Wood Quality of *Acacia* Hybrid and Second-Generation *Acacia mangium*

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Two new tree variants, namely *Acacia* hybrid and second-generation *Acacia mangium*, have been introduced in plantation forests in Sarawak, Malaysia, and their wood qualities were examined. The mean basic density of *Acacia* hybrid was comparable with *Acacia mangium*. However basic density and strength properties of second-generation *A. mangium* were significantly lower compared to *Acacia* hybrid. The mean fibre length and fibre wall thickness in the hybrid were found to be greater than that of second-generation *A. mangium*. Fibre diameter and fibre lumen diameter of *Acacia* hybrid were smaller compared to second-generation *A. mangium*. Runkel and slenderness ratios of *Acacia* hybrid and second-generation *A. mangium* fibres showed that they were suitable for pulp and paper production. *Acacia* hybrid was more resistant to *Coptotermes curvignathus* attack than second-generation *A. mangium*. A laboratory soil block test showed that *Acacia* hybrid and second-generation *A. mangium* were moderately durable timbers. In summary, marked differences in wood properties and qualities were observed between *Acacia* hybrid and second-generation *A. mangium*.

Keywords: Acacia hybrid; Second-generation Acacia mangium; Wood quality; Natural durability, Plantation species

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INTRODUCTION

Forestry remains a significant economic activity in Malaysia. Realizing the present importance of forestry and also to cater for future demands for wood and wood products, there have been efforts to establish forest plantations. One million ha of land in Sarawak, Malaysia's largest state, is earmarked for planted forests by the year 2020 (PERKASA 2009). This is a serious effort to meet the current and future raw material demand from the timber industry as well as to conserve the natural forests. The main forest plantation species in Malaysia is *A. mangium*. Besides *A. mangium*, other tree species planted in Sarawak are *Neolamarckia cadamba*, *Paraserianthes falcate*, and *Eucalyptus* spp.

Recently two improved tree variants have been introduced in Sarawak, *viz. Acacia* hybrid and second-generation *A. mangium*. *Acacia* hybrid is the cross between *A. mangium* and *A. auriculiformis*. The hybrid of *A. mangium* x *A. auriculiformis* has the potential to become an important tree variant in plantation forestry. In general, the tree form is satisfactory, since it inherits better stem straightness of *A. mangium* and self-pruning ability and better stem circularity of *A. auriculiformis* (Mohd Hamami and Semsolbahri 2003). The wood density is slightly higher than *A. mangium*, and moreover the shape of the log is almost completely round, which renders *Acacia* hybrid as a valuable and excellent source of timber.

Second-generation *A. mangium* is an improved and selected plus tree as a result of a tree improvement program. It is propagated from the seed of *A. mangium*, and the trees have gone through many years of tree improvement. The second-generation *A. mangium* trees have superior characteristics in comparison to the first-generation in terms of high growth rate, high volume, good stem form, and resistance to heart rot. The tree can reach the height and DBH of 20.9 m and 21.7 cm, respectively at the age of 4 years old, whereas at the same age first-generation *A. mangium* can only achieve the height of 16.8 m and DBH at 17.7 cm (PERKASA 2004).

The extent of future utilization of both *Acacia* hybrid and second-generation *A. mangium* depend on their wood quality. It is frequently assumed that improvement in growth rate and characteristics will also result in improvements in the wood properties. However, it is also possible that wood from hybrid and improved trees that showed superior growth rate, improved form, and adaptability may be less suitable for certain end-use products compared to wood of the parent trees. Little is known about the wood properties and qualities of *Acacia* hybrid and second-generation *A. mangium*. This study was conducted to evaluate and compare the physical and mechanical properties among *Acacia* hybrid, second-generation *A. mangium*, *A. auriculiformis*, and *A. mangium*. Fibre morphology and natural durability of the acacias were also examined.

EXPERIMENTAL

Sampling and Sample Preparation

Acacia hybrid and second-generation *A. mangium* were obtained from an approximately 7-year-old stand of *Acacia* hybrid and second-generation *A. mangium* from a forest plantation company, Borneo Tree Seeds and Seedlings Supplies Sdn Bhd based in Sarawak, Malaysia. For comparison, *A. auriculiformis* and *A. mangium* of the same age were selected from adjacent Queensland provenance trial plots. Seven trees were felled, and each tree was first marked according to DBH, 50%, 70%, and 90% of bole length. The bole length was taken from stump to 10 cm top diameter. From each height level one 1.2 m long bolt was cut. Two quarter-sawn flitch of 5 cm thick was cut through the centre from bark to bark from each bolt and subsequently conditioned to air-dry in a room for subsequent analyses.

