Resistance of the Inner Part of Oil Palm Trunk Impregnated with Aqueous Polymer-Isocyanate to Subterranean Termite Attack

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Isocyanate impregnation was studied relative to the subterranean termite (*Coptotermes curvignathus* Holmgren) resistance of the inner part of oil palm (*Elaeis guineensis* Jacq.) trunk. Unproductive oil palm trunk was harvested and divided into top and bottom parts. Samples were isolated from the inner part of the trunk with a size of 2.5 cm x 2.5 cm x 0.5 cm. The samples were impregnated with 10% and 20% aqueous polymer-isocyanate and then heated at 60 °C for 48 h. The specimens were fed to subterranean termites under laboratory conditions. The weight percent gain values were 15.3% to 21.0% and 9.2% to 14.7% for the top and bottom parts, respectively. A higher isocyanate concentration decreased the moisture content and increased the density of inner part of the oil palm trunk. Impregnation with aqueous polymer-isocyanate increased termite mortality at the bottom part and decreased the feeding rate and weight percent loss. Impregnation with 10% and 20% aqueous polymer-isocyanate enhanced the resistance class of the bottom part of the inner part of the oil palm trunk from very poorly resistant (V) to poorly resistant (IV) and moderately resistant (III), respectively, based on the standard adopted.

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INTRODUCTION

Oil palm (*Elaeis guineensis* Jacq.) plantations are common in tropical regions, including Indonesia. The number of oil palm plantations in Indonesia has gradually increased over the past few years. In 2018, the total plantation area was 14.33 million ha, which increased to 14.86 million ha by 2020 (Directorate General of Estate Crops 2021). Replanting to regenerate its stands after exceeding the economic life span of 25 years produces numerous underutilized residues in the form of trunks and fronds every year. Oil palm plantation in Indonesia produce 220 $m^3 \cdot ha^{-1}$ of unproductive oil palm trunks (OPTs) (Hambali and Rivai 2017) and 75 $m^3 \cdot ha^{-1}$ of OPT sawn timber (Febrianto and Bakar 2004; Balfas 2006). The chemical components of OPTs are holocellulose (73%), cellulose (41%), lignin (24%), and extractives (5%), which is similar to the chemical components of wood (Khalil *et al.* 2008). Therefore, OPTs have the potential for use as an alternative raw materials for wood products.

Anatomically, OPTs consist of two distinct cell components: solid vascular bundles and loose parenchyma ground tissue, which are axial cells (Hartono *et al.* 2016a). The outer part is one-third of the OPT diameter, while the inner part is two-thirds of the OPT diameter (Komariah *et al.* 2019). These two parts vary in their anatomical structures and density, which are the primary factors underlying other challenges, *e.g.*, drying, machining, gluing, dimensional stability, and eventually, the strength of the resulting products (Erwinsyah 2008). Bakar *et al.* (2008) extensively explained the anatomical and physical properties of OPT. The number of vascular bundles in the outer part of the OPT (OOPT) was found to be greater than the number in the inner part of the OPT (IOPT), and the number of vascular bundles decreases toward the center zone. The outer part of the OPT is rich in vascular bundles (51%), while the inner part of the IOPT is dominated by parenchyma ground tissue (70%). The cell wall of the parenchyma ground tissue of the OOPT is thicker than the cell wall of the IOPT. Therefore, the OOPT has better physical and mechanical properties compared to IOPT. To date, OOPTs have been utilized as furniture components (Ratnasingam and Ioras 2010), woodworking components (Balfas 2006), and composite products, *e.g.*, plywood (Rosli *et al.* 2016), particleboards (Lee *et al.* 2018), and laminated boards (Prabuningrum *et al.* 2020). However, IOPT commonly becomes waste in the industry, even though IOPT has a higher proportion compared to OOPT in OPT. The IOPT exhibits poor performance in terms of physical and mechanical properties, owing to the density variation and dimensional instability (Darwis *et al.* 2013). Moreover, the large portion of parenchyma ground tissue in the IOPT deposits some extractives, *e.g.*, starch. Furthermore, the IOPT has low resistance against degradative organisms because of its high starch content (Hashim *et al.* 2011). Therefore, modification of the IOPT is needed to improve its quality, in order to obtain valuable products.

