Quinones Distribution of Teak Wood Grown in Community Forest

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Abstract

Quinones and their derivatives are the main causes on the natural termite resistance in teak wood. By using different termite test methods, the previous paper in this series reported on the termite resistance of teak trees of juvenile ages (8- and 22-year old trees). In this study, the radial distribution of quinones (tectoquinone, lapachol, desoxylapachol and its isomer) and squalene in the different extracting solvents (*n*-hexane, ethyl acetate, and methanol) were analyzed by means of gas chromatography. Appreciable tree to tree variations were observed in extractive component contents even in the same stand. Each solvent gave different tendencies in analysis of variance of component contents. Significant differences in desoxylapachol or its isomer, and squalene content were found among the outer heartwood of 8- and 22-year old trees, as well as between the inner and outer parts of the heartwood. The highest correlation degree between extractive content and its components was measured in the tectoquinone content (*r*=-0.68). By using paper disc method, only modest correlations were observed between the mass loss and the content of isodesoxylapachol (*r*=-0.60) in the sapwood region whereas no significant corellations were measured in the heartwood region.

Keywords: *Tectona grandis,* antitermitic activities, extractive, tectoquinone, *Reticultermes speratus.*

Abstrak

Senyawa-senyawa kinon beserta turunannya adalah penyebab utama dari sifat ketahanan alami terhadap rayap di kayu jati. Hasil pengujian ketahanan terhadap rayap melalui metode uji yang berbeda pada kayu jati dari pohon muda (8 dan 22 tahun) telah dipublikasikan di makalah sebelumnya. Dalam penelitian ini, sebaran radial dari beberapa senyawa kinon (tektokinon, lapakol, desoksilapaol dan isomernya) serta skualen melalui ekstraksi dengan pelarut yang berbeda (*n*-heksana, etil asetat, dan metanol) dianalisis dengan alat gas kromatorafi. Variasi yang lebar kadar komponen ekstraktif antar pohon diamati bahkan dalam tegakan yang sama. Tiap pelarut memberikan kecenderungan yang berbeda dalam analisis variansi pada kadar komponennya. Perbedaan nyata diamati pada kadar skualen, desoksilapakaol dan isomernya untuk bagian teras luar antara pohon umur 8 dan 22 tahun demikian juga di antara bagian teras luar dan dalam. Derajat korelasi tertinggi antara kadar ekstraktif dan kadar komponennya dihitung di kadar tektokinon (*r*=-0.68). Melalui metode piringan kertas, hanya korelasi moderat yang diamati antara kehilangan berat dan kadar isodesoksilapakol (*r*=-0.60) di daerah kayu gubal dimana tidak ada korelasi nyata yang diukur di bagian teras.

Kata kunci: aktivitas anti-rayap, ekstraktif, *Reticultermes speratus, Tectona grandis,* tektokinon

Introduction

Teak (*Tectona grandis L. f.*) is a fancy hardwood prized for its workability and high natural durability. Teak grows naturally throughout southeastern Asia and widely planted in all tropical regions. In Indonesia, large teak community forests have been established and managed for fast-growth with trees harvested in a rotation period of less than 30 years. The wood from these trees is usually consists larger proportion of sapwood and juvenile wood. This condition causes in a reduced market value, although the technical data with regard to wood quality of young stage trees is still limited. Unfortunately, most studies focused on heartwood with little consideration given to sapwood, although several studies of fast-grown teak trees have shown that a high sapwood fraction is present. One report by Bhat and Florence (2003) demonstrated the lower durability of juvenile teak wood against fungi.

In teak, natural durability is ascribed to the presence of toxic extractives mainly quinones (Haupt *et al.* 2003, Rudman & Gay 1961, Sandermann & Simatupang 1966). Difference in natural durability may be related to the concentrations of toxic extractives. Further, Niamke *et al.* (2011) attempted to correlate the nonstructural carbohydrates and toxic phenolics to natural durability. In a preliminary result (Lukmandaru 2013), samples of young teak wood trees (8- and 22-year old trees) were compared to mature wood (51-year old trees) for antitermitic activities evaluation. That experiment exhibited the wide variation in antitermitic properties on the basis of tree age and radial direction. Further, the results also demonstrated the differences between wood block (natural condition) and wood extracts (paper disc/in vitro) method in termite tests.

