Chemical Characteristics of Teak Wood Attacked by *Neotermes tectonae*

Ganis Lukmandaru

The teak trees in certain areas of Java Island are frequently attacked by *Neotermes tectonae* termites. Trees attacked by this species have a tumor-like growth in the stem that can be easily identified in the field. This study evaluated the chemical properties of the attacked wood. Based on a visual inspection, the type of attacks were classified as either type I, if included phloem was formed in the heartwood, or type II, which was distinguished by the softened and hollowed areas in the heartwood. For each type, three trees were cut along with a healthy tree for comparison. Comparison among type I, type II, and normal tree tissues showed huge differences in hemicellulose and extractive contents, composition of ethanol-toluene soluble extracts, ash/acid insoluble ash contents, and pH values. Comparing the two types of abnormalities along the radial direction, significant differences were observed in the cellulose contents. The lowest values of both sugars were obtained in the soft part of type II. Further, the levels of ethanol-toluene soluble extracts and their fractions (mainly low-polarity fractions) were affected by the radial direction. No significant differences in radial direction were found in the inorganic materials levels or in pH values.

Keywords: Tectona grandis; Neotermes tectonae; Wood chemistry; Tumorous wood; Extractives; Cell wall

*Contact information: Department of Forest Product Technology, Faculty of Forestry, Gadjah Mada University, 55281, Jogjakarta, Indonesia; *Corresponding author: ganisarema@lycos.com*

INTRODUCTION

Teak is the undisputed hardwood timber leader of the world due to its unique combination of high durability and good appearance. The wood can resist termites and other insects; however, it has problems with the dry wood termite ‘inger-inger’ (*Neotermes tectonae* Damm.) in its sapwood. Trees attacked by this species have a tumor-like area in their stems that can be easily identified in the field. These attacks inhibit the tree’s growth and degrade wood quality. Under severe attacks, soft and hollow wood inside the tree forms and frequently causes die back. It is reported that these termites have spread through some 18,000 ha of teak forest in Java (Intari and Amir 1975).

The tumorous parts of the attacked wood are formed by a cambium reaction that produces wood with greater growth toward the bark due to the termites drilling the stem along the grain and plugging the flow of nutrients (Suharti and Intari 1974). The tumorous parts are also the nests of the termites, which are located 2 to 20 m above the ground. No study has been conducted so far, however, to examine the actual properties of this kind of wood. In other species, the chemical properties of tumorous wood for which the causes are unknown have been investigated (Rickey *et al.* 1974; Tsoumis *et al.* 1988; Gulsoy *et al.* 2005). Those results showed that some abnormal tree growths have different chemical properties compared to normal areas.

The present study was initiated from the point of view of utilizing abnormal wood. The objectives of this research were to observe the types of wood attacked by *Neotermes tectonae* as well as to compare the chemical properties of the abnormal tissues with the healthy parts. This work has practical importance because the attacks of these termites are a recurring event on teak plantations in Java.

EXPERIMENTAL

Materials

Attack types

After cutting cross-sections of the trees in the field, two types of abnormal tissues were apparent. The first type was distinguished by included phloem in the heartwood with surrounded by solid wood (Fig 1a). In type I attacks, the wood was still intact and no damage occurred from the bark toward the pith. The second type exhibited soft wood and hollowed areas in the heartwood region (Fig. 1b). Type II attacks did not have included phloem as in the first type.

Sample preparation

For each attack type, three trees from the Perhutani Plantation in Randublatung, Central Java Province, were felled. The tumorous parts of the trees were taken at heights between 3 to 7 m above the ground. Discs of 5 cm in thickness from the felled trees were cut. The sample characteristics are described in Table 1. Those parts were further divided into four sections (Fig. 1):

Each section from two opposing radii was converted into wood meal by drilling. It was then combined to form a single sample in order to minimize variations between radii. The meal samples were then ground to a size of 40 to 60 mesh for determination of chemical properties. For comparison, a healthy tree in the same living area was felled to obtain the samples of normal wood in the same manner.