Impregnation modification treatment is one of the most effective methods for improving wood properties, including OPT (Hill 2011; Dungani *et al.* 2013b; Hartono *et al.* 2016b). The impregnation method does not require a chemical reaction with the wood cell wall components, but the reagent must penetrate the cell wall and is non-leachable in service (Hill 2011). Resin impregnation has been applied for the enhancement of the strength and dimensional stability of wood as well as a wood-preservation technique to prevent biodeterioration. Many researchers have used polymer resin to improve the properties of OPT and reported that the resin was deposited extensively in the wood cell lumen and effectively improved its physical, mechanical, and durability properties (Furuno *et al.* 2004; Erwinsyah 2008; Bhat *et al.* 2010; Khalil *et al.* 2010). Resin penetration in IOPT should be easier because the IOPT has high porosity and thin-walled parenchyma cells, significantly improving resin penetration into IOPT. Dungani *et al.* (2013b) reported that the parenchyma tissue in dried IOPT behaves like a sponge that easily absorbs resin. The authors also found that most of the cured resin and nano-filler were located in parenchyma cells. In addition, Choo *et al.* (2013) also reported a higher water and gas permeability of IOPT compare to OOPT. Therefore, IOPT could be a suitable material for impregnation treatment.

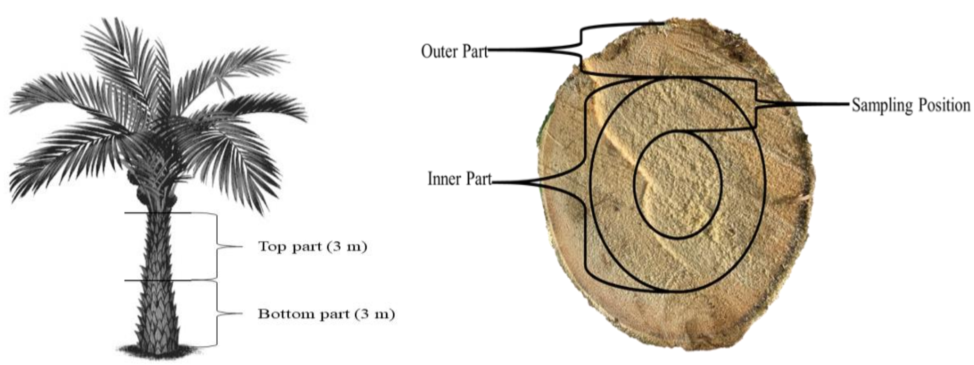
Polymer resins that have been used for OPT modification include urea, melamine, and phenol-formaldehyde (PF) resins (Bhat *et al.* 2010a; Dungani *et al.* 2013b; Manik *et al.* 2021). Among these resins, PF is used more often because it has the following advantages: a low viscosity, lack of odor, low volatility and heat generation during polymerization, good polymerization completion, and a low price (Khalil *et al.* 2010). In addition, Hartono *et al.* (2016b) reported that impregnation using PF resin increased the physical and mechanical properties of OPT. Furthermore, the PF impregnation of OPT also improved the resistance of OPT against termite attack and fungal decay (Dungani *et al.* 2013a; Nabil *et al.* 2016). Bakar *et al.* (2013) stated that PF is not toxic to the termite, but the termites die because of undigested impregnated samples. However, PF resin is a formaldehyde-based material that releases formaldehyde vapors, which causes consumer dissatisfaction and health-related issues. Therefore, to overcome these issues, another resin should be developed for impregnation treatment, in order to increase the resistance of OPT.

Methylene diphenyl diisocyanate is a conventional resin that is widely used in wood products. The performance of isocyanate resins is known to be highly suitable for improving the physical and mechanical properties of wood products. Isocyanate is capable of forming covalent bonds with the active hydroxyl groups of the bonded materials (Papadopoulos 2006). Previous studies have reported that isocyanates have high reactivity to hydroxyl groups and can block alcoholic groups (Zhao *et al.* 2011). Furthermore, the bond formation of wood-isocyanate reduces the moisture content (MC) and increases the wood resistance to fungi (Williams and Hale 1999; Williams and Hale 2003). However, the effects of isocyanate impregnation on OPT properties, particularly its resistance to destroying organisms, has not been reported. Thus, this study aimed to evaluate the effects of isocyanate impregnation on the subterranean termite (*Coptotermes curvignathus* Holmgren) resistance of the IOPT and the change in its physical properties for the effective utilization of IOPT.

