Measurements of Inorganic Materials and Acidity in Plantation Teakwood

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Abstract

Information concerning ash materials and acidity (pH values) within the wood of teak (*Tectona grandis* L.f.) plantations is especially limited. Samples taken from the stands of Perhutani plantation (Madiun and Randublatung) and community forests in Kulon Progo (Temon and Kalibawang) were analyzed to determine the ash content, metallic elements constituting the ash fraction, as well as pH values. The ranges of ash content were 0.55-3.88% whereas acid insolube ash content (silica/silicates) were 0.12-2.45%. The main four inorganic elements in wood were assayed by atomic absorption. The levels of these metals ranged from 340-4774 ppm for calcium, 17-4399 ppm for potassium, 143-1676 ppm for magnesium, and 0-247 ppm for iron. Further, the pH values varied from 5.33-7.25. Differences of inorganic variables and pH values in wood were found between trees of different growth-site and radial position. The variation among the different sites was significant in the contents of silica, calcium, magnesium, potassium, and sodium while the effects of radial direction were significant in the silica and potassium levels. Ash content was positively correlated with acid insoluble ash (r = 0.77) and potassium content (r = 0.47). Furthermore, pH values were positively correlated with the magnesium content (r = 0.65) and negatively correlated with potassium (r = -0.49) and sodium contents (r = -0.55). A description of the chemical properties of the soil, however, was not sufficient in determining whether there was a relationship between the levels of metal elements or pH values in the wood and in the soil.

Keywords: *Tectona grandis* L.f., ash content, silica, inorganic element, pH value.

Introduction

Teak (*Tectona grandis* L.f.) is one of the most important timbers in Indonesia because of its favourable physical and mechanical properties, combined with its high natural durability, high weather resistance, and beautiful grain. Thus, the wood is suitable for multipurpose use, from outdoor constructions to small handicrafts. On the basis of trading volume, teak wood is the number one for hardwoods in the world. As a consequence of high demand, besides teak plantations managed by the state-owned company Perum Perhutani, an increase in the quantity of teak produced in community forests or farmland has occurred In Indonesia within the last two decades.

Recently, studies on teak timber mostly focus on the basic properties and natural durability of wood from fast-growing or younger trees e.g. Basri and Wahyudi (2013), Hidayati *et al.* (2014), Lukmandaru (2013), Marsoem (2013), Marsoem *et al.* (2014). With regard to wood chemistry, other important information which also affects the wood utilization include the existence of inorganic materials and the acidity (pH) of the wood. These properties have been reported to affect the cutting (Shmulsky and Jones 2011), gluing and coating (Adamopoulus *et al.* 2005; Pedieu *et al*. 2008), and discoloration of the wood (Minato and Morita, 2005; Mayer and Koch 2007).

Several studies have been conducted to investigate the inorganic materials and acidity of teak wood from various origins (Kjaer *et al.* 1998; Lukmandaru *et al.* 2009; Ola-Adams 1992; Windeisen *et al.* 2003). Unfortunately, the data from teak plantations in Indonesia is still limited. Thus, the primary objective of this study was to determine the amounts of total ash, individual elements, and the acidity of teak wood from the stands of Perhutani plantation and community forests for scientific and technical interests in wood processing. The other purposes of this study were analyze the relationship between the content of the inorganic variables and acidity of the wood, as well as the chemical properties of the soil.

Materials and Methods

Sample Materials

Wood samples were obtained randomly from the farmland stands and the Perhutani plantation. Four field collection sites (Fig. 1) were selected; these sites were known to yileld a large annual harvest and had different ecological attribute. Tree samples from Perhutani plantation stands were felled from Madiun Forest Management Unit (East Java Province) and Randublatung Forest Management Unit (Central Java Province) at a class age of VI. Tree samples from the community forest were cut from Kulon Progo Regency i.e. Kalibawang and Temon village at a diameter class of 20-35 cm. This tree selection was based on the cutting period generally practiced in the related sites.

At each site, three trees with similar features were selected, and a 5-cm-thick disc was collected at approximately breast height from each tree. The test specimens were taken successively from sapwood to heartwood, and divided into three sections diametrically i.e. sapwood (SW, ca. 0.5 cm from the bark), outer heartwood (OH ca. 0.5 cm from the heartwood-sapwood boundary), and inner heartwood (IH, ca. 2 cm from the pith) (Fig.2). Each part from two opposing radii was converted into wood meal by drilling. The meals from two opposite radii were then combined to form a single sample in order to minimize any variation between radii. The condition of the sites and tree characteristics are described in Table 1.

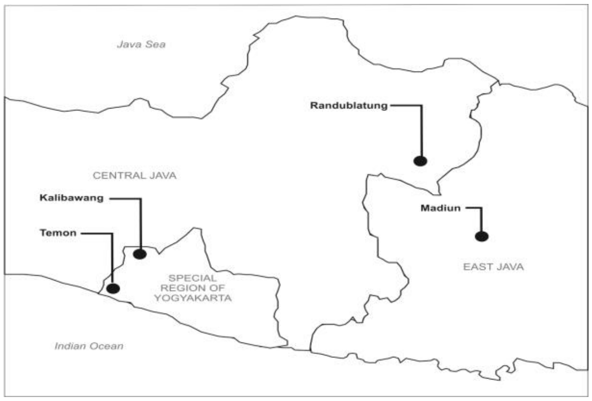


Figure 1. Geographic distribution of sampling sites.

