Growth performance of *Acacia mangium* provenances in Parung Panjang, Bogor and its correlation with physical and mechanical wood properties

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Abstract. Wood quality and growth are two important parameters that need to be analyzed for the utilization and selection of superior genotypes. The objective of this research was to investigate the ten provenances growth characteristics and their physical and mechanical properties of *Acacia mangium* at Parung Panjang, Bogor. The provenance trial was arranged in three blocks of a randomized completely blocks design. In every provenance, 18 trees were sampled resulting in a total of 180 trees in each block representing each provenance measured for their total height, clear bole height, stem diameter at breast height, stem form, branching system, and crown form. Three individual trees were selected randomly from each provenance for wood properties traits, i.e. moisture content, density, modulus of elasticity (MOE) and modulus of rapture (MOR). Significant differences among provenances were detected for stem diameter, clear bole height, branching system and crown form, while total height and stem form revealed not significantly different. Most of growth parameters was not significantly correlated with physical and mechanical wood traits, except for MOR, it revealed significant correlation with the total tree height, stem form, and branching system. Generally, some growth characteristics were not a good indicator for selecting the best provenance in wood properties. The best growth performance was revealed by Kiriu/Serisa WP, Bimadebun Village, and Balimo District, but from wood quality, the superior provenance was revealed by Bimadebun Village with the lower moisture content, the highest wood density, the highest MOE and MOR. The Bimadebun Village provenance is potential to be developed as provenance seed stand, especially for solid (contraction) wood.

1. Introduction

*Acacia mangium*, although turned out to be prone to a number of diseases [1,2], but it is still planted for pulp and paper production in most of forest plantation areas in Indonesia. Total area of plantation forest of this species in the country has reached 1.78 million ha [3]. The species is still promising, partly because of its far superior growth, wide site suitability, multiple uses and also it was easy to plant large areas as planting material was not difficult to obtain [4]. *A. mangium* wood makes attractive furniture and cabinets, molding, door and window components [5]. The wood is also suitable for light structural works, agricultural implements, boxes, crates [6], and decorative veneers [4]. At the present, the species have been planted in community forest especially in Java, for fulfilling the necessary of construction materials.

*Acacia mangium* has a fragmented natural distribution stretching from the Moluccas islands in Indonesia to Western Province of Papua New Guinea and northeastern Queensland in Australia. Many provenances that highly adapted to their natural habitats have been identified and studied, and they have shown variation among them in all respects [6]. International provenance trials were established during the 1980s and some trials revealed highly significant provenance differences in growth trait among experimental sites and provenance regions were observed [7]. For example, growth was generally faster at near-equatorial trial sites with mean annual height increment around 3-4 m, and slower at sites further from the equator. Papua New Guinea provenances were consistently the best performers, closely followed by the Claudie River.
provenance from north Queensland. The slowest growing provenances were from the Maluku province of Indonesia and southern parts of the distribution in Queensland. Other studies have given similar results that the PNG provenances had better growth performance than the Queensland provenances [8-10]. In wood characteristics, provenances were significantly affected to wood physical characteristics of *A. mangium*, but they were not significant on mechanical wood characteristics [11].

One of the main factors driving wood quality property difference is growth rate [12]. It is considered to influence wood density in a way that varies among the major tree groups (softwoods, ring-porous and diffuse-porous hardwoods). In the two groups of hardwoods, wood is affected differently by growth rate. In ring-porous hardwoods most studies indicated that high wood density is associated with fast growth [12-14]. On the other study on *Eucalyptus camaldulensis*, there were no significant differences in basic, oven-dry and green density values between fast and slow growth [15]. Growth rate differences have little effect on wood property of hardwoods [16-17], however, a quantitative assessment of the relationship between growth and wood quality is needed in the effective forest management [18]. Wood quality and growth are two important parameters that need to be analyzed for the utilization and selection of superior genotypes [19].

The objective of this research was to investigate the provenances growth characteristics and their physical and mechanical wood properties of *A. mangium*. A better understanding on the relationship between the provenances and wood quality will be helpful in making silvicultural strategies to produce high quality wood by the selecting the best provenance for establishing forest plantations.