EXPERIMENTAL

Materials

Three 35-year-old unproductive oil palm trunks (OPT) were harvested from Bogor area of West Java, Indonesia (6°33'5.55″ S and 106°42'55.35″ E).



a b

Fig. 1. Illustration of the IOPT sampling: (a) partition in the axial direction; and (b) black circled area in the cross section indicates the middle part of the OPT used for the sample in this study.

The trunks were divided into top and bottom parts (as shown in Fig. 1a), and the IOPT used for the sample in this study was obtained from the middle part of the OPT (as shown in Fig. 1b). Methylene diphenyl diisocyanate (a resin content of 40% to 44%, a viscosity of 5000 cps to 15000 cps, and a pH of 6.5 to 8.5) was obtained from Polichemie Asia Pacific (Jakarta, Indonesia). The subterranean termite (*C. curvignathus* Holmgren) soldiers and workers were gifted by the Forest Products Research and Development Centre (Bogor, West Java, Indonesia).

Impregnation Treatment

The IOPT samples were cut into pieces with the dimension of 2.5 cm × 2.5 cm × 0.5 cm, according to Indonesian standard SNI 7207 (2014). Before the impregnation process, the IOPT samples were oven-dried at a temperature of 60 °C for 48 h and then weighed. The MC of the samples was controlled at 8% in a desiccator. The IOPT samples were then placed in an impregnation chamber under a vacuum pressure of 76 $kg{\cdot}cm^{-2}$ for 15 min. After releasing the vacuum, aqueous polymer-isocyanate, a mixture of MDI with water at concentrations of 10% MDI or 20% MDI, was immediately poured into the chamber, which was then placed at a pressure of 12 $kg{\cdot}cm^{-2}$ for 60 min (Basri and Balfas 2014). The isocyanate-impregnated IOPT samples were wrapped in aluminum foil and heated in an oven at 60 °C for 48 h (Riedlinger *et al.* 2007). Finally, the IOPT samples were weighed without the aluminum foil. Each treatment combination was performed in five replicates. The specimens were maintained at room temperature for 3 weeks before baiting to subterranean termites (*C. curvignathus*).

Physical Properties of the Impregnated IOPT

Weight percent gain (WPG)

The amount of resin loaded was determined based on the constant weight before and after the treatment, according to Eq. 1,

$$\text{WPG}\ (\%) = \frac{W_1 - W_0}{W_0} \times 100 \tag{1}$$

where W_0 is the oven-dried weight (g) of the IOPT and W_1 is the oven-dried weight (g) of the specimen after impregnation with aqueous polymer isocyanate.

Density

The density of the impregnated IOPT, after curing in a conditioning room, was calculated using Eq. 2,

$$\text{Density}(g \cdot cm^{-3}) = \frac{W_a}{V_a} \tag{2}$$

where W_a is the air-dried weight (g) of the IOPT, and V_a is the air-dried volume (cm^{-3}) of the IOPT.

Moisture content (MC)

The moisture content of the impregnated IOPT was evaluated using Eq. 3,

$$\text{MC}\ (\%) = \left[\frac{(W_a - W_0 - W_2)}{(W_0 - W_2)}\right] \times 100 \tag{3}$$

where W_0 is the oven-dried weight (g) of the IOPT and W_2 is the weight (g) of the aqueous polymer-isocyanate used for impregnation (Thybring 2013).

Subterranean Termite Resistance Test

The subterranean termite (*C. curvignathus*) test was conducted in a laboratory, based on Indonesian standard SNI 7207 (2014). Each test specimen was placed in a glass container with 200 g of sterilized sand and 50 mL of water. Two hundred healthy and active subterranean termite workers from a laboratory colony were added to each container. The containers were placed in a dark room at a temperature of 25 to 30 °C and a relative humidity of 80% to 90% for 4 weeks. The containers were weighed weekly, and if the MC of the sand had decreased, water was added to achieve the MC standard. An illustration of this test is shown in Fig. 2.