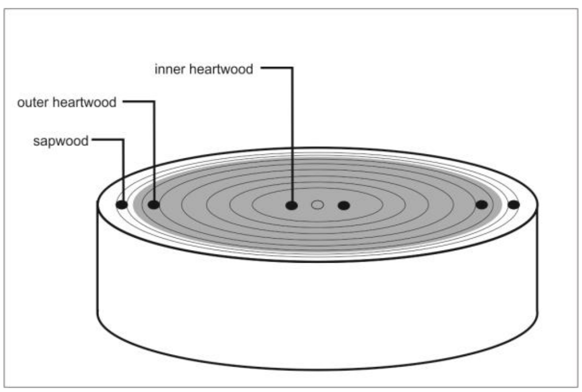


Figure 2. Schematic diagram of division of wood discs for the analysis of inorganic materials and pH value.

Inorganic Materials Analysis

Measurements of ash content and acid insoluble ash content (AIAC) were conducted according to the ASTM D-1102-2002 and TAPPI T244 om-88 standard method, respectively. The filtrates from the AIAC measurement were prepared for elements analysis. Measurements of potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), and iron (Fe) were carried out using an Analytik Jena 300 series atomic absorption spectrophotometer. Duplo measurements were made for each part. The results were shown according to the initial mass of dry wood.

Measurement of pH Value

The acidity of the wood was determined by its pH value. Wood powder (1 g per part eq. dry weight) was suspended for 48 hours in distilled water (20 mL). The pH of the filtrate was measured with a pH meter (OAKTON pH tester). Three measurements were made for each part.

Data Analysis

The testing for normality of data was conducted first then the data were analyzed (General Linear Models Procedure) by two-way analysis of variance (ANOVA) followed by Duncan's multiple range test (p = 0.05). The relationships between the independent variables were studied with a Pearson's correlation analysis. All statistics were performed with Excel (MS Word 2007) and SPSS-Win 16.0.

Table 1. Characteristics of the growth-sites and trees felled for sampling.

Origin	Kalibawang	Temon	Madiun	Randublatung
Altitude (m asl)	770	15	120	140
Annual rainfall (mm/year) [a]	2.227.8	1.966	1.600 - 2100	1300-2000
Parent rock	Volcanic	Limestone	Limestone	Limestone
Soil type [b]	Latosol, rocky	Mediteran, clay	Mediteran, clay	Grumusol, clay
- total potassium (%)	0.15	0.06	0.02	0.24
- total calcium (%)	0.58	6.14	0.67	6.09
- total magnesium (%)	0.45	0.51	0.35	0.50
- pH value	6.50	7.82	5.82	7.60
Dbh (cm)	20.7 – 23.4	20.8 – 34.2	36.3 – 50.3	54.8 – 67.7
Annual ring number	10 – 12	13 – 17	61 – 65	67 - 70
Heartwood percentage	61 - 64	60 - 65	77 - 83	94 - 98

Note :
[a] data were taken based on the annual report by local Badan Pusat Statistik (Statistics Indonesia)
[b] the determination of total calcium, potassium, and magnesium was conducted by extraction with HNO_3 and $HClO_4$ preparation method.

Results and Discussion

The quantification of inorganic contents and pH values based on growth-site factor is summarized in Table 2. It is noted that the levels of individual metals varied considerably, as can be seen from the high standard deviations. ANOVA was used to separate variation sources resulting from differences within growth sites and radial position which is presented in Table 3. The ANOVA indicated that there was significant interaction between the site and radial position in regards to the ash content and pH value. The variation among the different sites was significant in the contents of AIAC, Ca, Mg, K, and Na while the effects of radial direction were significant in the AIAC and K levels. As the data was not a normal distribution, Fe content was not further analyzed by ANOVA.

Ash and Acid Insoluble Ash Contents

In this study, dry ashing was conducted for removal of organic fraction. AIAC representing silica or silicates in the ash fractions was obtained by dissolving the remained ash with hydrochloric acid. The range of ash content in previous works were 0.97-4.10% for teak heartwood grown in Java (Lukmandaru 2010; 2011; 2012) or 0.7-2.8% for teak wood from Brazil (Polato *et al.* 2005). Furthermore, the range of silica contents in teak from various origins recorded in previous works were 0.18-1.40% (Kjaer *et al.* 1998) and 0.4 % from Indonesia (Martawijaya *et al.* 1981). For sapwood and heartwood region, the ash content ranged from 0.73 to 2.46% and 0.71 to 3.83%, respectively whereas the AIAC ranged from 0.12 to 1.34% and 0.20 to 2.45%, respectively. Thus, the corresponding values of ash content in this study are in the previously reported range whereas AIAC levels are slightly higher than those previously reported and probably reflect normal geographic variation. On the basis of total weight of ash content, 16.4-54.4% in the sapwood and 28.1-63.9% in the heartwood are attributed to the silica content. Although silica is impervious to insects and marine borers (Cookson *et al.* 2007), the timbers that contain more than about 0.3% of silica cause unduly rapid blunting of saws (Shmulsky and Jones 2011). Thus, in regards to wood utilization, these properties are disadvantage and tree selection should be applied to find trees with low silica content in the future.

