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# Characterization of natural provenances of *Acacia mangium* Willd. and *Acacia auriculiformis* A. Cunn. ex Benth. in Malaysia based on phenotypic traits

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**Abstract**

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*Acacia mangium* Willdenow and *Acacia auriculiformis* A. Cunningham ex Bentham and their hybrid have become important planting species in Malaysia. Due to their high demand and consumption, development of high quality planting materials is desired. Conventional breeding of *Acacia* Miller is slow but the utilization of marker-assisted selection breeding can expedite the breeding process. Markers associated with quantitative trait loci (QTLs) required pedigreed populations whereas association mapping can be used directly on diverse germplasm. This study was conducted to screen provenances of *A. mangium* and *A. auriculiformis* of different geographical origins for their performance under the Malaysian environment. *A. mangium* exhibited superior traits compared to *A. auriculiformis*. More trait variation was observed within and between provenances of *A. auriculiformis*. Provenances from Queensland (QLD) were superior to those from Papua New Guinea (PNG) and Northern Territory. The best performing provenance with all three superior traits was from Claude River QTL of *A. mangium* and the worst was Bensbach Western Province, PNG belonging to *A. auriculiformis*. For individual traits like DBH, Morehead, PNG was superior. For plant height, Morehead, PNG was the superior provenance for *A. mangium* and Morehead River, QLD was from *A. auriculiformis*. For stem straightness the *A. auriculiformis* provenance Jardines Garden, QTL was superior to West of Morehead (PNG) for *A. mangium*. Multivariate analysis grouped provenances together based on similar traits and genetic similarity. These provenances can be used for seed families which can be treated as a homogeneous population for association mapping or for the development of segregating hybrid populations for *Acacia* breeding. For the purpose of utilization, provenances of *A. mangium* can be used for sawn timber. For fuelwood and charcoal industries, *A. auriculiformis* provenances should be preferred by selecting multi-stemmed trees. The most variable provenances with superior phenotypic traits can be integrated with the genotypic data e.g. single nucleotide polymorphism markers for association mapping to identify quantitative trait loci for marker-assisted breeding.

**Keywords**: fuelwood; pulp production; association mapping; phenotypic selection; selection breeding

Acacias are an important global resource, more than 3.5 million ha are grown in Asia, Africa and South America (Griffin et al. 2011). *Acacia auriculiformis* A. Cunningham ex Bentham and *Acacia mangium* Willdenow are two of the most common plantation tree species that are widely planted in Asia, primarily in Malaysia, Vietnam, Indonesia, the Philippines and Thailand. Both species are gaining a high priority in reforestation programs in the humid and sub-humid tropics and priorities for provenance research have been emphasized (Turnbull 1991; Khasa et al. 1994). They are also used for timber, fuel wood, pulp wood, tanning, soil improvement and agroforestry. Ever increasing demand for paper coupled with declining fibre supply from the forests of the world is forcing the pulp and paper industry to find technically and economically viable fibre sources to supplement forest-based resources (Jahan et al. 2008). It has been demonstrated that *Acacia* Miller species like *A. mangium*, *A. auriculiformis*, *Acacia crassicarpa* A. Cunningham ex Bentham and *A. mangium* × *A. auriculiformis* hybrid are suitable for timber and pulp production (Hardiyanto 2014). In Malaysia, high demand for the consumption of pulp and paper products has prompted the government to plan for the establishment of local pulp and paper industry through domestic production and also by ensuring steady supply of raw materials from sustainably managed forests as well as through development of commercial forest plantations. Development of 375,000 ha of forest plantations by planting of 25,000 $ha \cdot yr^{-1}$ reflects ambitious efforts achieving new goals under the Forest Plantation Program (Anonymous 2009). High priority is given to the planting of *Acacia* hybrid as the realization of its potential uses in various applications is increasing.

