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RESEARCH

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Termiticidal activity of oil from *Jatropha curcas* L. and *Azadirachta indica* A. Juss against *Coptotermes sjostedti* Holmgren (Isoptera: Rhinotermitidae)

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Abstract

Background: *Coptotermes sjostedti* Holmgren (Isoptera:Rhinotermitidae) is one of the major termite species found infesting woods and other plant materials in Africa. Bioassays were carried out at the Arboretum of the Department of Forestry and Wildlife Resources Management, University of Calabar, Nigeria to investigate the effect of oils from the kernel of *Jatropha curcas* L. and *Azadirachta indica* oils A. Juss against the African subterranean termite (*Coptotermes sjostedti* Holmgren). Treatments comprised of the plant oils and Solignum (a synthetic termiticide, serving as positive control) applied at the rate of 5, 10 and 15 mL per 100 cm^3 of the wood from seven plant species. Untreated woods also served as control. Seven wood species were placed in a test arena and artificially infested with 50 termites per unit. The setup was a randomized complete block design with four replicates. Data on termite mortality and wood weight loss were recorded.

Results: The use of 10 and 15 mL of *J. curcas* oil caused more than 90% mortality of *C. sjostedti*, after 96 h, kept wood consumption by the insect below 6.0% after 3 months, and these outcomes were similar to that of Solignum at the same concentrations. About 35.0–65.2% reduction in weight was observed among untreated woods from the tested woods, indicating their susceptibility to *C. sjostedti* attacks. Correlation analysis shows a significant ($r > -0.900$; $P < 0.0001$) negative association between termite mortality and the rate of wood consumption.

Conclusion: The use of *J. curcas* oil at 10 mL per 100 cm^3 of wood could be a potent alternative to Solignum for the control of *C. sjostedti*.

Keywords: Termiticide, *Jatropha curcas*, *Azadirachta indica* solignum, Wood consumption, Termite mortality

Background

Termites are eusocial insects that belong to the order Isoptera in the animal kingdom. They demonstrate group integration, division of labour among caste [viz: the fertile (reproductives) and the sterile (workers, pre-soldiers and soldiers], and their population could grow drastically with several overlapping of generations (Myles 1998; Osipitan et al. 2010; Watanabe et al. 2014). The insect exhibits hemimetabolism which is characterized by a gradual development of individuals from the egg, through several moults of the nymphs and into one of the adult castes (Kuriachan and Gold 1998; Osipitan et al. 2010). Termites are ubiquitous, and they have gained the reputation of being among the most successful groups of insects found in tropical, subtropical, and warm temperate regions of the world. They play significant roles in the world's ecosystem by accelerating plant product decomposition, reclamation of damaged soil, contributing to atmospheric gases (such as carbon dioxide and methane),

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redistribution of minerals, fatty acids, vitamins, amino acids, etc. (Odelson and Breznak 1983; Guo et al. 1991; Abe et al. 2000).

The African subterranean termite, *Coptotermes sjostedti* Holmgren 1911 (Isoptera: Rhinotermitidae) is one of the major damaging species found in Nigeria, Cameroon, Democratic Republic of Congo, Gambia, Ghana, Guinea, Ivory Coast, Mozambique, Senegal, Angola, Sierra Leone, Somalia, Sudan, São Tomé and Príncipe, Tanzania and Uganda (Harris 1966; Ndiaye et al. 2019). They have been reported to thrive in other tropical biogeographical regions of the world as well (Chouvenc et al. 2016). The arthropod feeds mainly on living or dead trees tissues, but oftentimes, they also damage parts of arable crops by their networks of shelter and forage tubes. Like many termite species, their presence is usually indicated by earth-covered runways or tubes found on the external surfaces of trees and other targets (CABI Datasheet 2019). Generally, the genus Coptotermes is considered as the most aggressive subterranean termite, and the global damage they cause was estimated at US $ 22 billion to US $ 40 billion worldwide (Su 2002; Rust and Su 2012; Kuswanto et al. 2015).