Inorganic Elements

Ash fractions from teakwood have not been studied extensively, especially for their intra- or inter-tree variation. In general, the major elements in the wood is calcium (about 80%) and potassium and magnesium are the other predominating elements (Fengel and Wegener 1989). Atomic absorption analysis of the ash residues revealed the presence of 5 individual metals. On the basis of the sites, varied tendencies of element content were observed. The ranking of observed metals from high to low content was as follows : K>Ca>Mg (Kalibawang), Ca>K>Mg (Temon and Madiun), and Mg>Ca>K (Randublatung). Previous study in a partially black-streaked heartwood of teak showed a Ca>K>Mg trend in the normal heartwood and K>Ca>Mg trend in the sapwood (Lukmandaru *et al.* 2009). In other species, such as *Robinia pseudoacacia* (Adamopoulus *et al.* 2005) and some conifers and hardwoods from Japan (Tsuchiya *et al*. 2009), the highest exhibited content was Ca, followed by K and Mg.

Table 2. Contents of inorganic materials (% of oven-dry wood) and pH value of teakwood trees from different sites.

Parameter	Kalibawang			Temon			Madiun			Randublatung		
	Min.	Max.	Average (sd)	Min.	Max.	Average (sd)	Min.	Max.	Average (sd)	Min.	Max.	Average (sd)
Ash content (%)	0.55	3.88	2.61 (0.98)	0.62	1.64	0.83 (0.32)	0.71	2.82	1.39 (0.69)	0.88	2.36	1.59 (0.53)
Ash insoluble acid content (%)	0.41	2.45	1.22 (0.77)	0.12	0.46	0.38 (0.28)	0.22	1.52	0.67 (0.50)	0.20	1.76	0.81 (0.44)
Calcium (ppm)	356	1823	857 (600)	340	2166	861 (615)	1808	4774	2909 (1231)	607	1411	907 (281)
Potassium (ppm)	711	4399	1670 (1240)	197	1669	786 (652)	185	2211	813 (842)	17	1035	434 (450)
Magnesium (ppm)	143	1676	744 (411)	411	987	629 (171)	363	844	624 (141)	1094	1559	1323 (165)
Iron (ppm)	0	93	22.66 (36.62)	0	1	0.11 (0.33)	0	247	29.22 (81.81)	0	151	16.77 (50.33)
Sodium (ppm)	250	1390	757 (345)	273	1305	554 (335)	27	275	113 (88)	4.32	20	13 (4)
pH value	5.33	6.49	5.80 (0.35)	5.64	6.11	5.86 (0.18)	5.84	6.78	6.20 (0.41)	6.62	7.25	6.95 (0.34)

Note : min. = minimum value, max. = maximum value, sd = standard of deviation

Inorganic material amounts are expressed in percentage and part per million (ppm) based on dry weight of wood prior to ashing

Table 3. Different-site and radial direction analysis of variance in inorganic materials and pH value

Source of variation	df	Mean square						
		Ash content	Acid insoluble ash content	Calcium	Magnesium	Potassium	Sodium	pH value
Site (A)	2	4.9**	1.1**	9311611.7**	999054.8**	2111141.9**	1131189.3**	2.5**
Radial direction (B)	2	2.3**	1.0*	34658.3	24411.3	6036139.8**	62261.8	0.3*
A x B	4	0.7*	0.4	580784.7	43917.4	127197.2	62401.6	0.2**
Error	18	0.2	0.2	630172.0	69026.5	388625.1	59029.3	0.1

Note : df = degree of freedom * significance at the 5 % level ** significance at the 1 % level

The black-streaked heartwood grown in Java was reported to have contents of Ca, K, Mg, and Fe of 760-2500 ppm, 810-1950 ppm, 290-460 ppm, dan 30-55 ppm, respectively (Lukmandaru *et al*. 2009). Teakwood from Nigeria had a metal concentration ranging between 1130-2020 ppm for Ca, 3290-5980 ppm for K, and 480-1240 ppm for Mg (Ola-Adams, 1992). Ca content for teakwood from various provenances (India, Indonesia, Ghana, dan Mexico) was found to range between 2200-5800 ppm (Kjaer *et al.* 1998). Thus, these results in this experiment are still in the range of those above mentioned. However, Fe was distributed only in several samples. For instance, out of 3 individuals of Temon or Randbulatung, Fe was detected in only one individual. The exact reason for this is unknown but is probably related to the limited experimental techique used for detecting. Na content was not compared as no published work for Na content teak is available to the best of our knowlegde.