In this report, the radial distribution of quinones of teak was investigated on the corresponding samples of those trees to estimate the effect of extractives on the relative antitermitic activities of the wood. Squalene, a triterpene, was also analysed in this experiment as this compound was the most abundant substance in the teak extracts (Lukmandaru & Takahashi 2009, Weindeisen *et al*. 2003). This research used three different solvents on the basis of their polarities for extracting the wood by cold extraction. The purposes of this study also included to relate the amount of the major compounds to the extractive content, as well, as to relate the amount of the active compounds to previous data on antitermitic properties (paper disc method).

Materials and Methods

Preparation of samples

Nine Javanese teak trees were collected previously (Lukmandaru 2013) for this study. The samples of the 8-year group (trees 1 to 5) and 22-year old group (trees 6 to 9) were felled from farm forest (Jogjakarta Province). A 5 cm thick disc was removed at approximately breast height from the trees which were free of signs of incipient decay and colour variations. Each disc was divided into five parts: outer sapwood (OS), inner sapwood (IS), outer heartwood (OH), and inner heartwood (IH). With the limited amount of suitable material available, the IH zone in the 8-year old discs was excluded. Sections from two opposite radii were converted into wood meal by drilling and were then combined to form a single sample in order to minimize variation between radii, if any.

The wood meal samples were then ground to 20-40 mesh size for chemical analyses and determination of the content of the extractives.

Gas chromatography analysis

Wood meal samples (one gram oven dry weight) were extracted at room temperature with 10 ml *n*-hexane (C_6H_6) and retained for one week. The extracts of *n*-hexane (C_6H_6), EtOAc, and MeOH (concentration of 100 mg ml^{-1}) were analyzed using a Hitachi G-3500 GC equipped with FID and NB-1 capillary 30 m column. Operation temperature was 120-300 ºC with a heating rate of 4 ºC min^{-1} and held at 300 ºC for 15 min. Injector and detector temperatures were set at 250 ºC. Helium was used as the carrier gas, the split ratio was 80:1, and the injected volume was 1.0 µl. For quantification of individual substances, calibrations were made using known amounts of standard tectoquinone (2-methyl antahraquinone). The amounts of components were expressed as mg per 100 g of oven dry weight. Pure sample of squalene and lapachol purchased from Kanto Chem were also used for confirmation. Chemical analyses of ethyl acetate (EtOAc) and methanol (MeOH) extracts were obtained separately in the same manner as described for the C_6H_6 extract.

The identification of constituent compounds was based on their mass spectra and gas chromatographic retention behavior. GC-MS analysis was performed on a Shimadzu QP-5000 with operation conditions being similar to GC analysis. The MS operating parameters were temperature ionization voltage of 70 eV, transfer line temperature at 250 ºC, and scan range of 50-500 atomic mass unit. Desoxylapachol or its isomer was identified by comparison of their mass spectra with those from previous studies by Windeisen *et al.* (2003) and Perry *et al.* (1991). From the contents of tectoquinone, lapachol, desoxylapachol and its isomer, the total quinone content (TQC) was calculated.

Extractives content determination

The remainder of the extract taken for extractive analyses was filtered and the residue was washed three times with 10 ml of solvent. The extract was concentrated in a rotary film evaporator, dried and weighed to determine the extractives content. The extractives content has been calculated as a percentage (w/w) of moisture-free wood meal in the previous report (Lukmandaru 2013).

Termite resistance test

The termite resistance data were taken from the previous report (Lukmandaru 2013). A petri dish containing 20 g moistened and sterilized sea sand was used as a container test. Paper discs were impregnated with chloroform solution containing each extract of the test fractions. The treatment retention was 5 % (w/w) per disc. The control discs were impregnated with chloroform only and dried with the same manner. Fifty worker *Reticulitermes speratus* Kolbe termites were introduced into the petri dish. The petri dishes were placed in a dark chamber at 27 ºC and 80% relative humidity. After 10 days the disc were taken out, dried and the weight loss was determined. This procedure was replicated three times for each sample for each sample for a total of 93 observations. Dead termites were counted in the first day and at the end of observation. The mass loss since the start of the experiment was determined.