(a) (b)

Fig. 1. Schematic of wood sampling in *Neotermes tectonae* attacked teak trees: a) type I, and b) type II. Sapwood (SW): (*ca*. 0.5 cm from the bark), adjacent normal outer heartwood (ANOH): *ca*. 0.5 cm from the heartwood-sapwood boundary, included phloem (IP/ type I) or soft and hollowed area (SF/ type II): *ca*. 0.5 cm from the outer heartwood, adjacent normal inner heartwood (ANIH): *ca.* 0.5 cm from the IP or SF region

Table 1. Description of the Wood Sampling

Tree number	Disc Diameter (cm)	Tree-ring number	Sapwood thickness (cm)	Bark thickness (cm)	Heartwood proportion (%)
1	25.0	29	1.9	0.6	77.4
2	35.7	31	2.5	0.8	73.4
3	22.2	22	1.9	0.9	74.5
4	21.9	24	1.1	0.7	91.0
5	27.4	23	1.1	0.8	92.1
6	23.2	22	1.4	1.1	88.2
Normal	39.0	35	2.0	0.5	80.5

Note: Trees 1 through 3 had type I attacks by *Neotermes tectonae,* while trees 4 through 6 had type II attacks

Methods

Chemical properties

Lignin content, ash content, solubility values in 1% NaOH, hot water, ethanol 95%, and alcohol-toluene were determined according to ASTM standard methods (2002). The extractions by alcohol-toluene, ethanol 95%, and hot water were conducted in succession. Cellulose and holocellulose content were determined according to Wise's chlorite method (Browning 1967), while acid insoluble ash content was according to TAPPI T 244 om-88 (1988). Hemicellulose contents were calculated by subtracting holocellulose from the cellulose contents. The pH value was determined by stirring the wood meal sample at room temperature for 48 h, and then the filtrate was measured.

Fractionation of alcohol-toluene extracts was conducted by ether, butanol, and ethanol in a sequence. Each extract was dissolved with respective solvents under heating for 30 min and then was filtrated. Those extractions produced four fractions *i.e.* ether, butanol, and ethanol soluble fractions as well as the residues.

Statistical analysis

The effects of the radial position in abnormal wood were calculated by one-way analysis of variance (ANOVA) GLM procedures. The effects were taken into account only when significant at the 95% level using Type III Sums of Squares. A Duncan test for multiple comparisons was used to show which group means differed.

RESULTS AND DISCUSSION

Cell Wall Components

Termites consume the cellulose in the cell wall of wood. Li *et al*. (2012), who compared the differences between chemical composition in untreated sapwood of *Pinus massoniana* and excreted faecal materials of *Coptotermes formosanus* termite, found that termites are able to digest cellulose selectively with small magnitudes of lignin degradation. However, in this case, it is uncertain whether there were secondary attacks by other micro-organisms at the same time. The contents of cell wall components are shown in Table 2. In the heartwood region, the two types of abnormalities had higher hemicellulose contents compared to the healthy ones. Further, type I tended to show a higher level of holocellulose content in the heartwood.

The ANOVA indicated that there was a highly significant radial position effect in holocellulose (p=0.01) and cellulose content (p<0.01). Significant differences were found between the soft parts and sapwood in the holocellulose and the cellulose contents of type II. No significant differences were measured in hemicellulose and lignin levels in both types. Significant differences were found between the soft parts and sapwood in the holocellulose and cellulose contents of type II. Significant differences between type I and II were observed in the soft part of the type II wood, which differed from all the parts in type I. This indicates that the termites attacked more intensively in the soft part as it contained lower levels of polysaccharides. The soft parts seemed to have been initially attacked when they were sapwood, and years later the attacked area turned into heartwood. The comparatively high levels of holocellulose in the sapwood were interpreted as the termites having not reached that part. No significant differences were observed in all parameters in type I, which suggested less intensive attacks compared to those of type II; it is unknown whether type I was the initial stage of type II.

Table 2. Analyses of the Cell Wall Components in the Teak Wood of *Neotermes tectonae* Attacked Trees

Wood	Radial part	Holocellulose (%)	Cellulose (%)	Hemicellulose (%)	Lignin (%)
Type I	SW	77.30 (0.69)c	47.20 (1.00) bc	30.10(0.81)	33.42 (0.67)
	ANOH	76.27 (1.79)bc	46.54 (1.30) bc	29.73(3.04)	32.55 (1.96)
	IP	76.53 (1.34)bc	45.81 (1.17) bc	30.72(0.74)	32.26 (1.22)
	ANIH	77.28 (0.95)c	49.23 (1.83) c	28.05(1.14)	31.72 (1.07)
Type II	SW	76.49 (1.93)bc	45.58 (0.36) bc	30.91(1.92)	32.72 (0.33)
	ANOH	72.64(3.18)abc	44.19 (0.45) ab	28.45(2.78)	32.45(1.49)
	SF	70.92(4.65)a	40.68 (3.33) a	30.24(1.44)	30.67 (0.41)
	ANIH	71.90 (2.42)ab	44.18 (3.40) ab	27.72 (3.20)	32.25(0.58)
Normal	SW	78.95	49.28	29.67	30.33
	OH	69.70	46.74	22.96	30.71
	MH	71.88	44.84	27.04	31.02
	IH	72.24	47.01	25.23	30.85