Effect of Site and Radial Direction on Inorganic Contents

Inorganic materials enter the tree through the root system and are transported to all tissues within the growing tree. Variations may normally be affected by growth site. Duncan test (Fig. 3) revealed that the highest ash content was measured in the heartwood samples of Kalibawang (3.62%) and the lowest levels were in the samples of Temon (outer dan inner heartwood) and Madiun (inner heartwood). It is assumed that the levels of inorganic materials is higher in the sapwood for movement of minerals from the wood to younger plant tissue. In this experiment, that trend was observed only in the samples of Temon and Randublatung.

The wood of Kalibawang was by far the richest in AIAC (1.33%) compared to the other samples (Fig. 4). For inorganic elements, the wood of the Perhutani plantation (Madiun and Randublatung) contained more Na than the wood of the community forest in Kulon Progo by Duncan test (Fig. 5). The highest Ca amount (2909 ppm) was observed in the Madiun samples whereas the highest Mg amount (1323 ppm) in the Randublatung samples. Ca and Mg belong to the alkali earth metals (IIA) whereas Na and K belongs to the alkali metals (IA) groups in the periodic tables. The differences of age of tree and site factors in this study might account for this phenomenon as the trees would respond differently related to those metal groups.

The inorganic composition of the wood may reflect both the physiological changes (differentiation, aging, heartwood formation) and environmental conditions. By evaluating the soil properties (Table 1), the association with the wood properties seemed to be unclear. For instance, Kalibawang soil did not show the highest total Mg content but the wood samples did. The same case was also observed in the Madiun samples. Further studies should be conducted using larger samples in order to reduce the high variation in the same stand as well as to confirm whether the phenomenon above was systematic or coincidental.

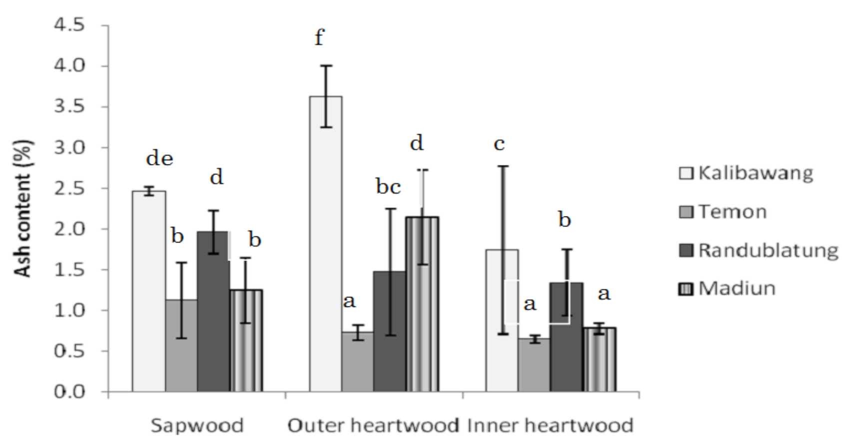


Figure 3. Ash content of teakwood by different sites and radial position. Average of 3 trees, with the standard deviation in the error bar. The same letters are not significantly different at $p < 5\%$ by Duncan's test.

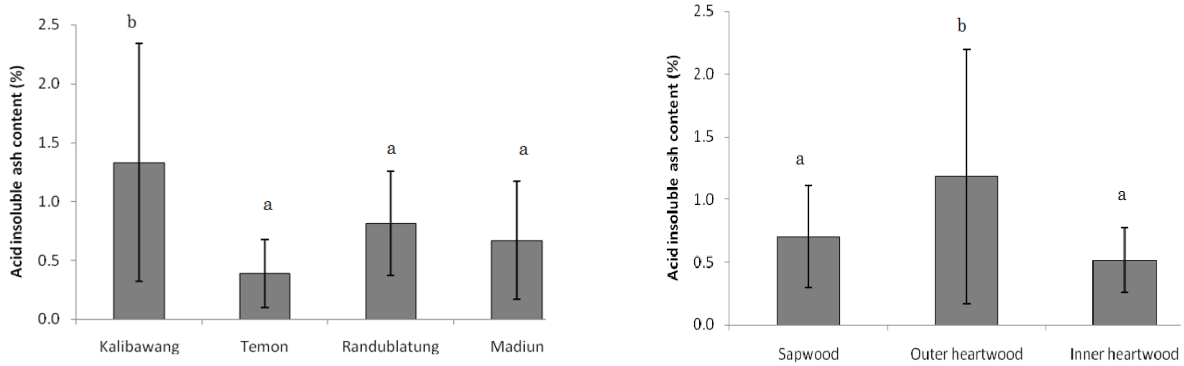


Figure 4. Acid insoluble ash content content of teakwood by different sites and radial position. Average of 3 trees, with the standard deviation in the error bar. The same letters are not significantly different at $p < 5\%$ by Duncan's test.