Woods are a widely available and relatively inexpensive natural resource in most tropical and sub-tropical regions of the world. When harvested from plants and processed, woods are subjected to a variety of uses due to their low electrical/thermal conductivity, workability, beauty, density, strength, etc. (Ross 2010). Besides, wood from many plant species has been used for centuries as fuel and as a construction material for houses, furniture, bridges, etc. (Briffa 2008). Unfortunately, woods are susceptible to attack by insects, bacteria, fungi, marine worms, and if left unprotected in some landscapes, they could deteriorate over time (Samuel 2004). Attacks by termites remain the most serious threat to wood structures, forest trees and crops (such as yam and cassava, sugar cane, groundnuts, sorghum, maize, etc.) in tropical and subtropical countries (Johnson and Wood, 1980; Logan et al. 1990; Osipitan and Oseyemi 2012).

For decades, man has relied on soil and wood treatment with termiticides such as like chlorpyrifos, bifenthrin, chlorfenapyr, permethrin, cypermethrin, imidacloprid, and fipronil as conventional tools for the control of termites (Su and Scheffrahn 1990; Femi-ola et al. 2008). But these chemical pesticides are usually expensive, hazardous for the environment and human exposure could create adverse health problems. There are also shreds of evidence indicating that many insect pests develop resistance to synthetic chemicals as a result of their repeated/injudicious use (Padi et al. 1999). Currently, research efforts have been directed at the search for a safe and eco-friendly alternative to synthetic chemicals used for the control of termites. Extracts, latex and quinones of many plant species have been tested against termites (Ganapaty et al. 2004; Upadhyay 2013). Ahmed and Girma (2013) investigated the efficacy of extracts from *Azadirachta indica* A. Juss, *Croton macrostachyus* Hochst. ex Delile, *Tagetes minuta* Linn. and *Datura stramonium* Linn. against *Odontotermes obesus* Rambur. *Ipomea carnea* Jacq., *Cleome viscose* Linn. and *Pavonia glechomifolia* A. Rich. were also tested against *Microcerotermes beesoni* Snyder (Singha et al. 2012). Their results suggested that plant-based products could play a significant role in the control of termites. But it is yet to be known if some important wood species like *Antiaria toxicera* Lesch., *Gmelina arborea* Roxb., *Parkia biglobosa* Jacq., *Pycnanhus angolensis* (Welw.) Warb, *Terminalia superba* Engl. & Diels, *Ceiba pentandra* (L.) Gaertn. and *Baphia nitida* Lodd will receive adequate protection from *C. sjostedti* attacks using biologically active oil extracts from *Azadirachta indica* A. Juss and *Jatropha curcas* L.

The growing global demand for botanical termiticides has made it imperative for research to be directed at the development of potent alternatives to Solignum, a well-known synthetic termiticide used for the control of many termite species. Generally, termiticides from plant sources are known to be safe for both man and the environment, exhibits broad insecticidal activity, demonstrates relatively specific mode of action, and their preparation/application methods are easier compared with synthetic chemicals (Addisu et al. 2014).

We therefore setup this experiment to test the toxicity of different concentrations of oil extracts from the kernels of *A. indica* and *J. curcas* against *C. sjostedti* using some wood species that are commonly found in Africa.

Methods

Study area

The experiment was carried out at the Arboretum of the Department of Forestry and Wildlife Resources Management, University of Calabar, Cross River State, Nigeria. The State lies within the rainforest zone of Nigeria (coordinates: Latitude 4°34′59.99″ N and Longitude 8°24′59.99″ E). The weather is characterized by a pattern of alternating wet and dry seasons. The period of rains is from April to September while the dry spell is from October to March.

Preparation of plant oil extracts

Oil from the kernels of *A. indica* and *J. curcas* were used for the experiment (Table 1). Matured ripe seeds were collected from the plant species found within University of Calabar, Cross River State, Nigeria. They were de-husked, de-shelled, and the kernels were sun-dried for one week. Oil was extracted from the kernels using a

Table 1 Plants evaluated for termiticidal activities against *Coptotermes sjostedti* (Isoptera: Rhinotermitidae)

Common name	Scientific name	Family	Sub-family	Product used
Neem	*Azadirachta indica* A. Juss	Meliaceae	Melioideae	Kernel oil
Jatropha	*Jatropha curcas* Linn	Euphorbiaceae	Acalyphoideae	Kernel oil

Soxhlet apparatus at the Department of Chemistry, University of Calabar, Nigeria. Petroleum ether 60/80 was the solvent used for the extraction. The oil extract was kept in a sterilized round-bottom flask and stored in a refrigerator (4 °C) until it was used for the experiment.