Note: Mean values (n=3), standard deviation in parentheses, percentages expressed on extractive-free weight bases. For a given test, values followed by the same letter do not differ significantly (5% level) by the Duncan test.
SW: sapwood, ANOH: adjacent normal outer heartwood, IP: included phloem, SF: soft and hollow part; ANIH: adjacent normal inner heartwood, OH: outer heartwood, MH: middle heartwood, IH: inner heartwood

Extractive Contents

Results of extractive content determinations are presented in Table 3. By successive extraction, both attack types tended to show higher levels of ethanol-toluene (ETSEC) and hot-water (HWSEC) soluble contents in their respective parts than did normal wood. Similar trends were also found in solubility in 1% NaOH. Those data show that the termite attacks caused more extractive formation due to self-defense mechanisms or there were higher degradation levels in sugar polymers of the cell wall.

By ANOVA, significant differences were observed only in ETSEC levels (p<0.01). In type I, considerable ETSEC levels were measured in the ANOH and IP areas. An explanation is that the phloem generally had higher values compared to the wood so that it contributed to such high ETSEC levels. The measurements of extractive content levels among the radial parts of type II attacked wood were not significantly different. Insignificancy between the soft part (type II) and other parts in terms of solubility in 1% NaOH was not expected since statistical differences were found in the amounts of cell wall components (Table 2). It might be that the solubility in 1% NaOH not only indicated the amounts of dissolved low molecular sugars but also the amounts of non-sugar extractives dissolved in hot water. That mix of both dissolved components would lead to inaccuracies in the data.

Table 3. Analyses of the Extractive Contents in the Teak Wood of *Neotermes tectonae* Attacked Trees

Wood	Radial part	ETSEC (%)	ESEC (%)	HWSEC (%)	NaOH 1 %(%)
Type I	SW	4.87 (0.10) a	0.93(0.15)	2.29 (0.71)	25.81 (2.36)
	ANOH	10.29 (2.81) b	0.66(0.09)	1.81 (0.71)	26.57 (2.18)
	IP	13.27 (3.67) c	1.08 (0.29)	2.06 (0.40)	29.47 (2.55)
	ANIH	5.58 (0.72) a	0.67(0.08)	0.97 (0.54)	21.90 (0.82)
Type II	SW	5.11 (0.82) a	1.08 (0.18)	2.14 (0.63)	25.96 (3.52)
	ANOH	7.82 (1.49) ab	0.70 (0.33)	1.80 (0.43)	27.47 (4.63)
	SF	7.07 (3.61) ab	0.79(0.23)	2.60 (1.51)	26.45 (6.77)
	ANIH	7.32 (3.02) ab	1.03 (0.73)	2.58 (1.05)	26.64 (0.36)
Normal	SW	2.67	1.39	1.40	20.18
	OH	4.50	0.49	1.35	20.58
	MH	5.75	0.67	1.08	21.77
	IH	3.68	0.67	0.89	21.59

Note: see Table 2;
Mean values (n=3), standard deviation in parentheses, percentages expressed on dry-wood weight bases.
ETSEC: ethanol-toluene soluble extractive content, ESEC: ethanol 95% soluble extractive content, HWSEC: hot-water soluble extractive content, 1% NaOH: solubility in 1% NaOH.

To find out the differences in extractive composition in the ethanol-toluene extracts, successive fractionation was conducted. On the basis of extract weight, the fractionation results are displayed in Table 4 and Fig. 2.

Table 4. Analyses of the Composition of Ethanol-Toluene Soluble Extractives in the Teak Wood of *Neotermes tectonae* Attacked Trees

Wood	Radial part	ETSF (%)	BTSF (%)	ELSF (%)	RESF (%)
Type I	SW	11.20 (5.87) a	80.51 (6.81) d	1.93 (1.27)	6.34 (2.21)
	ANOH	47.45 (15.84)cd	44.36 (16.09) ab	2.37 (1.75)	5.79 (2.25)
	IP	66.01 (3.67) d	29.83 (3.68) a	0.62 (0.82)	3.52 (1.49)
	ANIH	22.21 (15.26) ab	63.59 (6.82) c	7.39 (7.79)	6.78 (3.08)
Type II	SW	30.65 (5.94) abc	41.94 (2.81)b	6.31 (7.28)	21.06 (12.85)
	ANOH	32.96 (9.05) abc	53.36 (6.80)abc	2.13 (0.38)	11.52 (3.23)
	SF	29.59 (17.55) abc	42.97 (6.52) ab	5.88 (7.71)	21.52 (11.16)
	ANIH	38.43 (10.15) bc	38.56 (12.11) ab	2.09 (1.58)	20.88 (18.64)
Normal	SW	26.76	62.12	0.50	10.60
	OH	23.35	70.35	0.36	5.38
	MH	40.41	56.04	0.41	3.12
	IH	35.50	59.78	0.89	4.34