The woods in Kalibawang were the richest in ash content, AIAC, and K (Fig. 6). Previously, these variations in teak trees were attested to by Ca analysis performed in various provenances (Indonesia, Ghana, dan Mexico), where the values were affected by site factor (Kjaer *et al.* 1999). To estimate the availability of metals, top soil examination at each sampling site was also conducted (Table 1). However, a simple description of soil chemistry as a feature for interpretation was not sufficient. There is probably another factor that affects the metal ion content of wood beside the chemical composition of underlying bedrock such as climate or other environmental conditions (Fengel and Wegener 1989). Within growth-site factor, besides parent rock and soil type differences, the comparatively high average annual rainfall and the altitude of Kalibawang could be the cause of that phenomenon.

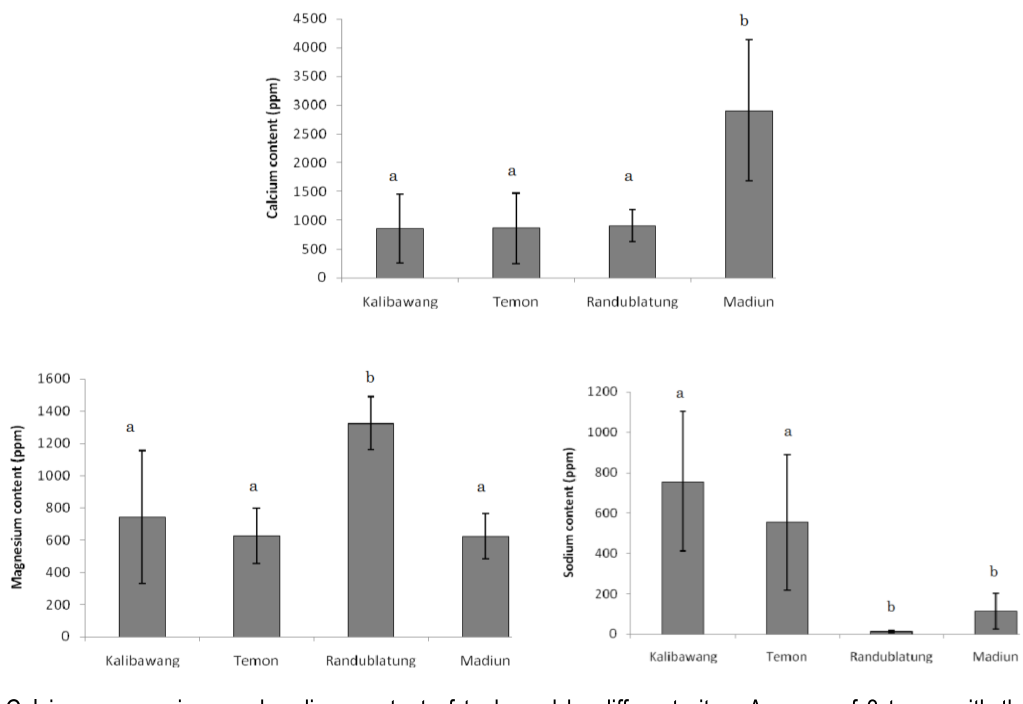


Figure 5. Calcium, magnesium, and sodium content of teakwood by different sites. Average of 3 trees, with the standard deviation in the error bar. The same letters are not significantly different at $p < 5\%$ by Duncan's test.

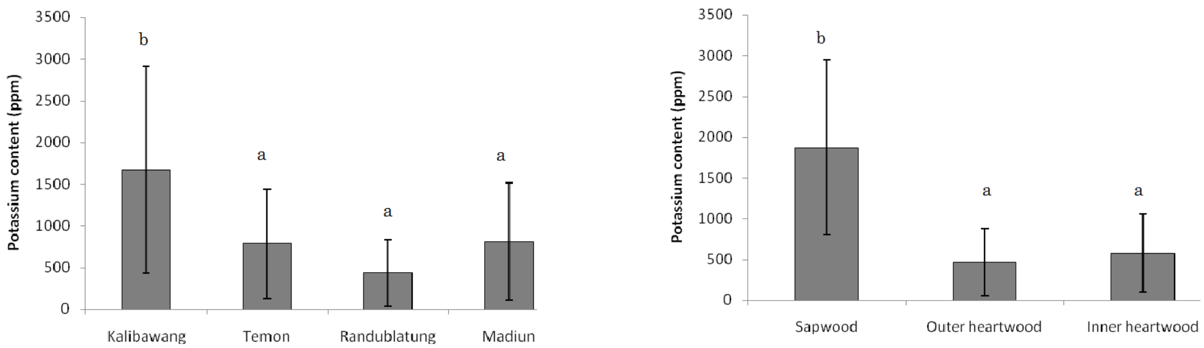


Figure 6. Potasssium content of teakwood by different sites and radial position. Average of 3 trees, with the standard deviation in the error bar. The same letters are not significantly different at p < 5% by Duncan's test.