2. Materials and methods

2.1. Materials
Growth and wood quality evaluation were conducted on 10 years of *A. mangium* provenance trial at Parung Panjang Forest Research Station (lat. 106° 6', long. 06° 20') Bogor, West Java. Ten provenances were evaluated for growth and wood properties. Table 1 presented the list of the 10 *A. mangium* provenances from Australia Tree Seed Centre, CSIRO Division of Forestry, collected from Queensland (Australia) and Papua New Guinea (PNG). The altitude of the planting site at Parung Panjang Forest Research Station is 51 m above sea level. Soil type is podzolic haplic with pH 4.8. The soil fertility, organic matter, nitrogen, phosphor, and potassium contents are low. The climate falls into type A according to Schmidt and Ferguson classification, with an annual rainfall between 2000 and 2500 mm (dry season 6-8 months/year) [20]. The original vegetations on the site were dominated by *Imperata cylindrica* grassland and *Schima wallichi* coppices.

| Provenance code | Origin of provenances | Latitude (S) | Longitude (E) | Altitude (m asl) |
|-----------------|-----------------------|--------------|---------------|-----------------|
| 16937           | Balimo District, PNG  | 8°17'        | 143°06'       | 30              |
| 16938           | Kini WP, PNG          | 8°05'        | 142°58'       | 12              |
| 17866           | Lake Murray, PNG      | 6° 51'       | 141°29'       | 55              |
| 17946           | Claudia River, Queensland | 12°48'   | 143°18'       | 20              |
| 18057           | Kuru, PNG             | 8°52'        | 143°05'       | 30              |
| 18204           | Bimadebun Village, PNG | 8°38'     | 142°03'       | 40              |
| 18206           | Arufi Village, PNG    | 8°43'        | 141°55'       | 25              |
| 18209           | Kiriwo/Serisa WP, PNG | 8°25'     | 141°30'       | 45              |
| 18216           | Wipin District-PNG    | 8°47'        | 142°52'       | 45              |
| 18207           | Mata Area WP-PNG      | 8°41'        | 141°51'       | 20              |

Source: Australia Tree Seed Centre, CSIRO Division of Forestry (file no. DA1/145)
2.2. Experimental Design and Growth Measurement
The *A. mangium* provenance trial approximately covers 3 hectares was planted in a randomized complete block design with 3 blocks and the spacing was 3 m x 3 m. In each block, provenance was represented by one plot of 40 trees (5 trees x 8 trees). In every provenance, 18 trees in the middle of plot were sampled randomly resulting in a total of 180 trees in each block representing every provenance. With three blocks, in total the sample trees were 540 trees.

Sampled trees were measured for their total height, clear bole height, stem diameter at breast height, stem form, branching system, and crown form. The stem form, branching system, and crown form were assessed based on field observation on typical trees and their categories as shown in Figure 1. Scoring system (1 up to 5) was utilized to assess the stem form, branching system, and crown form parameters.

![Stem forms scoring](image)

**Stem forms scoring:**
1: very crooked
2: crooked and leaning
3: straight, crooked begin at 5 m
4: straight, but leaning
5: very straight

![Branching system scoring](image)

**Branching system scoring:**
1: forking below at 5 m
2: forking above at 5 m
3: branches at a narrow angle, and big size at the base of crown.
4: big branches at the top of crown
5: small branches with width angle

![Crown form scoring](image)

**Crown form scoring:**
1: very small and thin crown
2: small and thin crown, oval form
3: small crown and divided in two part with heavy branches
4: big crown with heavy branches
5: big crown with small branches

**Figure 1.** Categories and scoring of stem form (a), branching system (b), and crown form (c)

2.3. Measurement of Physical and Mechanical Properties
Three trees, one tree per block, were randomly selected from each provenance and cut into logs. Wood samples were taken from each log by extracting 1.5 m long log from 3 parts of stem, i.e. the bottom, middle and tip of clear bole stem. The size and sampling technique from each tree, and physical and mechanical testing methods were carried out according ASTM D.143-94: Methods of testing small clear specimen of timber [21]. Physical testing was carried out on air dry moisture content and density, while the mechanical testing was conducted on static bending (modulus of elasticity, MOE and modulus of rapture, MOR)

2.4. Statistical Analysis
The data were analyzed using randomized completely block design to compare among provenances growth traits, while for wood properties (air dry moisture content, density, modulus of elasticity, and modulus of rapture), data analysis used complete randomized design. Duncan’s multiple range test at a significance level $p<0.05$ was used to compare significant differences in the means. Pearson correlation analysis was used to study the relationship among growth traits and some wood properties characteristics.
3. Result and Discussion