The genus *Acacia* includes more than 1,200 species of trees and shrubs that belong to the family Leguminosae and sub-family Mimosoideae. Most of the *Acacia* species can be found in Australia and the rest in Papua New Guinea (PNG), Africa, America and Asia. *Acacia* was first introduced into Malaysia directly from Australia and also via neighbouring countries in the 1930's. To date, eight *Acacia* species, i.e. *A. aulacocarpa* A. Cunningham ex Bentham, *A. auriculiformis*, *A. crassicarpa*, *Acacia farnesiana* (Linnaeus) Wight & Arnott, *Acacia holosericea* A. Cunningham ex G. Don, *A. mangium*, *Acacia podalyriifolia* A. Cunningham ex G. Don and *Acacia richii* A. Gray have been introduced into Malaysia (Hashim, Aminuddin 1994). *A. auriculiformis* was the first to be introduced into Malaysia in the year 1932 while *A. mangium* was introduced into Sabah from Queensland (QLD), Australia in 1966 (Hashim, Aminuddin 1994). At the age of 14 years, *A. mangium* grew up to 30 m tall, with a trunk of 40 cm in diameter. They grow so quickly that on good logged-over sites the canopy can close within one year of planting at a spacing of 3 × 3 m (National Research Council 1983).

Acacias have displayed excellent growth in Malaysia but they have also been affected by various diseases e.g. root rot and wilt (Potter et al. 2006). For example, *A. mangium* is highly susceptible to heart rot disease. Conversely crooked, twisted trunk of *A. auriculiform* makes it unsuitable for timber production (Kojima et al. 2009). Similarly, although *Acacia* hybrids prove superior to the parents, they still carry inferior parental traits such as high lignin content, low wood density, short fibre, resistance to insect pests, disease resistance and problems associated with production of viable seeds and recalcitrant germination either naturally or through controlled pollination (Kijkar 1992; Wickneswari, Norwati 1993). The breeding of elite *Acacia* planting materials meeting high industry standards and for sustainable production required finding promising materials carrying desired traits, i.e. low lignin content, high wood density, longer fibre length, straight stem, adaptation to different soil types, resistance to pests and diseases and high pulp yield (Hardiyanto 2014).

Conventional breeding in Acacias is hampered due to long reproductive cycle, difficulty in controlled crossing, production and germination of a large number of hybrid seed progenies (Ng et al. 2009). Therefore, breeding programs for *Acacia* like for most other forest trees have so far been based on recurrent selection from open-pollinated families (Butcher, Moran 2000). Marker-assisted selection (MAS) breeding is a promising approach for efficient selection of superior trees with improved wood and pulp properties for the establishment of forest plantations in a relatively shorter period compared with conventional breeding. MAS required development of quantitative trait locus (QTL) maps based on pedigreed populations segregating for desired trait/s. QTL mapping is laborious and technically demanding whereas genetic association mapping or linkage disequilibrium (LD) can be used directly on natural germplasm. Therefore, germplasm plays a key role in LD variation because the extent of LD is influenced by the level of genetic diversity captured by the population rather than by the number of individuals. Screening of natural germplasm for desired traits under local environmental conditions is a pre-requisite for association mapping. This study was initiated at assessing the variation in DBH, height and tree form within and between different provenances of *A. mangium* and *A. auriculiformis* originated from three different geographical regions of their place of origin, i.e. Northern Territory (NT), Australia, QLD, Australia and Papua New Guinea. Provenances found locally variable but closely related across different regions could be pooled and used for association mapping for QTL identification and MAS breeding.

## MATERIAL AND METHODS

The provenance trial was conducted at Plot A, Rumah Tumbuhan, University Kebangsaan Malaysia (UKM), Bangi Selangor, Malaysia. The latitudinal range of the plot is 02°55'N–02°56'N whereas the longitudinal range is between 101°46'E and 101°47'E. The altitude of the location was 29 m a.s.l. Seeds of *A. mangium* and *A. auriculiformis* were bought from the Australian Tree Seed Centre. Information about the two species' provenances is provided in Table 1. A total of 250 seedlings for each species were planted. Each of the provenances was represented by about 25 trees. For the measurement of growth parameters, 235 trees of *A. auriculiformis* and 248 trees of *A. mangium* were sampled. The age of the trees at the time of sampling was 29 months. The experimental design is a randomised complete block design with five blocks. Within each block, each provenance is represented by 5 trees in a plot, planted in a square of 5 × 5 trees. The trees have a spacing of 2 × 2 m.