Statistical analysis

The variation in the extractive component contents was analyzed using general linear models procedure by two-way (tree age and radial direction factors) analysis of variance (ANOVA) followed by Duncan's multiple range test (p = 0.05). The relationships between the dependent variables were observed with a Pearson's correlation analysis. All statistical calculations were conducted using SPSS-Win 10.0.

Results and Discussion

Distribution of extractives as related to natural durability

The gas chromatogram of heartwood EtOAc extract is shown in Figure 1. The major compounds detected in those chromatograms were lapachol, tectoquinone, desoxylapachol and its isomer (isodesoxylapachol), and squalene. All these compounds have been reported as teak components (Lukmandaru & Takahashi 2009, Niamke *et al.* 2011, Sandermann & Simatupang 1966, Windeisen *et al.* 2003).

The quantification of three soluble extracts was presented in Table 1-3. As expected, the extractive content of all of the tree age groups followed a general pattern of increasing from pith (IH) to the OH, then decreasing towards the OS. The highest amount levels of squalene, desoxylapachol and its isomer were measured in C_6H_6 extracts whereas tectoquinone content was determined in MeOH extracts. It was noted also that lapachol was not detected in C_6H_6 extracts but it was detected in other extracts although in trace amounts. In the sapwood region, particularly, the comparatively higher total quinone content levels were found in MeOH extracts. The current results also showed wide variation by examining standard deviations, even in trees from the same sites. This means that teak may not always have a high amount of certain compounds.

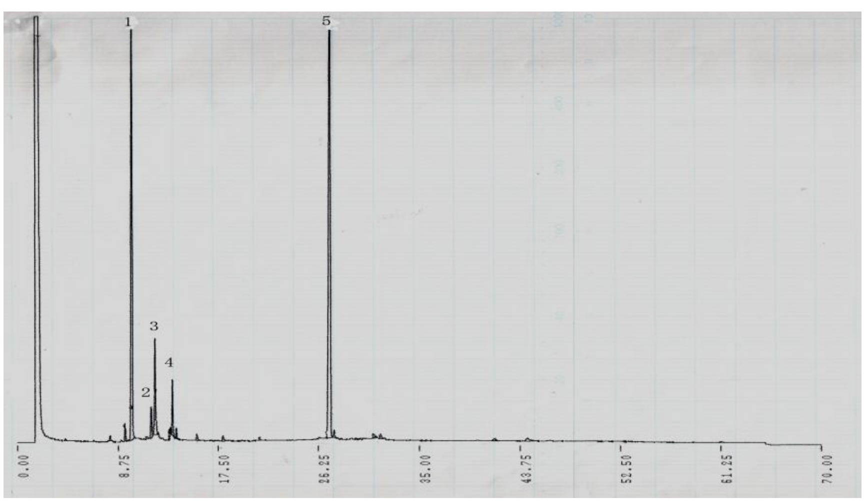

Figure 1 Gas chromatogram of teak from ethyl acetate extract of heartwood. Five major compounds are indicated : peak 1 (R_t 10.1) & 3 (R_t 12.1) = desoxylapachol and its isomer; peak 2 (R_t 11.8) = lapachol; peak 4 (R_t 13.7) = tectoquinone; and peak 5 (R_t 27.4) = squalene.

Table 1 Contents of major components (mg per 100 g of oven-dry wood) in the *n*-hexane soluble extracts of teakwood trees aged 8 and 22 (radial position)

Components	Radial position						
	Outer sapwood		Inner sapwood		Outer heartwood		Inner heartwood
	8 y	22 y	8 y	22 y	8 y	22 y	22 y
Desoxylapachol	0 (0)a	10.25 (10.55)b	5.65 (10.63)b	5.37 (6.18)b	9.46 (6.70)b	205.02 (144.70)c	65.85 (83.43)b
Lapachol	0 (0)	0 (0)	0 (0)	0 (0)	8.16 (20.00)	10.37 (12.95)	3.47 (4.14)
Isodesoxylapachol	3.50 (4.56)	0.35 (0.70)	3.66 (2.97)	2.90 (3.10)	11.05 (7.03)	331.15 (539.30)	18.95 (29.97)
Tectoquinone	0 (0)	3.90 (2.61)	2.78 (4.72)	4.15 (3.59)	42.06 (65.05)	19.37 (6.94)	26.87 (19.40)
Squalene	5.51 (4.84)d	22.40 (13.11)e	16.23 (7.21)e	100.45 (47.95)f	110.25 (89.08)f	473.78 (346.94)g	454.72 (453.15)g
Total quinone content	3.50 (4.56)h	14.50 (12.24)h	12.10 (14.25)h	12.42 (5.16)h	70.75 (92.52)i	565.92 (649.97)j	115.15 (130.41)i