3.1. Provenances Growth Characteristics

The growth characteristics of *A. mangium* provenances in Parung Panjang, Bogor showed significant differences in stem diameter, clear bole height, branching system and crown form, while total height and stem form revealed not significantly different. The best growth in stem diameter was the provenance of Balimo District that reached 29.11 cm but was not different significantly from the provenances of Bimadebun Village and Kiriwo/Serisa WP, in through out of PNG. Total height varied from 20 cm until 23 cm, clear bole height varied from 14.80 m until 18.60 m and stem form varied from 3.47 until 4.13 (Tabel 2).

| Provenance                  | Stem diameter (cm) | Total tree height (m) | Clear bole height (m) | Stem form | Branching system | Crown form |
|-----------------------------|--------------------|-----------------------|-----------------------|-----------|------------------|------------|
| Balimo District, PNG        | 29.11 a            | 22.00                 | 17.03 bcd             | 3.60      | 4.20 a           | 2.00 bc    |
| Kini WP, PNG                | 26.68 bc           | 22.93                 | 16.33 bcd             | 3.47      | 4.13 a           | 1.93 bc    |
| Lake Murray, PNG            | 26.07 cd           | 20.87                 | 16.03 cde             | 4.13      | 3.93 b           | 2.87 a     |
| Claudia River, Queensland   | 27.16 bcd          | 21.07                 | 16.33 bcd             | 3.80      | 4.60 bc          | 2.07 bc    |
| Kuru, PNG                   | 27.01 bcd          | 20.33                 | 15.90 de              | 4.13      | 3.73 abc         | 1.27 d     |
| Bimadebun Village, PNG      | 27.95 ab           | 20.60                 | 18.60 a               | 4.00      | 4.00 ab          | 2.53 ab    |
| Arufi Village, PNG          | 27.78 b            | 20.83                 | 15.80 de              | 3.73      | 3.93 b           | 2.60 ab    |
| Kiriwo/Serisa WP, PNG       | 28.42 ab           | 21.33                 | 17.60 ab              | 3.80      | 4.13 a           | 2.93 a     |
| Wipim District-PNG          | 25.97 d            | 20.07                 | 16.43 bcd             | 4.07      | 3.33 c           | 1.67 cd    |
| Mata Area WP-PNG            | 27.23 bc           | 22.37                 | 14.80 e               | 4.00      | 4.00 ab          | 2.03 bc    |

F test

| - Provenance | 2.923* | 0.451ns | 5.737** | 1.248ns | 3.084* | 6.081** |
|--------------|--------|---------|---------|---------|--------|---------|
| - Block      | 12.424** | 0.001ns | 14.040** | 6.371** | 172.108** | 0.194ns |

Notes: Different letters within a column indicate significant differences at P < 0.05; *Significant at P < 0.05; **Significant at P > 0.01; ns= no significant.

Branching system scoring varied from 3.33 to 4.13. The best branching system on trees is shown by the branches in the top crown [22]. In addition, the formed branches are relatively small. In the young trees, they are possibly used to self-pruning. The poor branching system is signed by the branches that are grown in the lowest position of the stem and big sizes, so it will affect the wood quality. The best performance for branching system was showed by Balimo District, Kini WP and Kiriwo/Serisa WP. Bimadebun Village provenance showed better clear bole height than others, while for branching system, Balimo District, Kini WP and Kiriwo/Serisa provenances had the highest values. The crown form which revealed the good performance was showed by Lake Muray and Kiriwo/Serisa WP provenances.

The difference in growth performance of *A. mangium* were influenced by site condition and genetic that implied in provenance itself. The tree survival and adaptability is often related with provenances (geographic) variation [23]. Genetically controlled provenance (geographic) differences are often large, especially for traits related to adaptability. The best provenance in a given site is the one that most suite to the site. Generally, provenance trials showed significant variation in height and diameter among *A. mangium* provenances as well as a significant interaction between site and provenance [24].

Some provenances revealed the best provenances based on the best performance on more the two growth parameters, such as Balimo District (stem diameter and branching system), Kiriwo/Serisa WP (stem diameter, clear bole height, branching system, and crown form), and Bimadebun Village (stem diameter,
clear bole height, branching system and crown form) provenances. The characteristics of stem diameter, clear bole height, stem form and branching system affect wood quality and values. The branching system and crown form will be more useful when the tree plays as tree seed in a tree seed stand. These parameters could be implied the capability of the seed source in seed production [10].