Physical Properties

Each quarter-sawn flitch was ripped to produce true radial, tangential, and longitudinal sample dimensions of 2.5 cm x 2.5 cm x 10.0 cm. A total of 100 specimens were chosen randomly from all height levels. The samples were first saturated in water and then weighed and measured at predetermined points in the radial, tangential, and longitudinal direction to the nearest 0.01 mm in green condition using a digital caliper. Green volumes were determined by the water immersion method following saturation of the samples. The samples were air-dried at room temperature and periodically weighed and measured until the weight was constant. They were maintained at a nominal 15% equilibrium moisture content (EMC) in a humidity room prior to oven drying. Oven-dried samples were weighed and measured again at the predetermined positions in the radial, tangential, and longitudinal directions. Physical properties determined from each sample include basic density, moisture content, and total (green to oven dry) radial and tangential shrinkage. Basic density for each sample was computed on an oven dry weight-green volume basis. Moisture content was determined on an oven dry basis to a constant weight at 103 ^{o}C. Shrinkage values for each structural direction were calculated from the ratio of change in dimension from swollen condition to oven dry condition, expressed as percentage.

Volumetric shrinkage was estimated from the summation of radial and tangential shrinkages. The method used in determining the physical properties was in accordance to ASTM D143-09 Standard Test Methods for Small Clear Specimens of Timber (ASTM 2010).

Mechanical Properties

The determination of mechanical properties was based on Methods of Testing Small Specimen of Timber in accordance with British Standard Institution 373:1957 (British Standard 1957). For this study, only two mechanical properties were determined. They were static bending and compression parallel to grain. These two tests were carried out because they are the most widely reported strength properties of wood. Besides, these two properties are commonly available for acacia species. For each test 150 clear and defect free specimen were selected randomly from all height levels. Both tests were carried out with a Testometric Universal Testing Machine (M500-25kN). The static bending and compression parallel to grain MOE and MOR at proportion limit were calculated and MCS and Young's modulus were computed from compression parallel to grain tests. All specimens were kept in the testing room environment prior to testing, and the testing was done under air-dry condition. Air-dry test tests were conducted after three months of conditioning at 15% EMC.

Fibre Morphology

Portions of the quarter-sawn flitch were ripped to obtain sample cubes of 1 cm x 1 cm x 1 cm. The cubes were softened using 4% ethylenediamine (Berlyn and Miksche 1976). Transverse sections of approximately 18 to 20 µm were used to measure the tangential fibre diameter, fibre wall thickness, and fibre lumen diameter. Wood slivers parallel to grain were macerated in a 1:2 (v/v) mixture of glacial acetic acid and 30% of hydrogen peroxide. Fifty unbroken fibres were selected for determination of fibre length. Runkel ratio was calculated as the ratio between twice the wall thickness and the lumen diameter (2 x fibre wall thickness/fibre lumen diameter). Slenderness ratio (fibre length/fibre diameter) was also determined.

Wood Natural Durability

Determination of wood natural durability was conducted using a decay test and termite resistance test. The wood decay test was done using a laboratory soil block test according to American Society for Testing and Materials (ASTM) Standard D2017-81 (ASTM 1998) with few exceptions. *Hevea brasiliensis* was used as both feeder strips and reference blocks due to its susceptibility to decay fungi. Fungi used in this study were *Trametes versicolor*, *Schizophyllum commune*, and *Rigidoporus microporus*. All of the fungal strains were obtained from the division of Forest Products Technology, Forest Research Institute of Malaysia (FRIM). Ten replicates of each species of wood sample blocks size 2 cm x 2 cm x 2 cm were exposed to each species of fungus for 10 weeks when three reference blocks gave 45 to 50% weight loss by *Trametes versicolor*. Prior to fungal exposure the blocks were conditioned at 60 ^{o}C and 70% relative humidity until constant weight. Following 10 weeks incubation period, the mycelium was wiped from the block surfaces and conditioned again at 60 ^{O}C and 70% relative humidity until constant weight. Weight losses of the samples blocks were calculated from the difference of the weight of the blocks before and after incubation.