With regard to radial distribution of inorganic materials, the levels were highest in the outer heartwood for AIAC and in the sapwood for K (Fig. 6). On the basis of radial pattern of trace elements, the former is in Type 3, those whose highest levels are attained at the borderline between sapwood and heartwood while the latter is in Type 1, those whose concentrations fall suddenly from the sapwood to the heartwood (Okada *et al.* 1993). Further, it has been mentioned that alkali metals mostly fell into Type 1 or 3. The abrupt changes in AIAC amounts around the sapwood-heartwood boundary are possibly related to the heartwood formation process. Of the five metals which were measured, only K was significantly different with respect to radial position. The high concentration of K presumably is related to the cambial zone or differentiating zone in the xylem which may transport large metal contents. The lack of significant diferences for all elements in the outer (mature zone) and inner heartwood (juvenile zone) is probably due to the absence of living tissue, making physiological reactions limited there.

Tabel 4. Pearson's correlation coefficients (*r*) between inorganic substance parameters and pH value in the sapwood and heartwood of teak.

Properties	AIAC	Ca content	Mg content	K content	Na content	pH value
Ash content	0.77**	-0.12	0.10	0.28	0.27	-0.17
AIAC		-0.17	0.15	0.15	0.15	-0.20
Ca content			-0.19	-0.01	-0.35*	-0.05
Mg content				0.12	-0.46**	0.65**
K content					0.34*	-0.08
Na content						-0.52**

Tabel 5. Pearson's correlation coefficients (*r*) between inorganic substance parameters and pH value in the sapwood of teak.

Properties	AIAC	Ca content	Mg content	K content	Na content	pH value
Ash content	0.71**	-0.38	0.43	0.33	0.03	0.08
AIAC		-0.40	0.57	0.48	-0.16	0.01
Ca content			-0.14	0.08	-0.31	0.11
Mg content				0.17	-0.56	0.44
K content					0.09	-0.36
Na content						-0.67*

Tabel 6. Pearson's correlation coefficients (*r*) between inorganic substance parameters and pH value in the heartwood of teak.

Properties	AIAC	Ca content	Mg content	K content	Na content	pH value
Ash content	0.80**	-0.05	-0.01	0.47*	0.37	-0.26
AIAC		-0.12	0.04	0.33	0.28	-0.22
Ca content			-0.23	-0.14	-0.38	-0.12
Mg content				-0.12	-0.41*	0.79**
K content					0.72**	-0.49*
Na content						-0.55**

Note = AIAC : acid insoluble ash content * significance at the 5 % level ** significance at the 1 % level

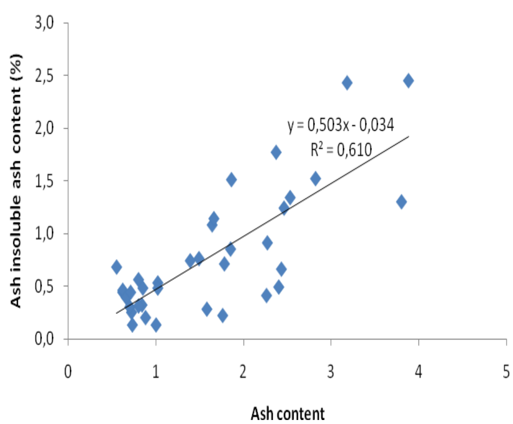
Relationship Among the Inorganic Variables

Correlation between inorganic variables is displayed in Table 4-6. Analysis results showed a highly significant relationship between ash content and AIAC both in the heartwood and sapwood (*r* = 0.71-0.80**). In the scatter diagram (Fig. 7), AIAC content obviously increased with increased ash content in a linear function. It is noted that some outliers were mostly from Kalibawang samples.

Besides silica, a significant correlation between ash content and inorganic elements was calculated on K element in the heartwood (*r* = 0.47*). As shown in Fig. 7, K content increased polynomially when K content was greater than 100 ppm. Some outliers were distributed evenly from Kalibawang and Madiun woods. Previous work on blackening *Cryptomeria japonica* heartwood (Kubo and Ataka 1998), showed that a linear relationship between ash and K content existed (*r* = 0.67). Furthermore, it has been shown that K element was also significantly correlated with its moisture content. In this experiment, however, moisture content of the samples was not measured to confirm whether any relationships exist between inorganic elements and moisture content as trees need water to transport the nutrients.

No significant correlation among AIAC and other inorganic elements was measured. Among the elements, the strongest degree of correlation was found between K and Na (*r* = 0.72**) in the heartwood. The study showed that K content increased with increased Na content in a polynomial function (Fig. 8) although several outliers appeared. It is noted that both elements belong to the alkali metals. As the functions of K in plants is mainly for electrochemical role, it is hypothesized that univalent cations of those elements are complementary for each other. On the contrary, no significant correlation in the sapwood region was interpreted as the high mobility of main elements due to physiological activities in trees would obscure the actual concentration.

When the data in the sapwood and heartwood were combined, a significant negative correlation was found between Mg and Na (*r* = -0.46**). The scatter diagram between the two displayed increased Mg content which was followed by the polynomially decreased Na content, and otherwise (Fig. 8). Mg belongs to the IIA as Na from IA groups. Mg is a mobile element and a catalyst in enzimatic reaction in physiological process (Okada *et al.* 1987). Although Mg and Na are quite different in chemical properties, this relation is interpreted as showing that they can substitute each other in some cases. The same explanation was also applied also for the negative correlation between Ca and Na to a lesser extent (*r* = -0.35*).