Table 2 Contents of major components (mg per100 g of oven-dry wood) in the ethyl acetate soluble extracts of teakwood trees aged 8 and 22 (radial position)

Components	Radial position						
	Outer sapwood		Inner sapwood		Outer heartwood		Inner heartwood
	8 y	22 y	8 y	22 y	8 y	22 y	22 y
Desoxylapachol	0 (0)a	0.30 (0.21)b	0.02 (0.04)b	1.00 (0.91)c	1.10 (1.70)c	70.70 (55.70)d	11.10 (12.19)c
Lapachol	0.10 (0.13)	trace	0.70 (0.84)	0.60 (0.39)	3.80 (4.54)	29.60 (51.30)	8.00 (12.85)
Isodesoxylapachol	0.30 (0.28)e	0.40 (0.78)e	0.50 (0.75)e	1.30 (1.62)e	4.60 (3.41)f	77.8 (76.50)g	13.60 (10.82)f
Tectoquinone	0.10 (0.17)h	0.90 (1.16)h	1.20 (2.77)h	3.10 (5.14)h	20.20 (20.63)i	44.8 (43.75)i	20.70 (24.40)i
Squalene	0.60 (0.56)j	1.30 (1.15)j	2.00 (3.09)j	10.90 (8.80)j	14.90 (26.14)j	75.80 (29.12)k	36.20 (24.73)k
Total quinone content	0.50 (0.19)l	1.60 (2.07)l	1.70 (4.08)l	2.50 (5.00)l	30.00 (26.83)m	490.00 (646.89)n	50.00 (57.15)m

Table 3 Contents of major components (mg per 100 g of oven-dry wood) in the methanol soluble extracts of teakwood trees aged 8 and 22 (radial position)

Components	Radial position						
	Outer sapwood		Inner sapwood		Outer heartwood		Inner heartwood
	8 y	22 y	8 y	22 y	8 y	22 y	22 y
Desoxylapachol	18.5 (31.05)	7.00 (4.00)	39.20 (74.11)	21.60 (39.41)	2.00 (2.43)	49.90 (98.16)	38.60 (39.27)
Lapachol	0.69 (0. 96)	5.00 (4.81)	1.10 (1.44)	3.80 (6.42)	2.50 (3.64)	41.10 (75.63)	5.40 (7.08)
Isodesoxylapachol	2.80 (2.67)	1.90 (3.21)	3.90 (2.45)	2.80 (3.82)	4.30 (4.04)	25.10 (36.17)	18.60 (20.48)
Tectoquinone	13.10 (20.62)a	10.90 (17.97)a	7.70 (14.79)a	14.20 (15.10)a	17.80 (10.82)a	101.60 (60.69)b	53.80 (17.92)b
Squalene	2.10 (2.75)c	7.30 (3.64)c	5.60 (4.19)c	26.90 (20.65)dc	22.00 (21.95)dc	143.80 (45.23)d	97.20 (44.52)d
Total quinone content	33.30 (37.77)e	25.00 (23.80)e	50.00 (76.42)e	42.50 (59.09)e	25.00 (17.61)e	215.00 (165.43)f	112.50 (60.21)f

Note for Table 1-3 : Mean of 5 trees (8 years old) and 4 trees (22 years old), with the standard deviation in parentheses. The same letters in the same row are not significantly different at $p < 5\%$ by Duncan's test. tr = trace (detected, the value < 0.01 %).

Factorial analysis of variance (Table 4) revealed different results among the extracts. For example in desoxylapachol content, significant interactions were calculated in both C_6H_6 and EtOAc extract but not in MeOH extracts. Further, in the analysis of tectoquinone content, radial variation affected signicantly in EtOAc extract. A significant interaction was found in MeOH content while no significant effects of tree age and radial direction in C_6H_6 extracts. With regard to total quinone content, however, interactions were found in all extracts. Those differences reflect the specific capacity in each extract to dissolve the main components of teak. In this regard, the most effective solvent should be choosen by considering the most extracting solvent.