**Climate**. The planting site had an average monthly temperature ranging from 23.6 to 24.8°C and a mean relative humidity of 95%. The temperature is of bimodal distribution with peaks in March to June and September to November. The duration from March to June was drier compared with September to November. Plot W, UKM experiences an average wind speed of 0.86 and 0.89 $m \cdot s^{-1}$, respectively. The mean total annual rainfall during the growing period ranged from 1,779.8 to 2,630.1 mm.

**Soil**. The parent material of Plot W, UKM Bangi, is mainly quartzite. The soils are primarily of Serdang series (Ultisols – Typic Paleudults), reddish brown in colour and sandy clay loam in nature. Texturally, the soil is a mixture of black loam and sandy clay with good drainage. The soil had high C, N, P and exchangeable bases in nature.

For the study of growth performance, four growth parameters, namely DBH, plant height, stem straightness and the formation of multiple leaders, were studied at 29 months of age after establishment. The latter two parameters represented the form of *A. mangium* and *A. auriculiformis*.

**DBH**. The diameter is measured at 1.3 m or 4.5 feet above the ground (Ek 1982). For multi-stemmed trees, the measurements were taken at 1.3 m a.g.l. for each stem.

Square root of the sum of squares of all individual stem diameters was used to calculate tree DBH of these multi-stemmed trees following Tuomela et al. (1996), as Eq. 1:

$$\text{DBH} = \left( \sum_{i=1}^{n} \text{DBH}_i^2 \right)^{\frac{1}{2}} \quad (1)$$

Table 1. Seedlot number, locality and geographical distribution of the *Acacia mangium* Willdenow and *Acacia auriculiformis* A. Cunningham ex Bentham provenances

| No. | Species | Locality | Label | Latitude | Longitude | Altitude (m a.s.l.) |
|---|---|---|---|---|---|---|
| 13231 | *A. mangium* | Northwest of Silkwood (QLD) | NSW | 17°42' | 145°57' | 40 |
| 13229 | | Claude River (QLD) | CRV | 12°44' | 143°13' | 60 |
| 13239 | | Syndicate Road Tully (QLD) | SRT | 17°55' | 145°52' | 50 |
| 13240 | | Ellerback Road Cardwell (QLD) | ERC | 18°14' | 145°58' | 60 |
| 13459 | | West of Morehead (PNG) | WMH | 08°45' | 141°18' | 30 |
| 13236 | | Kurrimine (QLD) | KRM | 17°46' | 146°05' | 10 |
| 19142 | | Binaturi (PNG) | BNT | 09°02' | 143°04' | 10 |
| 19139 | | Balimo Aramia River (PNG) | BAR | 08°03' | 142°38' | 15 |
| 17868 | | Morehead (PNG) | MHD | 08°45' | 141°37' | 40 |
| 18206 | | Arufi Village WP (PNG) | AVW | 08°43' | 141°55' | 25 |
| 17705 | *A. auriculiformis* | Olive River (QLD) | ORV | 12°11' | 142°59' | 4 |
| 16158 | | Gerowie Creek (NT) | GWC | 13°19' | 132°15' | 100 |
| 15477 | | Morehead River (QLD) | MHR | 15°02' | 143°40' | 70 |
| 18102 | | Mibini (PNG) | MBN | 08°50' | 141°38' | 18 |
| 16148 | | Manton River (NT) | MRV | 12°50' | 131°07' | 100 |
| 16149 | | Douglas River (NT) | DRV | 13°51' | 131°09' | 70 |
| 16160 | | South Alligator River (NT) | SAR | 13°16' | 132°19' | 40 |
| 18059/19390 | | Pohaturi River (PNG) | PRV | 09°10' | 142°11' | 40 |
| 15861 | | Jardines Garden (QLD) | JGD | 10°47' | 142°29' | 60 |
| 17553/18963 | | Bensbach Western Province (PNG) | BSW | 08°53' | 141°17' | 25 |

QLD – Queensland, PNG – Papua New Guinea, NT – Northern Territory

where:
$i$ – individual stem diameter,
$n$ – number of individual stem diameters.

**Tree height**. The height of the trees was measured in meters using a graduated pole. As the trees were closely planted, it was not possible to use a hypsometer. The height of multi-stemmed trees was taken at the highest point of the tree.