Preparation of wood samples

Antiaria toxicera Lesch., *Gmelina arborea* Roxb., *Parkia biglobosa* Jacq., *Pycnanhus angolensis* (Welw.) Warb, *Terminalia superba* Engl. & Diels, *Ceiba pentandra* (L.) Gaertn. and *Baphia nitida* Lodd at the Marian Forest Reserve, Calabar were identified. Wood samples obtained from these plant species were processed at the Marian Timber Market, Calabar. The samples were cut into 10 cm × 5 cm × 2 cm dimension using a saw and sun-dried for one week before the experiment.

Termites identification and collection

Workers of the African subterranean termites (*Coptotermes sjostedti* Holmgren) were used for the experiment. The termite colony was found on Kapok tree (*Ceiba pentandra* (L.) Gaertn) at the Arboretum of the Department of Forestry and Wildlife Resources Management, University of Calabar, Cross River State, Nigeria. Another termite colony was maintained at the Soil Science Research Laboratory of the University of Calabar, Nigeria. The termites were identified under a microscope, using the identification protocol described by Harris (1996) and Scheffrahn et al. (2004). The identification criteria considered were the size of termites head, mandible, body and number of antennal articles.

Experimental treatments and design

The setup was in a randomized complete block design with four replicates. Treatments comprised of *A. indica* and *J. curcas* kernel oils along with Solignum (as positive control) applied at the rate of 5.0, 10.0 and 15 mL/100 cm^3 of the selected wood. Untreated wood from each of the selected plant species also served as control. A modified soil barrier test method was used for the assay. The test arena comprised of trenches of about 20 cm × 20 cm × 20 cm dimension with the base having about 2-cm thick layer of moistened autoclaved soil. Different concentrations of the termiticides were applied on the woods samples and placed at the base of the test arena. The top portion was covered with 1-mm iron mesh net to prevent the escape of the insects. About 50 workers of *C. sjostedti* were introduced to each unit, and they were allowed to feed on the wood species while termite mortality data were recorded at 12 h intervals until 96 h after exposure. The percentage termite mortality was calculated using:

$$\text{Mortality}(\%) = \frac{\text{Number of dead termites} \times 100}{\text{Total number of termites}}$$

At 12 weeks after treatment, the remaining wood samples were cleaned, sun-dried for 24 h and the weight loss (WL) caused by the feeding activities of *C. sjostedti* was calculated using the formula below:

$$\%\text{WL} = [(\text{Wi}-\text{Wf})/\text{Wi}] \times 100.$$

where Wi and Wf are the initial and final weight of wood, respectively.

Data analyses

Data on mortality were normalized using arcsine transformation before subjecting them to analysis of variance (ANOVA). All data collected were subjected to ANOVA using of SAS (2009) software. Mean values were separated using Duncan New Multiple Range Test (DNMRT) at 5% level of significance. Pearson's correlation analysis was also carried out to show the strength of association between termite mortality and wood weight loss.

Results

A dose-dependent effect of the plant oils and Solignum were observed on adult *C. sjostedti,* mortality across the 96 h of mortality assessment (Table 2). The number of termites killed after contact with 15 mL of the tested termiticides was the highest, and it was significantly ($P < 0.0001$) different from mortality recorded in the control and on woods treated with 5 and 10 mL of the botanical oils and Solignum. *J. curcas* seed oil appeared to be more toxic to *C. sjostedti* compared with *A. indica* oil. The use of 15 mL of the synthetic chemical (Solignum) brought about the highest *C. sjostedti* mortality, but it was not different ($P > 0.05$) from the mortality caused by 15 mL of *J. curcas* throughout the 96 h period, except at 12 h after exposure. At 96 h after exposure, the use of 10 and 15 mL of *J. curcas* oil brought about 100% *C. sjostedti*