By ANOVA, in the C_6H_6 soluble extracts, the significant differences between IS and OS were measured in squalene contents while in the EtOAc and MeOH soluble extracts, no significant differences were found. In the C_6H_6 and EtOAc soluble extracts between the OH and IH, significant differences were found in desoxylapachol and its isomer as well as TQC contents. No significant differences were determined between IH and OH in any component contents in the MeOH soluble extracts. The tree age factor affected signicantly in desoxylapachol, isodesoxylapachol, squalene, and TQC contents in the heartwood region. Both in the C_6H_6 and EtOAc soluble extracts, the tree age factor affected signicantly desoxylapachol, isodesoxylapachol, squalene, and TQC contents in the heartwood region. In the sapwood region, the same tendency was found also in squalene content in the C_6H_6 extracts and desoxylapachol content in the EtOAc and MeOH extracts. In the MeOH extracts, it was noted that tree age factor affected significantly tectoquinone contents in the heartwood region.

Table 4 Factorial analysis of variance results (probability) for three different extracts (*n*-hexane, ethyl acetate, and methanol)

Components	Source of variation		
	Tree age	Radial direction	Tree age x radial direction
a) *n*-hexane extract			
Desoxylapachol	<0.01**	<0.01**	<0.01**
Lapachol	0.84	0.16	0.96
Isodesoxylapachol	0.12	0.12	0.09
Tectoquinone	0.59	0.09	0.54
Squalene	0.04*	<0.01**	0.13
Total quinone content	0.05	<0.01**	0.02*
b) Ethyl acetate extract			
Desoxylapachol	<0.01**	<0.01**	<0.01**
Lapachol	0.13	0.15	0.11
Isodesoxylapachol	0.01*	<0.01**	<0.01**
Tectoquinone	0.21	<0.01**	0.31
Squalene	<0.01**	<0.01**	<0.01**
Total quinone content	0.06	0.03*	0.04*
c) Methanol extract			
Desoxylapachol	0.74	0.84	0.31
Lapachol	0.12	0.26	0.23
Isodesoxylapachol	0.24	0.15	0.16
Tectoquinone	<0.01**	<0.01**	<0.01**
Squalene	<0.01**	<0.01**	<0.01**
Total quinone content	0.04*	0.05	<0.01**

** Significant at 1 % level, * significant at 5 % level

As expected, the interaction in the C_6H_6 and EtOAc extract showed that the highest desoxylapachol and TQC levels were found in the outer heartwood of 22 -year old trees while no significant differences were found between the IH of 22- and OH of 8-year old trees. Different tendencies between C_6H_6 and EtOAc extracts were seen in squalene and isodesoxylachol amounts. In the sapwood region, it was noted that IS of 22-year old trees gave the highest amounts in squalene content in C_6H_6 and MeOH extracts as well as desoxylapachol content in EtOAc extracts. In the MeOH extracts, with regard to tectoquinone content, significant differences were counted merely between sapwood and heartwood regions as the highest tectoquinone content were measured in the heartwood of 22-year old trees. Further, on the basis of interactions, it was also revealed that the highest TQC were found in the heartwood of 22-year-old trees.

The OH from 8- and IH from 22-year old trees were formed in approximately the same growing seasons (juvenile region, 4–6th ring). It was revealed the significant differences in the squalene (C_6H_6 and EtOAc soluble extracts), tectoquinone and TQC levels (MeOH soluble extracts). Sandermann and Dietrichs (1959) observed that the concentration of tectoquinone was highest in the center of heartwood. Although the highest tectoquinone level was measured in the OH region of 22-old trees, the ANOVA revealed that there was not a statistically significant difference with those in the IH.