Note: see Table 2
Mean values (n=3), standard deviation in parentheses, percentages expressed on extract weight bases.
ETSF: ether soluble fractions, BTSF: butanol soluble fractions, ELSF: ether soluble fractions, RESF: residual fractions

Non-polarity or medium-polarity fractions (ether and butanol solubles) composed the greater parts of both abnormal and normal wood. Striking differences were found between the ether soluble fractions (ETSF) of type I attacked wood and normal wood as well as in the ethanol soluble (ELSF) and residual (RESF) fractions between type II attacked wood and normal wood.

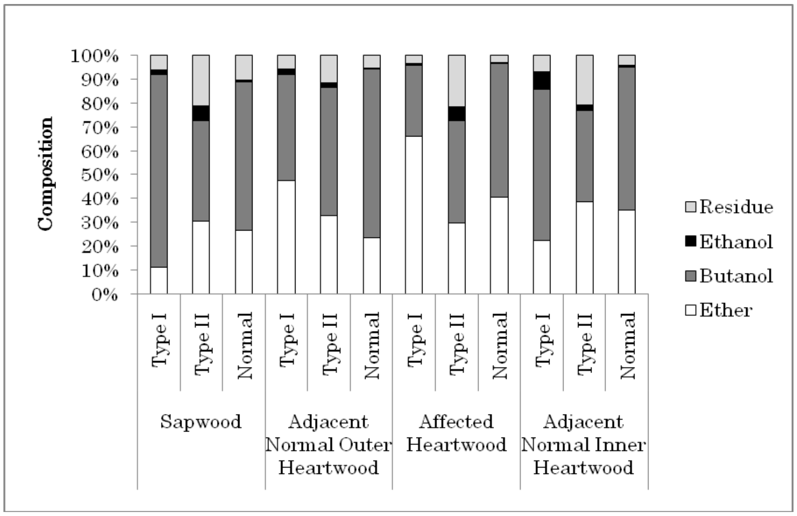

Fig. 2. Composition of ethanol-toluene soluble extracts in the teak wood of *Neotermes tectonae* attacked trees. The successive extraction was conducted by different solvents (ether, butanol, and ethanol). Mean values (n=3), percentages expressed on extract weight bases.

Natural durability is undoubtedly derived from the wood's extractives. Quinones and their derivatives have been reported to act against termite and fungal attacks (Rudman and Gay 1961; Sandermann and Simatupang 1966; Haupt *et al*. 2003; Sumthong *et al.* 2006; Thulasidas and Bhat 2007). Windeisen *et al.* (2003) detected some terpenes and toxic quinones in teakwood by petroleum ether and acetone in successive extractions. Furthermore, some sugars were detected by methanol. In this experiment, the low-polar fractions (ETSF and BTSF) were assumed to dissolve some toxic quinones and other low-molecular weight phenolics, as high polar fractions (ELSF and RESF) dissolved some non-active high molecular weight phenolics and sugars. In normal wood, BTSF levels were higher than those of abnormal parts, particularly in the heartwood. In addition, ELSF and RESF levels in the type II attacked wood were higher compared to the normal wood. Those trends suggest that differences in toxic quinone compounds could cause the termite attacks. With regard to healthy teak trees, however, Lukmandaru and Takahashi (2009) measured only modest correlations between the natural termite resistance parameters and the content of tectoquinone and isodesoxylapachol in the wood. In future studies, investigations of extractive components by spectroscopic instruments will be helpful in determining resistant and susceptible trees.

ANOVA showed the statistical differences by radial direction in the levels of ETSF ($p<0.01$) and BTSF ($p<0.01$). Those data indicated that the attacks affected the low-polar components more, especially in type I attacks. It could be seen that the high levels of ETSF were found in included phloem as well as low levels of BTSF in the sapwood region. Those tendencies were not found in type II or healthy trees. It was noticed that high levels of ETSF in the ANOH and IP (type I) also confirmed the more intensive formation of low-polarity extractive components. Furthermore, the reverse pattern was observed in the BTSF levels in the sapwood which were high in type I and low in type II attacks. No hypothesis, unfortunately, could be proposed to explain such patterns, as limited information is available on sapwood extractive components in teak, particularly the non-quinone components.