Table 2 Lethal effects of different concentration of *A. indica, J. curcas* and Solignum on *Coptotermes sjostedti* (Isoptera: Rhinotermitidae) at different time of exposure on wood from *Ceiba pentandra* (L.) Gaertn

Termiticide	Conc	Time of exposure (h)							
		12	24	36	48	60	72	84	96
A. indica	5	8.77 ± 0.40e	13.38 ± 0.67d	17.01 ± 0.60f	21.33 ± 0.88f	26.62 ± 0.87f	33.00 ± 0.92f	38.30 ± 0.95e	43.91 ± 0.71e
	10	13.61 ± 0.64d	19.57 ± 1.72b	25.18 ± 1.09e	32.83 ± 0.77e	39.56 ± 0.85e	48.87 ± 2.31e	54.08 ± 1.25d	62.84 ± 1.62d
	15	16.83 ± 0.60c	22.77 ± 0.87c	28.38 ± 0.92d	36.03 ± 0.64d	42.76 ± 0.88de	52.07 ± 0.71d	72.28 ± 1.03c	80.04 ± 1.12c
J. curcas	5	12.40 ± 0.75d	19.55 ± 1.90c	25.49 ± 1.07e	48.52 ± 1.89c	59.62 ± 0.99c	66.00 ± 0.91cd	76.86 ± 1.88c	80.76 ± 1.06c
	10	18.14 ± 1.51b	30.03 ± 1.20b	35.00 ± 1.40c	61.62 ± 1.52b	73.29 ± 0.96b	79.95 ± 0.96b	83.38 ± 2.23b	100.00 ± 0.00a
	15	19.88 ± 0.93b	34.77 ± 0.93a	54.74 ± 2.21ab	65.36 ± 1.11a	76.03 ± 0.97a	85.69 ± 1.01a	89.12 ± 1.13a	100.00 ± 0.00a
Solignum	5	13.78 ± 0.90d	22.10 ± 0.78c	38.62 ± 2.48c	50.91 ± 2.45c	60.52 ± 1.66c	71.19 ± 1.72c	77.81 ± 1.30c	85.91 ± 1.31b
	10	19.08 ± 1.25b	33.49 ± 2.12ab	50.95 ± 1.79b	60.67 ± 0.97b	72.29 ± 1.20b	80.57 ± 0.77b	85.76 ± 0.87b	100.00 ± 0.00a
	15	24.18 ± 2.97a	35.69 ± 1.13a	57.15 ± 0.73a	66.87 ± 0.97a	77.49 ± 1.05a	86.77 ± 0.87a	100.00 ± 0.07a	100.00 ± 0.00a
Control	0	0.00 ± 0.00f	0.00 ± 0.00e	0.00 ± 0.00g	0.00 ± 0.00g	0.00 ± 0.00g	0.00 ± 0.00g	0.00 ± 0.00f	0.00 ± 0.00f
P		< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001

Data (%) were transformed (arcsine) before the analysis of variance; Means (± Standard error) are values of four replicates**;** Means with the same lower case alphabet in a column are not significantly different from each other (DNMRT: $P > 0.05$); [b]concentration (mL/ 100 m^3 of wood surface); P = Probability value

mortality, and it was similar to the mortality caused by 10 and 15 mL of Solignum.

The mortality levels described by the probit models for each termiticides tested showed low χ^2-values and high *P*-values over the 4 days of exposure (Table 3). Among the two plant oils, *J. curcas* had a lower LC_{50} value (138.70, 36.08, 14.29, 5.30, 2.75, 2.50, 0.95 and 0.05 mL at 12, 24, 36, 48, 60, 72, 84 and 96 h after exposure, respectively) compared with *A. indica* (215.78, 138.70, 72.45, 33.66, 21.59, 12.26, 7.70 and 6.19 mL at 12, 24, 36, 48, 60, 72, 84 and 96 h after exposure, respectively). The slope of the probit models also shows that the termiticidal activity was more rapid in *J. curcas* than in *A. indica.*

The dose-dependent mortality trend of the botanical oils was also sustained when used against *C. sjostedti* in all the wood species evaluated (Table 4). *C. sjostedti* mortality increased as the concentration of the tested termiticides increases. More *C. sjostedti* were killed by the use of *J. curcas* oil than *A. indica* oil. Irrespective of wood species, the use of 10 and 15 mL of *J. curcas* oil brought about ≥ 90% mortality of *C. sjostedti* mortality, but it was not significantly ($P > 0.05$) different from the mortality caused by the same concentrations of Solignum.