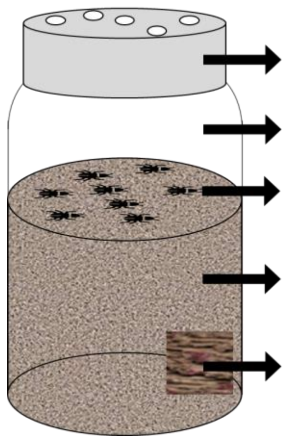


Fig. 2. Illustration of the subterranean termite attack test

At the end of the exposure period, the samples were cleaned and oven-dried at a temperature of 60 °C for 70 h. The termite mortality, feeding rate, and weight percent loss were evaluated using Eqs. 4 through 6, respectively,

$$\text{Termite mortality (\%)} = \left[\frac{(T_1\text{-}T_2)}{(T_1)}\right] \times 100 \tag{4}$$

where T_1 and T_2 represent the number of live termites before the test and the number of live termites after the test, respectively,

Feeding rate (g/termite number/day) = weight of IOPT consumed (g)/average number of termites alive during the test/test period (days) (5)

$$\text{Weight percent loss (\%)} = \left[\frac{(W_3\text{-}W_4)}{(W_3\text{-}W_2)}\right] \times 100 \tag{6}$$

where W_3 and W_4 are the oven-dried weights of the IOPT specimens before and after the test (mg), respectively (Thybring 2013). The classification of the wood resistance against subterranean termites was based on SNI standard 7207 (2014), as shown in Table 1.

Table 1. Resistance Classes Against Subterranean Termite Attack

Resistance Class	Sample Condition	Mass Loss (%)
I	Very resistant	Less than 3.52
II	Resistant	3.52 to 7.50
III	Moderately resistant	7.50 to 10.96
IV	Poorly resistant	10.96 to 18.94
V	Very poorly resistant	Greater than 18.94

Data Analysis

The data were analyzed using Microsoft Excel 2019 and SPSS Statistics (version 22, IBM, Armonk, NY). A completely randomized block design was used for data analysis to determine the effect of the treatments on all response variables, *i.e.*, the WPG, MC, density, termite mortality, weight percent loss, and termite feeding rate. The blocks were the top and bottom parts of the IOPT, and the factors were the concentrations of isocyanate (untreated, 10%, and 20%). Duncan's multiple range tests were used for further analysis if a factor was significantly different ($p \leq 0.05$).

RESULTS AND DISCUSSION

Physical Properties of the IOPT Impregnated with Aqueous Polymer-Isocyanate

The density, WPG, and MC of the untreated and impregnated IOPTs are shown in Table 2. The analysis of variance and Duncan's multiple range tests of the physical properties of the impregnated IOPT are shown in Tables 4 and 5, respectively.

Table 2. Density, WPG, and MC of Each Part of the Impregnated IOPT

Part of IOPT	Treatment	Density (g·cm^{-3})	WPG (%)	MC (%)
Top	Untreated/0%	0.41 (0.02)	-	8.74 (0.52)
	10%	0.51 (0.04)	15.29 (6.63)	8.76 (0.52)
	20%	0.54 (0.04)	21.00 (4.55)	7.88 (0.98)
Bottom	Untreated/0%	0.47 (0.02)	-	8.83 (0.47)
	10%	0.57 (0.06)	9.19 (4.87)	7.88 (0.98)
	20%	0.61 (0.12)	14.72 (3.77)	6.28 (1.39)

Note: the values in parentheses are the standard deviations. WPG: Weight Percent Gain, MC: Moisture Content.

Density

The densities of the untreated IOPTs ranged from 0.41 to 0.61 g·cm^{-3} (as shown in Table 2), which are classified as medium density, according to the Indonesian Wood Atlas (Martawijaya *et al.* 2005). The top part of the IOPT showed a significantly lower density than the bottom part of the IOPT. This could have been caused by variations in the anatomical structure between the top and bottom parts of the OPT. The bottom part of the OPT is dominated by mature vascular bundles with a high density, whereas the top part of the OPT is dominated by juvenile vascular bundles with a low density (Bakar *et al.* 2008).

The impregnated IOPT had a higher density than the untreated OPT, and the densities increased as the isocyanate concentration increased. The analysis of variance showed that the varying concentrations had a significant effect on the density of the IOPT ($p \leq 0.05$). Duncan's multiple range tests showed that the density of the untreated IOPT was significantly different from the density of the impregnated IOPT, but the densities of the OPTs impregnated with 10% and 20% isocyanate concentration showed no significant difference. The density of the impregnated IOPT could have increased because the isocyanate polymer filled the cavities in the IOPT. Dungani *et al.* (2014) also reported an increase in the density of impregnated wood and woody materials. The authors reported that the density of OPT impregnated with PF increased from 0.29 to 0.42 g·cm^{-3}. Sumardi *et al.* (2020) also reported that PF-impregnated *Falcataria* wood has a higher density than untreated *Falcataria* wood. Furthermore, Hadi *et al.* (2021) reported that furfurylated wood has a higher density than untreated wood.