The termite test resistance test was conducted according to Japan Wood Preserving Association (JWPA) standard 11(1)-1981 (JWPA 1981) with modification. This is a no-choice test experiment using a test container consisting of an acrylic cylinder (80 mm in diameter and 60 mm in height) having one end sealed with hard plaster to form a 5 mm thick bottom. The sample blocks sized at 10 mm (radial) x 10 mm (tangential) x 30 cm (longitudinal) were mixed randomly and all sample blocks were cleaned to remove any dust, then underwent drying and conditioning to constant weight at an oven temperature of 60 °C for four days. Ten sample blocks from each species were randomly selected and weighed prior to the termite resistance test. One hundred fifty workers and 50 soldiers of *Coptotermes curvignathus* were introduced into each container.

Data Analysis

One-way analysis of variance (ANOVA) and two-way ANOVA were performed at a 5% significance level to determine the differences of mechanical and physical properties, fibre morphology, and weight losses among the *Acacia* species. Tukey tests were used to further analyse the differences among the means. All analyses were computed using SPSS 14.0 for Windows.

RESULTS AND DISCUSSION

Physical Properties

Mean values of basic density, tangential, radial, and volumetric shrinkages are given in Table 1. *Acacia* hybrid recorded the highest basic density, and second-generation *A. mangium* mean basic density was significantly lowest among the *Acacia* species. Basic density of *Acacia* hybrid and *A .mangium* did not differ at the 5% level. The results indicated that the basic density of *Acacia* hybrid was between the parental species (*A. mangium* and *A. auriculiformis*) basic densities, but statistically its basic density did not differ with that of *A. mangium*.

Results showed the quicker growth of second-generation *A. mangium* was associated with lower basic density than *A. mangium*. In general faster growth does not necessarily affect wood density (Zobel and Buijtenen 1989), and according to Bowyer *et al*. (2003) no consistent relationship was found between wood density and growth rate in diffuse-porous hardwoods. Zobel and Jett (1995) stressed that specific gravity in diffuse-porous hardwoods is related to fibre wall thickness.

Table 1. Physical Properties of *Acacia* Hybrid, Second-generation *A. mangium*, *A. mangium*, and *A. auriculiformis*

Species	Basic density (kg/m^3)	Shrinkage (%)		
		Radial	Tangential	Volumetric
Acacia hybrid	472 b (40)	2.71 a (0.51)	5.74 ab (0.73)	15.99 b (1.89)
A. mangium (2nd generation)	334 a (80)	3.27 a (0.99)	6.25 b (1.09)	14.42 a (2.01)
A. mangium	464 b (23)	3.06 a (0.62)	5.12 a (0.94)	15.89 b (3.53)
A. auriculiformis	636 c (13)	2.26 a (0.49)	4.72 a (0.45)	18.18 c (1.01)

Means values followed by different letter within a column are significantly different at 5% level. Values in parentheses represent standard deviation.

Volumetric shrinkage of *A. auriculiformis* was significantly higher among the species studied. This can be explained by higher basic density in *A. auriculiformis*. Higher density woods have the tendency to shrink more (Bowyer *et al*. 2003).

Tangential shrinkage of *Acacia* hybrid recorded in this study was higher (5.74%) than as reported (3.30%) by Mohd Hamami and Semsolbahri (2003). Shrinkage values between *Acacia* hybrid and *A. mangium* were not statistically different

Mechanical Properties

Results showed that values for Young's Modulus of compression parallel to grain were similar for all the acacias tested. Comparison of means indicated that static bending and compression parallel to grain values for second-generation *A. magium* were lowest among the acacias studied and its static bending MOR and MOE were significantly lower than *A. mangium* (Table 2). The low density in second-generation *A. mangium* is responsible for the low strength. The effect of density on strength has long been recognized (Panshin and De Zeeuw 1980; Bowyer *et al*. 2003). Apparently there were no significant differences in static bending and compression parallel to grain among *Acacia* hybrid, *A. mangium*, and *A. auriculiformis*. The lack of differences in strength is consistent with results of a similar study (Mohd. Shukari *et al*. 2002) performed on six-year-old *A. mangium* and four-year-old *Acacia* hybrid.