All the wood species tested in the study appear to be susceptible to damage induced by *C. sjostedti*. However, the rate of damage caused by the feeding activities of the insect varied among the wood species (Table 5). About 35.0–65.2% reduction in wood weight was observed among untreated wood from different plants species, and it was significantly ($P < 0.0001$) higher compared with the weight loss in treated woods. The use of 15 mL of Solignum brought about the lowest loss in weight of all the woods tested, but it was not significantly ($P > 0.05$) different from the loss that occurred when 10 and 15 mL of *J. curcas* and 10 mL of Solignum was used. There were strong negative correlations between percentage termite mortality and percentage loss in wood weight ($r > -0.900$; $P < 0.0001$) (Table 6).

Discussion

The study shows that infestation by *C. sjostedti* could induce serious damage on susceptible plant materials if preventive or curative measures are not employed as mentioned in previous studies by (Harris 1966; Johnson and wood 1980; Scheffrahn et al. 2004; Loko et al. 2019). The two plant oils (*J. curcas* and *A. indica*) evaluated in this study showed significant termiticidal activity against *C. sjostedti*. However, the oil extract of *J. curcas* kernel seems to be the most potent when compared with that of *A. indica*. Both *C. sjostedti* mortality and wood weight loss results from 10 and 15 mL of *J. curcas* were not different from that of the synthetic chemical, Solignum. This outcome conforms to the reports of Goktas et al. (2007) and Okweche et al. (2015) who observed the effectiveness of some plant oils in preventing decay and enhancing the resistance of some wood species to withstand attack by some pests and diseases. All the concentrations of *J. curcas* oil tested was able to increase *C. sjostedti* mortality significantly within 96 h, and provided better protection against wood consumption by the insect when compared with oil from *A. indica* kernel. The use of plant extracts have also been reported by several authors to be effective in the management of termite and could serve as an alternative to synthetic insecticides (Sen 2001; Sbeghen et al. 2002; Sohail et al. 2005; Abdullah et al. 2014; Ekhuemelo and Musa 2015). Furthermore, the non-significant

Table 3 Lethal concentration (LC_{50}) of *A. indica, J. curcas,* and *Solignum* on adult *Coptotermes sjostedti* (Isoptera: Rhinotermitidae)

Time (h)	Termiticide	Slope ± SE	LC_{50} (95% FL)	χ^2	*P*
12	*A. indica*	0.66 ± 0.32	215.78 (52.40–1.43E + 08)	0.05	0.951
	J. curcas	0.83 ± 0.34	138.70 (41.12–4.80E + 06)	0.03	0.855
	Solignum	0.81 ± 0.38	113.23 (38.23–1.60E + 05)	0.06	0.808
24	*A. indica*	0.76 ± 0.31	138.70 (41.17–4.81E + 06)	0.03	0.855
	J. curcas	0.99 ± 0.28	36.08 (21.36–416.45)	0.12	0.729
	Solignum	0.87 ± 0.28	36.23 (20.51–383.22)	0.61	0.436
36	*A. indica*	0.81 ± 0.29	72.45 (30.08–1.08E + 04)	0.14	0.714
	J. curcas	1.58 ± 0.27	14.29 (12.01–18.96)	3.70	0.554
	Solignum	0.99 ± 0.26	9.71 (7.52–13.12)	0.02	0.878
48	*A. indica*	0.94 ± 0.28	33.66 (20.08–215.62)	0.43	0.514
	J. curcas	0.93 ± 0.26	5.30 (2.49–7.05)	0.29	0.592
	Solignum	0.86 ± 0.26	4.74 (1.67–6.59)	0.01	0.908
60	*A. indica*	0.95 ± 0.27	21.59 (14.98–67.01)	0.53	0.468
	J. curcas	1.01 ± 0.27	2.75 (0.72–4.31)	0.52	0.469
	Solignum	1.03 ± 0.27	2.73 (0.74–4.26)	0.02	0.888
72	*A. indica*	1.06 ± 0.27	12.26 (9.82–18.30)	0.85	0.358
	J. curcas	1.38 ± 0.29	2.50 (1.03–3.70)	0.01	0.908
	Solignum	1.14 ± 0.30	1.65 (0.290–2.96)	0.14	0.709
84	*A. indica*	1.79 ± 0.27	7.70 (6.55–8.79)	2.06	0.151
	J. curcas	1.00 ± 0.31	0.95 (0.03–2.24)	0.35	0.552
	Solignum	1.06 ± 0.32	0.96 (0.05–2.20)	0.02	0.884
96	*A. indica*	1.01 ± 0.27	6.19 (5.13–7.07)	1.64	0.200
	J. curcas	0.35 ± 0.29	0.05 (0.01–1.71)	0.15	0.697
	Solignum	0.26 ± 0.29	0.02 (0.00–0.04)	0.13	0.721