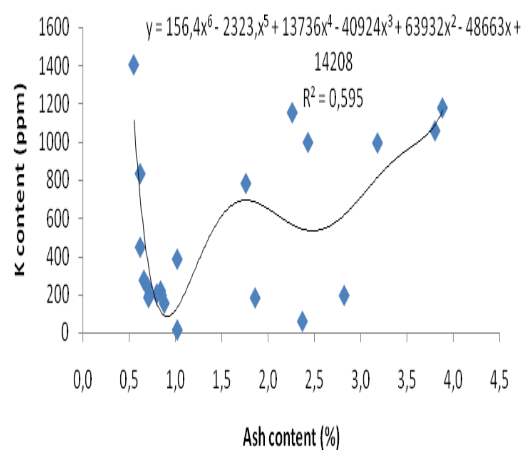


Figure 7. Scatterplots between ash content value against acid insoluble ash content in the sapwood - heartwood and between ash content against K content in the heartwood.

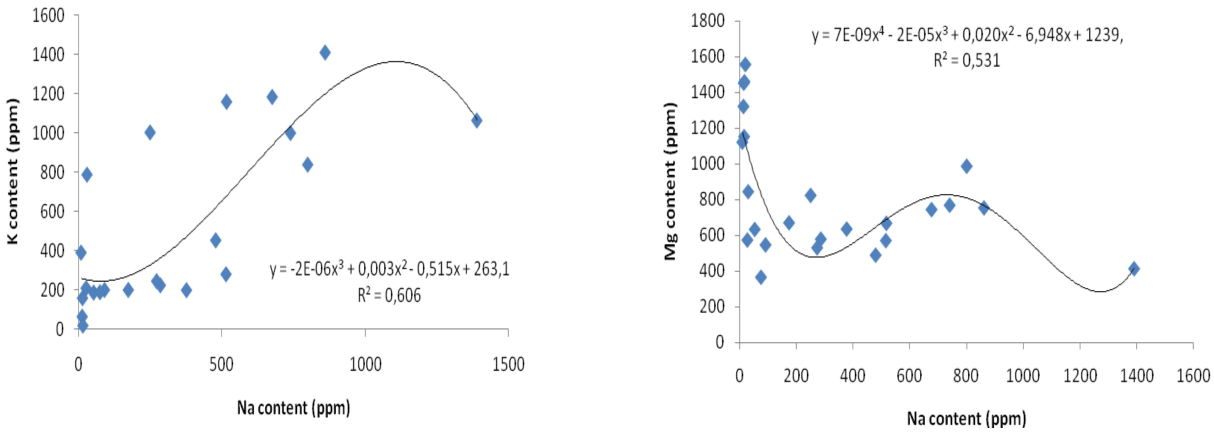


Figure 8. Scatterplots between Na content against Mg content and between Na content against K content in the heartwood.

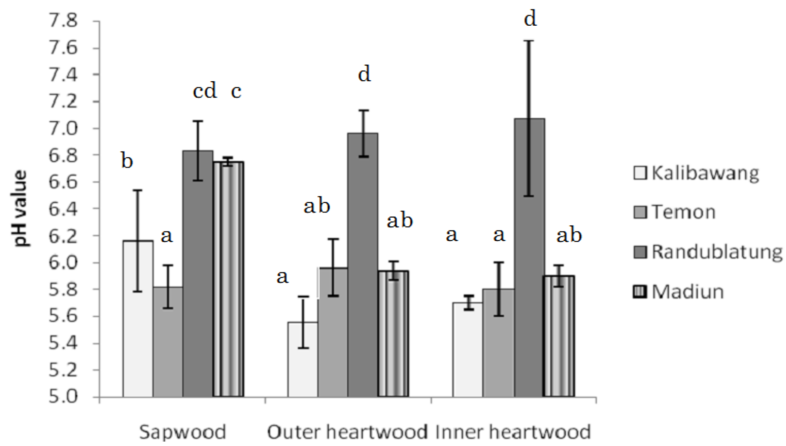


Figure 9. The pH value of teakwood by different sites and radial position. Average of 3 trees, with the standard deviation in the error bar. The same letters are not significantly different at $p < 5\%$ by Duncan's test.

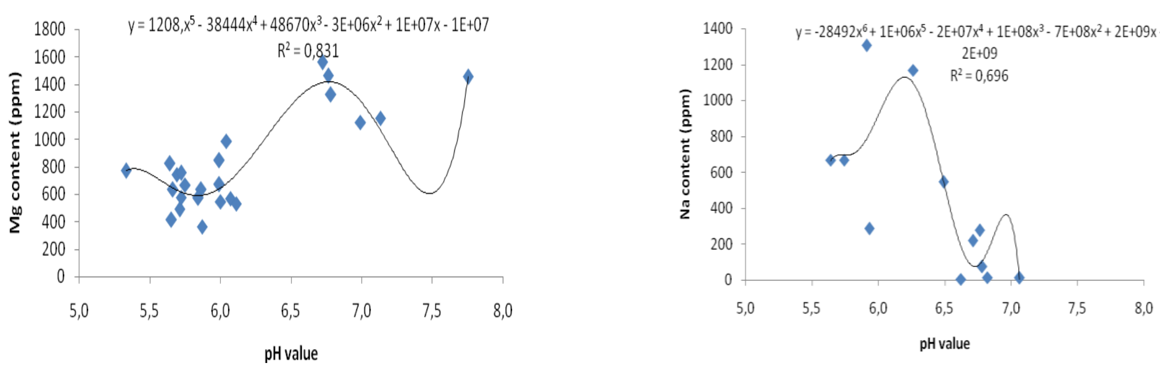


Figure 10. Scatterplots between pH value against Mg content in the heartwood and between pH value against Na content in the sapwood.