Comparing the strength values of *Acacia* hybrid with previous results showed a mixed trend. The MOR and MOE for static bending and MCS recorded in this study were higher than the values reported by Mohd Shukari *et al*. (2002). However, these values were slightly lower compared to values observed by Mohd Hamami and Semsolbahri (2003) except for MOR. This discrepancy can be explained by the variation effect due to geographic locations, age, growth rates, and genetic details (Zobel and Buijtenen 1989). Generally the strength properties among *A. mangium*, *Acacia* hybrid, and *A. auriculiformis* did not show any significant differences, which indicates that the strengths are similar. However, second-generation *A. mangium* consistently recorded significantly lower strength values. This was expected by the fact that the density was significantly lower than the other *Acacia* species studied.

Table 2. Comparison of Mean Values on Some Mechanical Properties of *Acacia* Hybrid, Second-generation *A. mangium*, *A. mangium*, and *A. auriculiformis*

Species	Static Bending		Compression Parallel to Grain	
	MOR (N/mm^2)	MOE (N/mm^2)	MCS (N/mm^2)	Young's Modulus (N/mm^2)
Acacia hybrid	85 b (6.67)	9614 b (1038)	62 b (12)	1253 a (159)
A. magium (2nd generation)	55 a (17.99)	8185 a (2295)	50 a (15)	901 a (235)
A. mangium	78 b (18.4)	9992 b (1880)	53 ab (15)	1076 a (194)
A. auriculiformis	89 b (5.61)	8214 ab (1862)	59 ab (16)	1094 a (203)

Means values followed by different letter within a column are significantly different at 5% level. Values in parentheses represent standard deviation.

Fibre Morphology

The mean main-stem fibre length in *Acacia* hybrid was 0.96 mm, which is significantly longer than *A. auriculiformis* and *A. mangium* (Table 3). The mean fibre length of 10-year-old *Acacia* hybrid planted in Sabah, Malaysia was 1.03 mm (Mohd Hamami and Semsolbahri 2003); while a study conducted by Yahya *et al.* (2010) reported a fibre length of 1.06 mm for a seven-year-old plantation from South

Sumatra, Indonesia. This study did not show any significant difference in fibre length between *A. auriculiformis* and *A. mangium*. Table 3 showed that *Acacia* hybrid recorded the smallest mean fibre diameter (17.16 μm) and fibre lumen diameter (12.75 μm), however its mean fibre wall thickness (2.21 μm) was significantly thicker than *A. mangium*. A previous study by Mohd Hamami and Semsolbahri (2003) showed thicker mean fibre wall and a greater fibre diameter in *Acacia* hybrid from Sabah, averaging 3.69 µm and 15.73 µm, respectively.

Anatomical ratios calculated from the dimensional measurements of fibres help to assess various properties relative to the production of paper. For hardwoods one of the most important and primary observations in order to find suitability of any raw material for pulp production is the Runkel ratio (2 x fibre wall thickness/fibre lumen diameter) (Valkomies 1969). Favorable fibre strength properties are usually obtained when the value of Runkel ratio is below 1 (duPlooy 1980; Bamber 1985). On the basis of the observed Runkel ratios, all the acacias apparently could produce paper of good quality and strength (Table 3). The Runkel ratio of *Acacia* hybrid was comparable with the Runkel ratio of *Acacia* hybrid obtained from South Sumatra (Yahya *et al.* 2010). A Runkel ratio of 0.25 to 1.5 indicates that the wood should be able to yield pulp of acceptable quality (Valkomies 1969). Higher Runkel ratio fibres are stiffer, less flexible, and form bulkier paper of lower bonded areas than the lower Runkel ratio fibres (Ververis *et al.* 2004). Runkel and slenderness ratios among the acacias studied were significantly different.