Table 5 Pearson's correlation coefficients between extractive content and extractive component contents in three different solvents

Compound	Extractive content		
	n-hexane	Ethyl acetate	Methanol
Desoxylapachol	0.52**	0.67**	0.37*
Lapachol	0.48**	0.44 **	0.07
Isodesoxylapachol	0.41*	0.55**	0.41*
Tectoquinone	0.55**	0.68**	0.44**
Squalene	0.68**	0.79**	0.48**
Total quinone content	0.49**	0.54**	0.49**

** Significant at 1 % level, * significant at 5 % level

Previous communication (Lukmandaru 2013) exhibited the less antitermitic activity in the sapwood parts compared to heartwood in all extracts. Further, it was showed that the OH was more resistant compared to the IH in C_6H_6 and EtOAc soluble extracts. As would be expected, the sapwood values were significantly lower than heartwood for desoxylapachol, isodesoxylapachol, tectoquinone, squalene, and TQC contents. Levels of desoxylapachol, and TQC in the OH were significantly higher than in the IH of 22-year old groups. On the basis of radial direction and tree age, no statistical differences were observed with regard to termite mortality rates in the MeOH extracts. This is unexpected result as there was a significantly higher tectoquinone content in the heartwood of 22-year old tree samples.

It is thought that MeOH extracts more extractives than other solvents so that more compounds, especially non-quinones, affected the behaviour of mortality rates in the previous experiment.As lapachol, desoxylapachol, and tectoquinone have been reported to be active against termites (Lukmandaru 2012, Rudman & Gay 1961, Sandermann & Simatupang 1966), this finding confirms that teak from community forest trees begin producing toxic constituents at the young tree stage. The low amounts of toxic compounds in the sapwood and inner heartwood corresponds reasonably well with Da Costa *et al.* (1958), Lukmandaru and Takahashi (2008), and Rudman *et al.* (1967), who reported that the wood regions near pith and sapwood were much less resistant to termite attack than the outer heartwood by using wood blocks method. Rudman *et al.* (1958) concluded that, although tectoquinone exhibited strong antitermitic properties, this compound was not the sole cause of termite resistance. The considerable amounts of desoxylapachol and its isomer identified in this study suggests that these compounds, along with tectoquinone, play an important role in generating resistance to termites. Da Costa *et al.* (1958) reported that termite antifeedancy of the outer heartwood increases significantly with the age of the tree. That phenomenon may be related to differences in the amount of desoxylapachol and its isomers between the trees.

Relationship between extractive compounds and total extractive contents

The Pearson correlations between the extractive content and various extractive compounds are presented in Table 5. Correlations of a comparatively high degree were observed between the EtOAc extrative content and squalene (*r*=0.79) whereas the highest degree of quinone compounds were observed between EtOAc extractive content and tectoquinone content levels (*r*=0.68). This result suggests that squalene and some quinones were more dissolved in EtOAc so that it could describe its extractive content. The preliminary work (Lukmandaru 2013) revealed that extractive content moderately correlated with antitermitic properties. Thulasidas *et al.* (2007) demonstrated that the quinones present in teak wood even in minor amount is more significant than its extractive content level against some fungi. As this present results confirmed that no strong correlation was found between quinones and antitermitic propertes, it might partially explain the weak relation between extractive content and antifungal or antitermite properties.

Relationship between extractive compounds and antitermitic properties

Correlation analysis between termite resistance parameters and main compounds is shown in Table 6. The highest degree of correlations were determined between mass loss and squalene content in C_6H_6 extract (*r*=-0.62) or MeOH extract (*r*=-0.57) in the sapwood region. Further, in the EtOAc extracts, the correlations were measured between mass loss and desoxylapachol content (*r*=-0.60) as well as between mortality rates and isodesoxylapachol content (*r*=-0.58) in the sapwood region. Those correlations meant the wood is more resistant against the termites when the content of squalene or desoxylapachol was higher in the sapwood areas. A negative correlation between mortality rates and isodesoxylapachol seemed to be odd as it is interpreted the more isodesoxylapachol content, the less mortality rates of termites will be. The explanation might be the low quantity of isodesoxylapachol in the sapwood did not directly affect its toxicity but along with the non-structural carbohydrates, it affected the formation other toxic quinones in the sapwood (Haupt *et al.* 2003, Niamke *et al.* 2011).

As the corellations were observed merely in the sapwood region, it is assumed that the less complexity of extractive composition in that area would make it easier to predict its natural termite resistance properties than in the heartwood. Although the tritrepene squalene was never mentioned to be an active compound against termites, this finding suggests that this compound could be a hydrophobic barrier, particularly in the sapwood parts. It is generally known that subterranean termites requires more humidity to survive compared to dry-wood termites. Thus, it is necessary to explore the role of squalene in the future work. On the other hand, tectoquinone, as the principal component against termites (Sandermann and Simatupang 1966), did not show any significant correlations with antitermitic properties by this method.