3.2. Physical and Mechanical Properties

Effects of provenances on wood moisture content and density of *A. mangium* were significant. Wood samples from all of the trees that were sampled for this study had air moisture content varied from 15.9% (Balimo District and Bimadebun Village provenances) to 17.4% (Lake Murray provenance) (Table 3). The *A. mangium* wood moisture content in Malaysia was reported an average of 17% and 15.5% [25], while the other study showed the moisture content at 12%±2% [26]. Moisture content was known to have a great influence on strength [27].

The most essential wood properties for solid wood like sawn timber and poles (construction material) are technical quality of stems, density, strength and shrinkage [28]. The density of *A. mangium* varies depending on the provenance, ranged from 0.493 g/cm³ to 0.559 g/cm³ (Table 3). The study on *A. mangium* wood density in Sabah, Malaysia reported the ranges of wood density from 420-483 kg/m³ based on green soaked volume [29], while the other study reported the wood density of *A. mangium* for the 8 years old ranged between 420-483 kg/m³, and the wood density of *A. mangium* increases with age [30].

| Provenance                        | Moisture content (%) | Density (g/cm³) | MOE (kg/cm²) | MOR (kg/cm²) |
|----------------------------------|----------------------|----------------|--------------|--------------|
| Balimo District, PNG             | 15.9 b               | 0.523 ab       | 83825        | 617.5        |
| Kini WP, PNG                     | 16.2 b               | 0.496 b        | 82737        | 596.2        |
| Lake Murray, PNG                 | 17.4 a               | 0.499 b        | 92286        | 677.9        |
| Claudia River, Queensland        | 17.2 a               | 0.502 b        | 86977        | 668.1        |
| Kuru, PNG                        | 17.1 ab              | 0.519 ab       | 93592        | 701.7        |
| Bimadebun Village, PNG           | 15.9 b               | 0.559 a        | 101297       | 708.5        |
| Arufi Village, PNG               | 17.6 a               | 0.512 ab       | 91806        | 645.0        |
| Kiriwo/Serisa WP, PNG            | 16.9 ab              | 0.493 b        | 95616        | 649.6        |
| Wipin District-PNG               | 17.1 ab              | 0.502 b        | 79221        | 606.9        |
| Mata Area WP-PNG                 | 16.1 b               | 0.521 ab       | 90787        | 648.3        |

F test 16.17* 2.31* 1.36** 1.84**

Notes: Different letters within a column indicate significant differences at P < 0.05; *Significant at P < 0.05; **Significant at P > 0.01; ns= no significant.

MOE and MOR was not affected by the provenances. The similar result was reported in Malaysia that the mean values of MOE and MOR of several provenances were not significantly different at 95% confidence level [31]. On the other hand, the effects of provenance were found to be significant for both MOE and MOR [32]. Differences of the result may be becoming from differences of sites. The MOE and MOR in this study for individual tree varied from 79221 kg/cm² (Wipin District provenance) to 101297 kg/cm² (Bimadebun Village provenance), and 596.2 kg/cm² (Kini WP provenance) to 708.5 kg/cm² (Bimadebun Village provenance), respectively (Table 3). The other study reported the MOE of *A. mangium* at 16 years old from Johore, Malaysia with MOE ranged of 77360-104210 kg/cm² [33]. MOE and MOR are among the most important properties of the wood associated with structural quality. It is commonly used to evaluate the stiffness and strength of the wood.
3.3. Correlation among Growth Traits and Wood Properties

Simple correlation was calculated between growth parameters showed that branching system revealed positive correlation with stem diameter ($r = 0.665$) and total tree height ($r = 0.708$) (Table 4). In construction, stem form, stem diameter, and the clear bole height of wood are preferred because they are related to strength, flexibility and easiness to work. The log wood would be more efficient in use as log sawn when the stem form looked more perfect in the straightness and the height of clear bole. In this research, stem form was not significantly different among provenances and not significantly correlated with other growth traits because the stand was planted in relative dense with the spacing of 3 m x 3 m. The stem form of *A. mangium* was affected more by the environment when the trees are young than the seed origin [10].

|                      | Stem diameter (cm) | Total tree height (m) | Clear bole height (m) | Stem form | Branching system |
|----------------------|--------------------|-----------------------|-----------------------|-----------|------------------|
| Total tree height    | 0.369              |                       |                       |           |                  |
| Clear bole height    | -0.248             | 0.442                 |                       |           |                  |
| Stem form            | -0.393             | 0.496                 | -0.300                |           |                  |
| Branching system     | 0.665*             | 0.708*                | 0.045                 | -0.508    |                  |
| Crown form           | 0.321              | 0.221                 | 0.120                 | 0.011     | 0.510            |