Another important morphological characteristic is the slenderness ratio (fibre length/fibre diameter). This ratio can be used to assess the potential of fibres for developing strength properties such as bursting and tensile strength (Ona *et al.* 2001). Bursting and tensile strengths of pulps are two properties highly dependent upon fiber-to-fiber bonding. Generally, a slenderness ratio of more than 33 is good for papermaking (Xu *et al.* 2006). All acacias studied exhibited slenderness ratios of more than 33, which make them suitable for pulp and paper production. The higher the value of slenderness ratio, the better will be the fibre flexibility and tearing resistance (Ona *et al.* 2001). Pulping and paper-making properties of *A. mangium* were reported to be of favorable quality (Logan and Balodis 1982; Peh *et al.* 1982). It has been shown that kraft pulping and papermaking properties of *A. mangium* are comparable with those of plantation-grown *Gmelina arborea* and *Eucalyptus deglupta* (Mohlin and Harnatowska 2005).

Table 3. Fibre Characteristics of *A. mangium,* Second-generation *A. mangium*, and *Acacia* Hybrid

Anatomical properties	*Acacia* hybrid	*A. mangium* (2^{nd} generation)	*A. mangium*	*A. auriculiformis*
Fibre length (mm)	0.96 b (0.18)	0.91 a (0.21)	0.93 ab (0.19)	0.89 a (0.18)
Fibre Wall thickness(µm)	2.21 c (0.40)	1.88 a (0.48)	2.03 b (0.39)	2.50 d (0.70)
Fibre diameter (µm)	17.16 a (2.20)	20.34 d (2.80)	17.43 b (2.70)	17.80 c (1.90)
Fibre lumen diameter (µm)	12.75 a (2.10)	16.56 c (2.90)	13.35 b (3.20)	12.80 a (1.90)
Runkel ratio	0.35 c (0.004)	0.23 a (0.003)	0.31 b (0.004)	0.39 d (0.004)
Slenderness ratio	57 d (0.51)	45 a (0.53)	54 c (0.55)	50 b (0.45)

Means values followed by different letter within a row are significantly different at 5% level.
Values in parentheses represent standard deviation.

Natural Durability

Wood blocks following 10 weeks exposure to the three test fungi exhibited different susceptibility to fungal attack. Significant differences of the mean weight loss were observed between *Acacia* species (Table 4). Severity of decay by *T. versicolor*, *S. commune*, and *R. microporus* were significantly different. This showed that the amount of wood decayed by the three test fungi on *A. mangium*, *A. auriculiformis*, second-generation *A. mangium*, *Acacia* hybrid, and *H. brasiliensis* differed. *Trametes versicolor* generally caused higher mass loss, followed by *R. microporus* and *S. commune*.

Hevea brasiliensis recorded the highest weight loss among all the wood species for all fungi in this study. *Hevea brasiliensis* is a nondurable wood and reportedly recorded a weight loss of 61% and 65% following 12 and 16 weeks exposure, respectively to *T. versicolor* (Jusoh and Kamdem 2001; Rahman *et al*. 2013). Among the *Acacia* species, *A. mangium* and *Acacia* hybrid recorded the highest weight loss due to *T. versicolor*. *Rigidoporus microporus* apparently decayed *A. auriculiformis* the most. All *Acacia* species seem to be less susceptible to *S. commune.*

Further analyses of weight loss showed that no significant differences were found in *Acacia* species after exposure to *T. versicolor* and *S. commune*. *Rigidoporus microporus* resulted in significantly higher weight loss of *A. auriculiformis* than the other *Acacia* species. *Hevea brasiliensis* was more susceptible to decay compared to *Acacia* species in this study. *Acacia auriculiformis* and *Acacia* hybrid heartwoods were classified as durable with weight loss of less than 5% following 3 months exposure to *T. versicolor* and *Tyromyces palustris* in an accelerated test (Yamamoto *et al.* 2003). In a soil burial test, *Acacia* hybrid exhibited weight loss of 14.3% following 12 months of soil burial (Khalil *et al.* 2010).

Table 4. Mean Weight Loss of *A. mangium, A. auriculiformis,* Second-generation *A. mangium, Acacia* Hybrid, and *H. brasiliensis* after Ten Weeks of Exposure to *T. versicolor, S. commune*, and *R. microporus*

Species	Mean weight loss (%)		
	T. versicolor	*S. commune*	*R. microporus*
Acacia hybrid	10.2 a (3.4)	1.5 a (0.4)	3.4 a (0.9)
A. mangium (2nd generation)	7.6 a (2.3)	1.4 a (0.2)	4.7 a (1.2)
A. mangium	11.2 a (4.2)	1.8 a (1.1)	5.6 a (3.0)
A. auriculiformis	7.2 a (3.2)	1.4 a (0.7)	8.9 b (1.7)
Hevea brasiliensis	38.8 b (4.8)	11.3 b (2.9)	18.5 c (4.1)

Means within a column followed by the same letter are not significantly different at 5% level. Values in parentheses represent standard deviation.