Table 6 Pearson's correlation coefficients between antitermitic properties by paper discs method and extractive component contents in three different solvents

Components	Antitermitic properties					
	Mass loss			Mortality rate		
	Total	Sapwood	Heartwood	Total	Sapwood	Heartwood
a) *n*-hexane extract						
Desoxylapachol	-0,37*	-0.39	-0.19	-0.37*	-0.46	-0.18
Lapachol	-0.34	-	-0.32	-0.30	-	-0.16
Isodesoxylapachol	-0.21	0.31	-0.13	-0.20	0.20	-0.09
Tectoquinone	-0.41*	-0.45	-0.31	-0.40*	-0.34	-0.24
Squalene	-0.51*	-0.62**	-0.39	-0.43*	-0.33	-0.18
Total quinone content	-0.32	-0.36	-0.20	-0.31	-0.41	-0.15
b) Ethyl acetate extract						
Desoxylapachol	-0.33	-0.60**	-0.18	-0.28	-0.52*	-0.08
Lapachol	-0.19	-0.12	-0.13	-0.18	0.16	-0.07
Isodesoxylapachol	-0.34	-0.48*	-0.23	-0.35	-0.58**	-0.23
Tectoquinone	-0.49**	-0.38	-0.44	-0.57**	-0.36	-0.52
Squalene	-0.56**	-0.58*	-0.40	-0.47**	-0.45	-0.15
Total quinone content	-0.27	-0.22	-0.18	-0.26	-0.23	-0.14
c) Methanol extract						
Desoxylapachol	-0.08	-0.05	-0.13	-0.26	-0.10	-0.27
Lapachol	-0.13	-0.27	0.12	0.00	0.08	0.26
Isodesoxylapachol	-0.28	-0.07	-0.06	-0.32	-0. 03	-0.15
Tectoquinone	-0.37*	-0.14	0.04	-0.35	-0.26	0.04
Squalene	-0.55**	-0.57*	-0.20	-0.46*	-0.33	-0.09
Total quinone content	-0.30	-0.13	-0.02	-0.33	-0.01	-0.05

** Significant at 1 % level, * significant at 5 % level

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Previous investigation (Lukmandaru & Takahashi 2009) in the form of wood blocks resulted negatively moderate correlation between mass loss and tectoquinone (*r*=-0.49) or isodesoxylapachol (*r*=-0.47). Thus, it is still difficult to predict its termite resistance by choosing one parameter, particularly in the juvenile stages both in the natural condition form (wood blocks) and extracts form (in vitro). Multivariate regressions would be helpful to describe any possibilities of sinergistic or antagonistic relationship among the extractive components of teak wood. In other species, Taylor *et al.* (2006) found that variations in extractive components could not sufficiently explain the variation in fungal and termite resistance of *Thuja plicata* and *Chamaecyparis nootkanensis* wood. De Bell *et al.* (1997) found that the variations in tropolone contents, particularly in low levels, could not directly related to its antifungal properties of *Thuja plicata*.

Conclusions

Tree age and radial position affected the presence and amount of quinone components detected in teak extracts. In addition, the extracting solvents also influenced the results of which *n*-hexane gave the highest amount of some quinones. This study demonstrated that teak at the young tree stage begin producing toxic constituents such as tectoquinone, desoxylapachol and isodesoxylapachol even in the sapwood. Considerable variation was observed in the extractive component contents of wood samples taken from the same site. On the basis of significant interactions, the highest desoxylapachol and total quinone contents were found in the outer heartwood of 22-year old trees. In the sapwood region, the highest amounts in squalene and desoxylapachol were observed in the inner sapwood of 22-year old trees. The toxic quinone component contents were positively correlated with total extractive content, with the highest correlation degree being observed in the tectoquinone content. The amount desoxylapachol was moderately correlated with antifeedant properties in the sapwood. Variation in the individual active quinone contents as well as total quinone components, however, could not explain satisfactorily the variation in termite resistance.

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Riwayat naskah:

Naskah masuk (*received*): 29 April 2015
Diterima (*accepted*): 30 Juni 2015