Note: **Significant at P < 0.01

Some growth parameters have had significant correlation with wood properties. The total tree height, stem form, and branching system were revealed significant correlation with MOR, with coefficient of correlation -0.678, 0.719 and -0.785, respectively (Table 5). Modulus of Rupture, frequently abbreviated as MOR, (sometimes referred to as bending strength), is a measure of a specimen’s strength before rupture. It can be used to determine a wood species’ overall strength.

|                      | Moisture content | Wood density | MOE | MOR     |
|----------------------|------------------|--------------|-----|---------|
| Stem diameter        | -0.136           | -0.206       | -0.388 | -0.538 |
| Total tree height    | -0.466           | -0.361       | -0.476 | -0.687*|
| Clear bole height    | -0.090           | -0.407       | -0.065 | -0.219 |
| Stem form            | 0.254            | 0.327        | 0.485  | 0.719*  |
| Branching system     | -0.054           | -0.612       | -0.559 | -0.785**|
| Crown form           | 0.298            | -0.489       | -0.069 | -0.314  |

Note: * Significant at P < 0.05

Most of growth parameters was not significantly correlated with physical and mechanical wood properties. This result indicated that the most of growth characteristics were not a good indicator for selecting the physical and mechanical wood properties of *A. mangium*, except for total tree height, stem form, and branching system. Similar study was reported on *Eucalyptus camaldulensis*, that stated there were no significant differences in basic, oven-dry and green density values between fast and slow growth [15]. The other study also stated that not significant association was found between wood basic density and growth and form traits of *Pinus ponderosa*, except for stem straightness [34]. Some studies also reported that growth rate differences have little effect on wood property of hardwoods [16,17]. The provenance that
growing faster compared to other provenances does not mean will affect the wood physical and mechanical traits [12], and there is no consistent relationship was found between wood physical and mechanical traits and growth rate in diffuse-porous hardwoods [35].

Most of the correlation was a negative, except for stem form. The negative correlation indicated that increase of growth caused the decrease of wood quality. The genetic correlations between stem straightness and growth traits in the progeny test of *A. mangium* in Malaysia were favourable but weak, while those between growth traits and dynamic modulus of elasticity (MoE) were weak and unfavourable [36]. The result was similar with the study on *Pinus radiata* [37]. The other studies also reported a weak genetic control in the stem form (tendency for forking and in straightness of the bole) for *A. mangium* provenances [7,38]. The substantial difference in the forking of *A. mangium* was found among provenances, but an even larger difference between different locations among some provenances [6].

3.4. Implication for Provenances Seed Stand

For solid wood like sawn timber and poles (construction material) the most essential wood properties are technical quality of stems, density, strength and shrinkage [28]. In construction, straight stem or wood is preferred because straightness is related to strength, flexibility and easiness to work. Stem straightness is a big factor affecting harvesting efficiency [39]. The best performance of *A. mangium* based on growth traits was Kiriwo/Serisa WP Bimadebun Village, and Balimo District, but from wood physical and mechanical traits, the superior provenance was revealed by Bimadebun Village with the lower moisture content, the highest wood density, MOE and MOR. The provenance is potential to be developed as provenance seed stand, especialy for solid (contruction) wood.

4. Conclusion

Provenance difference was significant affected on growth performance of *A. mangium*, except for total height and stem form. Most of growth parameters was not significantly correlated with wood physical and mechanical traits, except for MOR, it revealed significant correlation with the total tree height (r = -0.678), stem form (r = 0.719), and branching system (-0.785). Generally, some growth characteristics were not a good indicator for selecting the best provenance in physical and mechanical wood properties of *A. mangium*. The best performance of *A. mangium* based on growth traits was Kiriwo/Serisa WP Bimadebun Village, and Balimo District, but from wood physical and mechanical traits, the superior provenance was revealed by Bimadebun Village with the lower moisture content, the highest wood density, the highest MOE and MOR. The provenance is potential to be developed as provenance seed stand.

Acknowledgement

This study was funded by the Forest Tree Seed Technology Research and Development Institute. The authors are grateful to Nurwati Hadjib for helping in the wood quality testing and the operational staffs in Parung Panjang Forest Research Station who helped in field data collection.

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