N = 50 termites; SE, standard error; LC: Lethal concentration ($mLkg^{-1}$); FL, Fiducial limits; χ^2, *Chi*-square value, *P*, Probability value; h, hours

chi-square values for both *J. curcas* and *A. indica* oils shows that toxicity models generated from the probit regression were similar to the theoretical models which described the observed mortality of *C. sjostedti* on treated wood samples as an outcome of the toxic effect of the botanical oil extracts (Finney 1971).

Jatropha plant has been reported to contain several toxic metabolites such as sterols and terpene alcohols which are known to possess insecticidal properties (Adolf et al. 1984). Oskoueian et al. (2011) reported the presence of gallic acid and pyrogallol (phenolics), rutin and myricetin (flavonoids) and daidzein (isoflavonoid) and phorbol esters in extract extracts from the kernel of *J. curcas.* The GC–MS analysis conducted in their study also identified 2-(hydroxymethyl)-2 nitro-1, β-sitosterol, 3-propanediol, 2-furancarboxaldehyde, 5-(hydroxymethy) and acetic acid in extracts from the kernel. The phorbol esters (tetra-cyclic diterpenes) fraction in *J. curcas* kernel oil was reported to exhibit insecticidal activity against some insect pests (Ratnadass and Wink 2012). About 40% of neem kernel is made up of oil, and *azadirachtin* was reported as the major bioactive component of this oil (Isman et al. 1991).

The mode of action of *J. curcas* kernel oil on insects has been described in some studies. The oil has been reported to exhibit contact toxicity (Wink et al. 1997; Ratnadass et al. 2009; Li et al. 2004; Devappa et al. 2012), feeding deterrence (Ratnadass et al. 1997; Devappa et al. 2012; Li et al. 2004), anti-oviposition/ovicidal effects (Adebowale and Adedire, 2006; Agboka et al. 2009; Ratnadass et al. 2009; Kshirsagar, 2010; Nabil and Yasser 2012), repellency (Boateng and Kusi, 2008), insect growth regulatory effect (Singh and Sushilkumar, 2008; Wink et al. 1997; Sauerwein et al. 1993; Ratnadass et al. 2009), and reduction in amylase/lactic acid dehydrogenase activities (Dowlathabad et al. 2010) against many insect species. A combination of these properties may have influenced *C. sjostedti* mortality and the reduction in wood-feeding damage that was induced by *J. curcas* oil. Also, the *azadirachtin* component of neem oil has been reported to exhibit toxicity, long-term repellency, and feeding deterrent activity towards a species in *Coptotermes* genus (Isman et al. 1991; Grace and Yates, 2008).