Weight percent gain

The WPG of the impregnated IOPT was 9.19% to 4.72% at the bottom part and 15.29% to 21.10% at the top part (as shown in Table 2). Significantly higher WPG was observed at the top part of the OPT compared to the bottom part. This may have been caused by the higher porosity in the top part of the IOPT, compared to the bottom part, which resulted in easy resin penetration into the pores of the IOPT. Furthermore, enhancing the isocyanate concentration from 10% to 20% increased the WPG of the IOPT. Duncan's multiple range tests showed that the WPG of the IOPT impregnated with a 10% isocyanate concentration was significantly lower than that impregnated with 20% isocyanate. These findings were supported by Wang *et al.* (2019), who reported an increase in the WPG in low-molecular-weight PF-resin-treated Masson pine.

Moisture content

The overall MC of the IOPT ranged from 6.28% to 8.76% (as shown in Table 2). The analysis of variance showed that there were no significant differences in the MC between the parts of the IOPT ($p \leq 0.05$). The isocyanate impregnation treatment changed the MC of the IOPT. Varying the isocyanate concentration significantly affected the MC of IOPT (Table 4). Duncan's test showed that the MC of IOPT impregnated with 20% isocyanate concentration was significantly lower than that treated with 10% isocyanate and the untreated IOPT (Table 5). The MCs of the untreated IOPT and the impregnated IOPT with 10% and 20% isocyanate concentrations were 8.79%, 8.32%, and 7.29%, respectively. The decrease in the MC of the IOPT was expected to be caused by the replacement of some of the OPT-moisture linkages by the OPT-isocyanate linkage (Williams and Hale 1999). Therefore, the impregnated IOPT must have fewer available moisture sites than the untreated IOPT. Furthermore, the higher concentration could improve polymer penetration to the IOPT and reduce the number of free hydroxyl groups in the cell wall of the IOPT. In addition, Hadi *et al.* (2021) reported that furfurylated wood has a lower MC than untreated wood.

Subterranean Termite Resistance of the IOPT Impregnated with Aqueous Polymer-Isocyanate

Termite mortality

The termite mortality in the top and bottom parts of the IOPT was 8.60% to 12.30% and 11.90% to 17.90%, respectively (Table 3). The analysis of variance showed that there was a significant difference in the termite mortality between the bottom and top parts of the IOPT ($p \leq 0.05$) (Table 4). The top part of the IOPT had a lower termite mortality compared to the bottom part, which indicated that the bottom part was more resistant to termite attack than the top part. The bottom part of the IOPT had a higher density than the top part, suggesting that the bottom part of the IOPT was more difficult to digest and less preferred by termites. When termites are repulsed from their preferred food option, it leads to a higher termite mortality rate. The termite mortality rate in the untreated OPT was lower than the mortality rate in the impregnated OPT, which showed that the impregnated OPT containing isocyanate polymer had a higher density and lower MC, which contributed to the resistance of the IOPT against termite attacks. Hadi *et al.* (2021) reported that treated wood samples were more hydrophobic and had a lower MC compared to untreated wood due to chemical component alteration. The lower MC of the OPT conferred upon it greater resistance to termite activity (Abdullah *et al.* 2013). These factors affect the feeding preference of termites for digestion. However, the analysis of variance showed that varying the concentrations did not affect termite mortality (Table 5).

Feeding rate

The macroscopic morphologies of the impregnated IOPT samples after the termite test are shown in Fig. 3. The top part of the IOPT showed cavities in the untreated and treated samples, showing a higher feeding rate.