**Formation of multiple leaders**. The formation of multiple leaders was recorded as any branching that occurred below 1.3 m a.g.l.

**Stem straightness**. The stem straightness was observed and scored using a scale with four classes: 1 = very crooked stem with more than 2 serious bends, 2 = slightly crooked stem with 1 serious and/or more than 2 small bends, 3 = almost straight stem with 1 or 2 small bends, 4 = straight stem.

**Klason lignin determination**. Wood core samples were collected from different classes of tree form and dried at 70°C in an incubator and ground to powder form and passed through Thomas Willey mill, with a 10 mesh screen. Lignin content of wood tissues was determined using procedures described in TAPPI T 222-om-88 (Schoening, Johansson 1965). Klason lignin of the investigated tissues was determined from the extractive free wood. About 1 g of wood meal was placed in a 100 ml beaker followed by the addition of 15 ml of 72% $H_2SO_4$. The mixture was subjected to occasional stirring for 2 h at room temperature. The solution was transferred into a 1 l Erlenmeyer flask and topped up with deionized water until it reached 575 ml and refluxed for 4 h. The solution was filtered using crucible No. 4 and the acid insoluble lignin was determined gravimetrically.

### Statistical analysis

The DBH, height and tree form were analysed and provenance means were compared using one-way ANOVA. Tukey's post hoc test was carried out for traits with significant differences. This statistical analysis was carried out using the MINITAB statistical software (Version 14, 2006). As for the stem straightness evaluation qualitative data was presented in different frequency classes. The number of multiple leaders and stem straightness for each species were compared by region and provenance. Pearson correlation among the phenotypic traits was computed in R software (Version 3.2.1, 2011).

**Least-squares (LS) means and best linear unbiased predictors (BLUPs) analyses**. Based on the models, two sets of estimates are presented, i.e. the LS means and the BLUPs (White, Hodge 1989). The estimates for different provenances (seedlots) are usually calculated as the so called LS means. The main difference between raw means and LS means is that LS means account for missing values, imbalanced designs and effects of co-variates. In case of the complete and balanced design there are no differences between LS means and raw means. However, in all other cases the LS means are the best estimates for the given provenances in the trial and are often presented graphically to demonstrate the results of trial. In our studies several tree genotypes either died or were excluded due to the ridge effect thus leaving gaps in the data. Therefore to overcome the confounding effects LS means analysis was conducted. There is a difference between models regarding the effect of provenance as fixed or random variable when it comes to the calculation of estimation. Fixed effect approach is the conventional LS means method. However, there is an alternative using the random approach called BLUP. When the provenance effect is random, they are seen as representative of a larger group of provenances (the population). Since the purpose of the trial is to get an idea of the variation within this group of provenances rather than to investigate the specific provenances. In the random approach the provenances are believed to be a population, and the growth of individual provenances is seen as coming from a normal distribution with an expected value and a variance. In brief, the LS means give the best estimates of the performance of the chosen provenances at a trial site, whereas the BLUPs give the best indication of the range of variation within the species. It should be noted that in the calculation of BLUPs it is assumed that the provenances represent a random selection, which may be a critical assumption in this case. LS means and BLUP analyses were conducted by using "LS means" (Lenth 2016) and "lme4" (Bates et al. 2015) packages which were incorporated in R software environment.

**Multivariate analysis**. The estimated provenance means for DBH, plant height and tree form were subjected to principal component analysis (PCA). PCA was done in R software using the "prcomp" function. PCA is a multivariate technique which analyses data in which observations are described by several, usually intercorrelated quantitative dependent variables. Its goal is to extract the important information and to represent it as a set of new orthogonal variables called principal components (PCs), and to display the pattern of similarity of the observations and of the variables as the points in a map. The principal components analysis tries to reduce the number of variables by formation of new variables, i.e. principal components, where the first two or three of them would describe the greatest possible part of the total variation. These two, or at most three, principal components can then be conveniently used to represent a relationship between objects (provenances in this case) on two or three dimensional graphs.