Woods are known to differ in their susceptibility to termite attack; these differences may be attributed to factors such as chemical composition, wood density and availability of susceptible species (Jambere et al. 1995; Gérard et al. 2019). However, all the woods tested showed significant susceptibility to *C. sjostedti* attacks. Particularly, the untreated wood samples from all the tested plant species recorded the highest weight loss when compared with the treated samples, and it indicates high susceptibility of the wood species to *C. sjostedti* attacks. Termites are polyphagous in nature and could thrive on a wide range of economically important crops, forestry, rangelands, houses and other wooden structures (Debelo, 2020). Based on the results, wood consumption by *C. sjostedti* seems to be higher in *Ceiba pentandra* wood than other wood types tested. This result agrees with the report of Faruwa et al. (2015) who observed a significant impact of bio-based preservatives as control measures against damage caused by fungi and termite in *Triplochiton scleroxylon, Gmelina arborea, Ceiba pentandra* wood samples.

The significant negative association between termite mortality and wood weight loss further shows that the toxicity of the termiticides may be responsible for the significant reduction in termite wood consumption

Table 4 Termiticidal efficacy of *A. indica, J. curcas,* and Solignum on *Coptotermes sjostedti* (Isoptera: Rhinotermitidae) in seven wood species

Termiticide	Conc	Termite mortality at 96 h after exposure (%)						
		AT	GA	BN	PB	PA	TS	CP
A. indica	5	41.60 ± 1.20f	47.33 ± 3.45d	47.00 ± 0.58d	43.00 ± 1.53d	40.00 ± 1.16e	43.33 ± 0.88e	43.91 ± 0.71e
	10	70.62 ± 1.76e	50.59 ± 1.60d	67.10 ± 1.49c	55.00 ± 2.89c	64.17 ± 0.46d	67.67 ± 1.45d	62.84 ± 1.62d
	15	72.60 ± 3.70d	55.00 ± 2.89c	68.33 ± 1.67c	58.33 ± 0.41c	66.33 ± 1.86c	71.67 ± 4.41cd	80.04 ± 1.12c
J. curcas	5	82.64 ± 3.70c	87.67 ± 1.45b	82.33 ± 2.45b	81.67 ± 2.03c	82.67 ± 3.46bc	75.00 ± 2.89c	80.76 ± 1.06c
	10	93.00 ± 5.16ab	90.00 ± 4.15ab	90.30 ± 3.15ab	92.00 ± 1.15ab	95.00 ± 1.16a	90.00 ± 2.70ab	100.00 ± 0.00a
	15	95.30 ± 3.30ab	92.67 ± 3.72ab	95.33 ± 2.67a	94.00 ± 3.15a	96.00 ± 0.56a	94.33 ± 2.96a	100.00 ± 0.00a
Solignum	5	90.00 ± 1.15b	90.33 ± 3.67ab	90.30 ± 3.15ab	88.33 ± 1.67b	88.33 ± 1.67b	86.67 ± 2.67b	85.91 ± 1.31b
	10	97.30 ± 2.67a	96.33 ± 3.18a	96.67 ± 2.33a	95.50 ± 2.68a	94.00 ± 3.05a	91.33 ± 4.09ab	100.00 ± 0.00a
	15	98.50 ± 0.00a	98.80 ± 1.00a	97.00 ± 2.40a	98.30 ± 0.86a	98.60 ± 1.20a	96.67 ± 1.33a	100.00 ± 0.00a
Control	0	0.00 ± 0.00g	0.00 ± 0.00e	0.00 ± 0.00e	0.00 ± 0.00e	0.00 ± 0.00f	0.00 ± 0.00f	0.00 ± 0.00f
P		< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001

AT, *Antiaria toxicera*; GA, *Gmelina arborea*; BN, *Baphia nitida*; PB, *Parkia biglobosa*; PA, *Pycnanhus angolensis*; TS, *Terminalia superba*; CP, *Ceiba pentandra*;

Data (%) were transformed (arcsine) before the analysis of variance; Means (± Standard error) are values of four replicates**;** Means with the same lower case alphabet in a column are not significantly different from each other (DNMRT: $P > 0.05$); [b]concentration (mL/ 100 m^3 of wood surface); P = Probability value

Table 5 Termite-induced weight loss in wood from seven plant species treated *A. indica, J. curcas,* and Solignum