pH Values

The pH of wood meal suspensions was taken to estimate the acidity of wood. The pH values in the heartwood and sapwood were found to lie between 5.33-7.35 and 5.64-7.06, consecutively. Those values were in the range of previous results in teakwood from Java which ranged 5.2-6.7 (Lukmandaru 2009; 2012) and teakwood from Brazil i.e. 4.6-6.7 (Polato *et al* 2005). By Duncan test, the Randublatung woods had the highest values especially in the inner (6.96) and outer heartwood (7.07), while Temon sapwoods (5.82) and inner heartwoods (5.80) as well as Kalibawang outer (5.55) and inner heartwoods (5.70) had the lowest values. The difference between the two groups was seen in the sapwood parts of which Perhutani samples showed higher values than those of community forests (Fig. 9). Another striking difference was found in the pH values of the heartwood samples from Randublatung, which were in a weak basic range. The relationship between the values of soil pH (Table 1) and and wood pH is unclear. For example the soil pH values of Temon and Randublatung were comparatively high (weak basic) but showed different trends in the pH values of the wood.

Wood acidity is derived from hydronium ions mainly released by free and bound organic acids present in extractives and non-cellulosic sugar as well as by simple phenols and complex polyphenols (Balaban and Ucar 2001). Generally, heartwoods exhibit a more acidic nature than sapwood due to the phenolics. However, this tendency was observed only in the Kalibawang and Madiun samples. Previously, the difference between sapwood and heartwood was seen in the earlier study of Panama teakwood (Windeisen *et al.* 2003). Thus, the further research should cover phenolics and short-chain sugars measurements to explain the site differences.

Wood acidity is affected by several factors, one of them being inorganic elements (Rowell *et al.* 2005). The correlation coefficients calculated between inorganic variables and pH values are shown in Table 4-6. Based on these correlations, it was clear that the levels of ash content or AIAC could not substantially explain the variation in pH values. The most correlated variable to pH values was Mg content in the sapwood and heartwood (r = 0.65**). The degree correlation in a polynomial relationship was stronger (r = 0.79**) in the heartwood only (Fig. 10). This trend agreed with the highest values of Mg content (1323 ppm) and pH value (6.95) in Randublatung woods (Fig. 5 and 9). This could be explained by the fact that divalent Mg^{2+} would direct the pH value to a basic range. Theoretically, Mg is easily translocated and functions as the activator of many enzymes (Okada *et al.* 1987).

On the contrary, the pH value was inversely correlated to K (r = -0.49*) or Na (r = -0.55**) contents measured in the heartwood. Okada *et al.* (1987) assumed that the high amount of alkali metals in the heartwood is to regulate the pH as a counter ions of phenolics formation. In the sapwood, a moderate and negative correlation between the pH value and Na content (r = -0.67*) was measured. This means that increased Na content was followed by decreased pH values or in other words, towards the acidic range. The scatter diagram showed a polynomial relation between the two (Fig. 10). It was found that several outliers were from Temon and Randublatung woods.This association was unexpected as Na belongs to the alkali metal (IA) and directs to basic pH by carbonates neutralization (Balaban and Yilgor 1995). Furthermore, phenolics are still limited as the heartwood has not been formed. The cause of this phenomenon is uncertain. Another factor could be the such as the presence of non-cellulosic sugars in the sapwood region.

Conclusions

Ash content and pH value were dependent on the interaction of site and radial position. The highest ash content was measured in the heartwood samples of Kalibawang whereas the Randublatung woods had the highest pH values in the heartwood regions. In comparison of samples of different sites, the woods from the Perhutani plantation (Madiun and Randublatung) was significantly richer in sodium than the woods from Kalibawang and Temon. Kalibawang teak wood contained more acid insoluble ash and potassium than others. The position of the wood in relation to radial position was another source of variability. There were larger amounts of divalent cations (magnesium, calcium) in the Perhutani plantation stands, whereas monovalent alkalines (sodium, potassium) were more abundant in the Kulon Progo stands. The radial gradient of potassium content was characterized by higher levels in the sapwood than the heartwood. There were larger amounts of acid insoluble ash content in the outer heartwood parts. The concentrations of all metals tested showed no significant differences in the heartwood region. Variation in the soil properties, in general, could not adequately explain the variation in wood properties in this experiment. Significant correlations were found between ash content and its fractions as well as between inorganic variables and pH values.

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