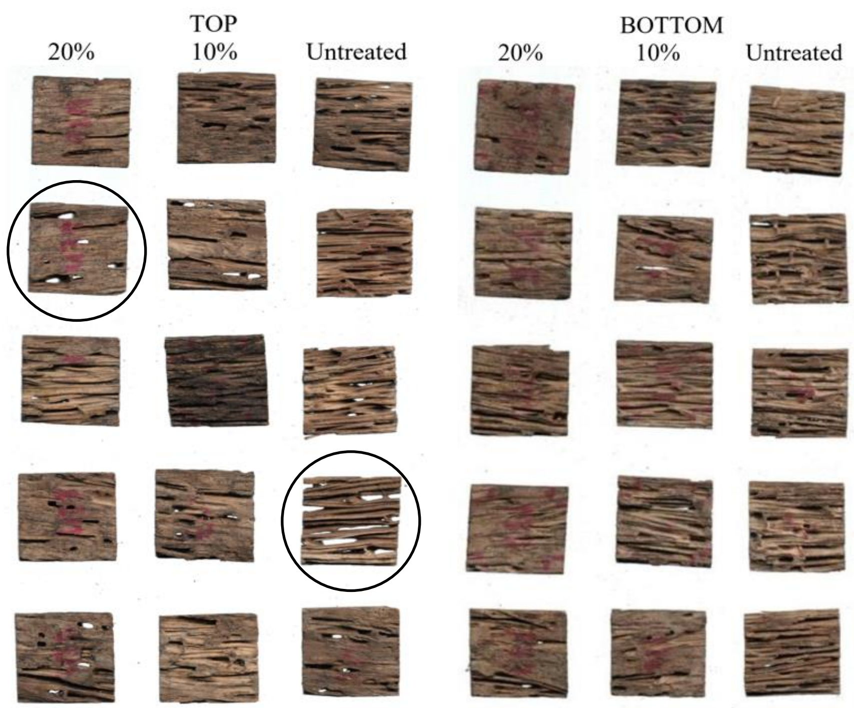


Fig. 3. The IOPT samples after termite test (Note: the photos in the circle show the morphology of the samples with high feeding rate)

The subterranean termite feeding rates of the top and bottom parts of the IOPT were 63.2 µg/termite/day to 70.3 µg/termite/day and 46.2 µg/termite/day to 64.5 µg/termite/day, respectively (as shown in Table 3), which indicated a higher termite feeding rate in the top part compared to the bottom part of the IOPT ($p \leq 0.05$). This could be related to the differences in the anatomical characteristics between the bottom and top parts of the IOPT. As mentioned in a previous study by Bakar *et al.* (2008), the IOPT is dominated by parenchyma ground tissue, and the vascular bundles and their distribution vary between the bottom and top parts of the IOPT. The number of vascular bundles increases from the bottom to the top. However, the top part of the OPT is dominated by juvenile vascular bundles (Darwis *et al.* 2013). The juvenile vascular bundles are not lignified and are soft, which makes it easier for the termites to attack. Moreover, the cell walls of the bottom part of the fibers are thicker than the cell walls of the top part. A thicker cell wall is associated with a high resistance of a material (Shirley 2002). The high termite feeding rate achieved in this experiment was presumably due to starch. The starch content of the IOPT was higher in the top part than the starch content in the bottom part (Omar *et al.* 2011). Starch is an attractive food that is easily extracted by mandibles and digested into glucose in the guts of termites (Fujita *et al.* 2010). Therefore, termites prefer the top part of the IOPT for easy digestion.

Impregnation of the IOPT with isocyanate decreased the feeding rate of the termites. Duncan's multiple range tests showed that the termite feeding rate of the untreated IOPT was different from the termite feeding rate of the impregnated IOPT with a 20% isocyanate concentration. The impregnated IOPT with isocyanate reduced the termite feeding rate by up to 18%. A higher concentration of isocyanate decreased the termite feeding rate due to isocyanate impregnation, thereby increasing the density, and reducing the MC of the IOPT. The termites were unable to digest the denser IOPT, so the feeding rate of the termites was lower in the impregnated IOPT. These results are in line with those of Hadi *et al.* (2021), who reported that treated samples were more difficult for the termites to eat and digest compared to the untreated samples.

Weight percent loss and resistance class

The weight percent loss determined the resistance class of the IOPT, as shown in Table 3. The weight percent losses of the top and bottom parts of the IOPT were 24.6% to 29.8% and 12.6% to 25.2%, respectively. The analysis of variance showed that the part of the IOPT and the concentrations had a significant effect on the weight percent loss ($p \leq 0.01$). Duncan's test showed that the weight percent loss of the top part of the IOPT was significantly different from the weight percent loss of the bottom part. The higher weight percent loss in the top part could be caused by a higher proportion of soft cell components, *e.g.*, juvenile vascular bundles and parenchyma. Dungani *et al.* (2013a) reported that the termites attacked the soft section and then progressed toward the hard section of the impregnated OPT. Furthermore, the weight percent loss was due to the starch in the parenchyma tissue. The parenchyma tissue has a function of food storage in OPT, so termites primarily attack the parenchyma of the OPT.