Ash Contents and pH Values

The determinations of pH values, ash, and acid insoluble ash contents are shown in Table 5. In contrast to the normal trees, ash content levels in the outer heartwood were higher than those of the sapwood region in the abnormal types. Generally, both types had higher values in the heartwood compared to the values of the normal tree. This trend was interpreted as more nutrients being needed for the formation of heartwood in the attacked wood. Acid insoluble ash contents, which indicate the amounts of silica and silicates, go hand in hand with the trend in ash contents. By ANOVA, however, no significant differences were observed in both types in the radial direction.

In general, the pH values in both types were higher (values: 6.16 to 7.56) than those of the normal wood (values: 5.4 to 5.8). The abnormal tissues showed pH values in the neutral or basic range, in which the type I were more acidic compared to type II. By ANOVA of both types, significant differences (p<0.01) were measured among the radial directions. The included phloem and sapwood regions of type I were the most acidic. Those values are explained to some extent by the high levels of ash contents in the respective parts. Theoretically, inorganic materials of wood are composed mostly (*ca*. 80 %) of calcium, potassium, and magnesium. The slightly higher pH values in the radial section was also observed in black streaked areas of teak wood (Lukmandaru *et al.* 2009)

Table 5. Analyses of the pH Value, Ash, and Acid-Insoluble Ash Contents in the Teak Wood of *Neotermes tectonae* Attacked Trees

Wood	Radial part	Ash content (%)	Acid insoluble ash content (%)	pH value
Type I	SW	1.03 (0.11)	0.42 (0.05)	6.31 (0.39)ab
	ANOH	2.46 (0.83)	1.24 (0.37)	6.98 (0.70) bcd
	IP	2.26 (0.67)	1.05 (0.71)	6.16 (0.21) a
	ANIH	1.33 (0.36)	0.41 (0.23)	6.54 (0.27) abc
Type II	SW	1.45 (0.92)	0.89 (0.60)	7.13 (0.25) cd
	ANOH	3.35 (2.51)	1.60 (1.05)	7.03 (0,12) cd
	SF	1.77 (0.92)	0.78 (0.51)	7.56 (0.35) d
	ANIH	2.80 (1.89)	1.30 (0.82)	7.26 (0.43) cd
Normal	SW	1.50	0.67	5.60
	OH	0.78	0.28	5.85
	MH	1.24	0.70	5.43
	IH	0.72	0.17	5.87

Note: see Table 2. Mean values (n=3), standard deviation in parentheses, percentages expressed on dry-wood weight bases.

Chemical Properties of Tumorous/Insect Attacked Wood

The between-tree comparison of normal and abnormal wood in this experiment showed similiar tendencies (in hemicellulose, ethanol-toluene, hot-water solubles, and solubility in NaOH 1% rates) as a previous report of tumorous wood in *Quercus robur* (Gulsoy *et al.* 2005) and *Erica arborea* in extractive and ash contents (Tsoumis *et al.* 1988). Rickey *et al.* (1974), working with *Picea sitchensis*, also noted that hemicellulose content in tumorous wood was higher than in normal wood but that other parameters were even. The increase in solubility in 1% NaOH was also reported in *Abies balsamea* wood attacked by *Choristoneura* insects (Koran and Nlombi 1984), *Quercus* spp. wood attacked by the *Lymantria dispar* moth (Labosky *et al*. 1990), and in *Pinus taeda* wood attacked by the *Dendroctonus frontalis* beetle (Shamoun and Levi 1985). With regard to cell wall components, the lignin and holocellulose amounts of the attacked trees and the normal wood in this experiment differed with the findings of Shamoun and Levi (1985) as well as Labosky *et al*. (1990). Thus, it is suggested that various insects cause some specific characteristics in chemical properties.

CONCLUSIONS

1. The tumorous parts could be divided into two types of attack. Type I was distinguished by the included phloem formed in the heartwood, and type II was distinguished by the soft and hollow parts in the heartwood.
2. In the between-tree variations, the comparison of those types and normal tissues showed huge differences in hemicellulose contents, extractive contents, composition of ethanol-toluene soluble extracts, ash contents/acid insoluble ash contents, and pH values.
3. In the radial direction of the two type abnormalities, significant differences were observed in the cellulose contents which the low values were measured in the soft part of type II attacked wood. Further, the levels of ethanol-toluene soluble extracts and its fractions (mainly low-polar fractions) were affected by the radial direction.
4. No significant differences in radial direction between the two types were found in the inorganic materials levels nor in pH values.

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