Visual ratings of test samples for termite resistance test were based on a rating consisting of numbers from 0 to 10, which indicate 0 as failure due to attack and 10 as completely sound, or undamaged. The mean visual rating of test samples is represented in Table 5. *Hevea brasiliensis* recorded the lowest mean scores at 2.2, while second-generation *A. mangium* recorded a mean score of 3.0. *Acacia mangium* and *A. auriculiformis* were rated at 3.7. The *Acacia* hybrid score was averaged at 6.1. Attack of termites on *H. brasiliensis* and second-generation *A. mangium* were categorized as heavy damage. Based on this rating, *Acacia* hybrid was classified as moderately resistant, and the rest of the samples were classified as non-resistant to termites attack. In a four-week in-ground termite test, *A. mangium* was rated as susceptible to subterranean termites with mean visual rating of 4.8 (Wong *et al.* 1998).

Table 5. Visual Ratings of *A. mangium, A. auriculiformis, A. mangium,* Second-generation *Acacia* Hybrid and *H. brasiliensis* Exposed to 150 workers and 50 Soldiers of *Coptotermes curvignathus* for Three Weeks in a No-choice Laboratory Test

Tree species	Visual Rating	Classification
Acacia hybrid	6.1	Moderately resistant
A. mangium (2nd generation)	3.0	Non-resistant
A. mangium	3.7	Non-resistant
A. auriculiformis	3.7	Non-resistant
Hevea brasiliensis	2.2	Non-resistant

The results of the termite resistance test in terms of weight loss of the test samples after three weeks exposure to *Coptotermes curvignathus* following a no-choice laboratory test are shown in Table 6. *Hevea brasiliensis* and second-generation *A. mangium* recorded the highest mean weight loss (19.4%). Weight loss of *A. auriculiformis* was averaged at 18.1%, *A. mangium* at 17.5%, and *Acacia* hybrid recorded the lowest weight loss averaged at 8.4%. There are significant differences in weight losses due to termite attack between *Acacia* hybrid and all the four *Acacia* species. In a no choice laboratory test of *A. mangium* exposed to 400 *Coptotermes formosanus* for four weeks, Grace *et al*. (1998) recoded mean weight loss of 7.1%. Higher mean weight loss for *A. mangium* was recorded (23%) following an in-ground termite test (Wong *et al.* 1998). The results indicated that all species, except for *Acacia* hybrid, were susceptible to termite attack.

Table 6. Results of Three Weeks, No-choice Laboratory Test of *A. mangium, A. auriculiformis,* Second-generation *A. mangium, Acacia* Hybrid with a *H. brasiliensis* as Control, Exposed to 150 workers and 50 Soldiers of *Coptotermes curvignathus*

Tree species	Mean weight loss		Mean Termite mortality
	Weight loss (mg)	Weight (%)	%
Acacia mangium	227.4 b	17.5 b	99.17
Acacia auriculiformis	227.1 b	18.1 b	99.17
Acacia mangium (2nd generation)	197.4 b	19.4 b	99.33
Acacia hybrid	124.3 a	8.4 a	99.33
Hevea brasiliensis	303.7 b	19.4 b	98.00

Means within a column followed by the same letter are not significantly different at 5% level.

CONCLUSIONS

1. Basic density and static bending values of second-generation *A. mangium* were significantly lower than all *Acacia* species determined. Anatomical properties in the hybrid were closer to that of *A. mangium* than *A. auriculiformis*. Based on the

fibre morphology, it can be concluded that all the acacias presented here have the potential to be used as raw material for pulp and paper industry.

2. *Acacia* hybrid was classified as moderately decay resistant. Other *Acacia* species were also found to be moderately decay resistant except for *A. auriculiformis* which was durable. The order of decreasing severity of fungal attack was *T. versicolor*, *R. microporus*, and *S. commune.*
3. Based on visual ratings, all the woods are susceptible to termite attack except for *Acacia* hybrid. This study showed that second-generation *A. mangium* was most susceptible to termite attack.

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