Table 3. The Termite Mortality, Feeding Rate, Weight Percent Loss, and Resistance Class for Each Part of the Impregnated IOPT

Part of IOPT	Treatment	Termite Mortality (%)	Feeding Rate (µg/termite/day)	Weight Percent Loss (%)	Resistance Class
Top	Untreated/0%	8.60 (1.52)	70.26 (11.28)	29.82 (4.73)	V
	10%	12.30 (4.37)	65.23 (14.47)	26.66 (6.93)	V
	20%	11.00 (2.42)	63.24 (8.56)	24.59 (2.22)	V
Bottom	Untreated/0%	11.90 (7.69)	64.47 (12.2)	25.22 (1.38)	V
	10%	15.40 (5.33)	60.16 (6.49)	16.51 (3.92)	IV
	20%	17.90 (8.01)	46.22 (5.96)	12.60 (3.14)	III
Note: the values in parentheses are the standard deviations					

Table 4. Variance Analysis of the Density, WPG, MC, Termite Mortality, Feeding Rate, and Weight Percent Loss

Response	Part of IOPT	Treatment
Density	**	**
WPG	*	**
MC	ns	**
Termite mortality	*	ns
Feeding rate	*	*
Weight percent loss	**	**
Note: ** highly significantly different ($p \leq 0.01$); * significantly different ($p \leq 0.05$); and ns is not significant		

Table 5. Duncan's Multiple Range Tests for the Density, WPG, MC, Termite Mortality, Feeding Rate, and Weight Percent Loss of the Impregnated IOPT

Parameter	Part of IOPT		Treatment		
	Top	Bottom	Untreated/0%	10%	20%
Density	0.49a	0.55b	0.44c	0.54d	0.58d
WPG	18.15a	11.96b	-	12.24c	17.86d
MC	8.46a	8.19b	8.79d	8.32d	7.29c
Termite mortality	10.63a	15.07b	10.25c	13.85c	14.45c
Feeding rate	66.24a	56.95b	67.37d	62.70cd	54.73c
Weight percent loss	27.02a	18.11b	27.05d	21.59c	18.60c
Note: values followed by the same letter in a row are not statistically different according to Duncan's multiple range tests					

The resistance of the IOPT against termites increased as the isocyanate concentration increased during the impregnation treatment. The untreated IOPT showed a weight loss of 27.5%, which indicated that the termites were active. The weight percent loss of the IOPT impregnated with 10% and 20% isocyanate was 21.6% and 18.6%, respectively. Duncan's test showed that the weight percent loss of the untreated IOPT was different from the weight percent loss of the impregnated IOPT. The IOPT impregnated with 20% isocyanate showed a lower weight loss than the IOPT impregnated with a 10% concentration. The weight percent loss trend was similar to the WPG value. Williams and Hale (1999, 2003) reported that a higher WPG of isocyanates results in a higher wood resistance to biological attack. Although the weight percent loss of the impregnated IOPT at the top part decreased, its resistance to subterranean termites was still categorized as very poorly resistant (resistance class V). However, the resistance to subterranean termites at the bottom part was improved from very poorly resistant (resistance class V) for the untreated IOPT to poorly resistant (resistance class IV) for the IOPT impregnated with 10% isocyanate and to moderately resistant (resistance class III) for the IOPT impregnated with 20% isocyanate.

CONCLUSIONS

1. The density, weight percentage gain (WPG), weight percent loss, termite mortality, and termite feeding rate, but not the moisture content (MC), were significantly affected by the inner part of the oil palm trunk (IOPT). The top part of the IOPT showed a higher WPG, termite feeding rate, and weight percent loss, while the bottom part showed a higher density and termite mortality.
2. Impregnation of the IOPT with isocyanate significantly changed some physical properties. The density and WPG increased as the isocyanate concentration increased, whereas the MC decreased as the isocyanate concentration increased.
3. The weight percent loss and feeding rate of the aqueous polymer-isocyanate-impregnated IOPT were significantly lower than the weight percent loss and feeding rate of the untreated samples, while the impregnation treatment showed no significant effect on the termite mortality.
4. Aqueous polymer-isocyanate impregnation at 10% and 20% concentrations improved the resistance class of the bottom part of the IOPT.
5. In conclusion, the impregnation of IOPT with aqueous polymer-isocyanate improved its physical properties, *i.e.*, density, MC, and WPG. Furthermore, the treatment significantly improved the resistance class of the bottom part of the IOPT against subterranean termites.

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