workers and striped mealy bugs. All three wood vinegars investigated in this study exhibited termiticidal and pesticidal activities 50% exceeding mortality at the minimum dilution of 1:50 and 1:10 (v/v), respectively. Among the three wood vinegars investigated, wood vinegar A exhibited the strongest termiticidal activity; still, all three wood vinegars A, B and C exhibited similar pesticidal activity against striped mealy bugs. Finally, the field study showed that plywood coated with tar extracted from wood vinegars could prevent termite attacks. Wood used in housing or wood constructions treated with wood vinegar and tar extracted from wood vinegars produced from coconut shells and coir may prevent penetration of termite workers.

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