Termiticide	Conc	Weight loss (%)						
		AT	GA	BN	PB	PA	TS	CP
A. indica	5	17.33 ± 1.45b	20.00 ± 2.88b	13.33 ± 1.67b	23.33 ± 3.01b	15.00 ± 2.88b	8.00 ± 1.58b	26.67 ± 3.82b
	10	8.67 ± 0.8 d	10.00 ± 1.16c	6.68 ± 1.33c	16.67 ± 2.41c	13.33 ± 1.66c	6.00 ± 0.57c	18.33 ± 2.66c
	15	6.50 ± 1.68de	6.67 ± 0.33d	6.68 ± 1.33c	6.67 ± 0.67e	7.33 ± 0.33d	4.67 ± 0.66d	10.67 ± 0.66d
J. curcas	5	12.33 ± 2.33c	11.67 ± 0.67c	10.00 ± 2.88bc	13.33 ± 4.09d	11.67 ± 2.67cd	8.00 ± 1.52b	18.33 ± 2.66c
	10	5.20 ± 2.16efg	4.10 ± 2.56def	3.67 ± 1.66de	4.67 ± 1.76fg	4.67 ± 1.67f	4.00 ± 1.57de	6.00 ± 2.88ef
	15	4.00 ± 1.58g	3.67 ± 0.87f	3.17 ± 1.33de	4.00 ± 1.00g	3.33 ± 3.88fg	3.83 ± 0.33e	4.68 ± 0.56f
Solignum	5	4.67 ± 2.82f	3.94 ± 0.86f	4.33 ± 0.33d	6.67 ± 1.67e	6.67 ± 1.66e	6.33 ± 1.33c	7.00 ± 1.00e
	10	4.17 ± 1.67fg	3.90 ± 0.68f	3.03 ± 0.67e	4.67 ± 0.00fg	4.00 ± 1.00fg	3.80 ± 1.02e	5.33 ± 0.66fg
	15	4.07 ± 0.67g	3.20 ± 1.57f	3.00 ± 0.58e	4.33 ± 0.33g	3.67 ± 0.56g	3.67 ± 0.66e	4.60 ± 0.33g
Control	0	46.33 ± 5.64a	51.67 ± 3.67a	45.00 ± 5.00a	50.28 ± 2.88a	46.67 ± 3.33a	35.00 ± 5.74a	65.20 ± 2.88a
P		< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001

AT, *Antiaria toxicera*; GA, *Gmelina arborea*; BN, *Baphia nitida*; PB, *Parkia biglobosa*; PA, *Pycnanhus angolensis*; TS, *Terminalia superba*; CP, *Ceiba pentandra*; Data (%) were transformed (arcsine) before the analysis of variance; Means (± Standard error) are values of four replicates**;** Means with the same lower case alphabet in a column are not significantly different from each other (DNMRT: $P > 0.05$); [b]concentration (mL/ 100 m^3 of wood surface); P, Probability value

Table 6 Pearson's correlation between termite mortality and wood weight loss

	Wood weight loss (%)						
	A. toxicera	***G. arborea***	***B. nitida***	***P. biglobosa***	***Py. angolensis***	***T. superba***	***C. pentandra***
Mortality (%)	− 0.948**	− 0.953**	− 0.939**	− 0.935**	− 0.930**	− 0.902**	− 0.909**

** Correlation is significant at 0.0001 level (2-tailed)

observed in the study. Stirling et al. (2015) reported similar outcome on *Coptotermes formosanus* Shiraki mortality and damage caused on Western Red Cedar Heartwood (*Thuja plicata* L.).

Conclusion

Both *J. curcas* oil and *A. indica* kernel oils showed significant termiticidal activity against *C. sjostedti*. But wood treatment with *J. curcas* kernel oil proved to be more efficacious against the insect, and the protection it provided for the seven wood species against *C. sjostedti* was similar to that of Solignum. We, therefore, recommend the use of *J. curcas* oil as a potent substitute to synthetic termiticides which has the drawbacks of been toxic to man and the environment. *J. curcas* kernel oil is relatively cheaper compared to synthetic chemical, and it possesses no risk to humans, livestock and other non-target organisms. However, more research is required to ascertain the persistence of the bioactive compounds *J. curcas* kernel oil over a long period. This will further enhance the commercial application of these results.

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