## RESULTS

The provenances of both species showed high germination and survival rates. Trees at the edges were excluded to avoid the edge effect as they are less prone to competition from neighbouring trees and receive more sunlight, thus they are more productive. The number of *A. mangium* trees was reduced to 198 after about 20% of trees were excluded due to the edge effect. For *A. auriculiformis* 23 trees (10%) were excluded to circumvent the edge effect. Finally, 202 trees of *A. auriculiformis* were analysed for phenotypic trait evaluation.

### DBH

Ten provenances of *A. mangium* and ten of *A. auriculiformis* were evaluated for DBH and height and tree form. *A. mangium* provenances came from QLD and PNG whereas *A. auriculiformis* provenances belonged to three geographical regions, i.e. QLD, NT and PNG (Table 1). All traits were significantly different both within and between provenances originated from different geographical regions (Table 2). The mean and ranking of each provenance for *A. mangium* and *A. auriculiformis* in terms of DBH is shown in Table 3. The DBH between the provenances of *A. mangium* showed significant differences at $P \leq 0.05$. In the ranking based

Table 2. Results of ANOVA for DBH, height and tree form of *Acacia mangium* Willdenow and *Acacia auriculiformis* A. Cunningham ex Bentham provenances from Queensland (QLD), Northern Territory (NT) and Papua New Guinea (PNG) at 29 months of age

| Sources of variation | *df* | Mean square | *F*-value | Mean regional value | | |
|---|---|---|---|---|---|---|
| | | | | QLD | PNG | NT |
| *A. auriculiformis* | | | | | | |
| **DBH (cm)** | | | | | | |
| Between regions | 2 | 19.19 | 14.4** | 5.29 ± 1.38 | 4.24 ± 1.38 | 4.68 ± 1.19 |
| Within regions | 7 | 13.63 | 10.27** | | | |
| Residuals | 216 | 1.327 | | | | |
| **Plant height (m)** | | | | | | |
| Between regions | 2 | 48.45 | 19.76** | 7.38 ± 1.9 | 5.72 ± 1.5 | 6.89 ± 1.5 |
| Within regions | 7 | 16.71 | 6.82** | | | |
| Residuals | 216 | 2.45 | | | | |
| **Tree form** | | | | | | |
| Between regions | 2 | 7.11 | 9.77** | 2.86 ± 0.953 | 2.21 ± 0.977 | 2.52 ± 0.818 |
| Within regions | 7 | 3.82 | 5.25** | | | |
| Residuals | 216 | 0.727 | | | | |
| *A. mangium* | | | | | | |
| **DBH (cm)** | | | | | | |
| Between regions | 1 | 59.95 | 17.24** | 8.09 ± 2.06 | 7.11 ± 2.24 | |
| Within regions | 8 | 39.27 | 11.29** | | | |
| Residuals | 238 | 3.48 | | | | |
| **Plant height (m)** | | | | | | |
| Between regions | 1 | 48.56 | 25.81** | 10.57 ± 1.97 | 9.69 ± 1.14 | |
| Within regions | 8 | 24.06 | 12.79** | | | |
| Residuals | 238 | 1.88 | | | | |
| **Tree form** | | | | | | |
| Between regions | 1 | 0.004 | 0.007 | 2.64 ± 0.809 | 2.63 ± 0.923 | |
| Within regions | 8 | 5.658 | 9.59** | | | |
| Residuals | 238 | 0.590 | | | | |

*df* – degrees of freedom, **highly significant at $P > 0.01$

on the mean of DBH, the highest value was recorded by the provenance of Morehead, PNG with a mean of 8.94 cm followed by Claude River, QLD (8.86 cm), Ellerback Road Cardwell, QLD (8.62 cm), Northwest of Silkwood, QLD (8.59 cm), West of Morehead, PNG (8.47 cm), and Kurrimine, QLD (8.24 cm). Binaturi from PNG was the worst performer with 6.03 cm DBH. As for *A. auriculiformis*, four provenances from NT and three provenances from QLD and three from PNG were compared. DBH between provenances showed significant differences $P \leq 0.05$ (Table 3). The highest value in the overall ranking based on the DBH mean was observed for Mibini from PNG with a mean of 6.24 cm followed by Manton River, NT (6.17 cm), Morehead River, QLD (5.76 cm), and Jardines Garden, QLD (5.56 cm). Two provenances Bensbach Western Province, PNG and Pohaturi River from PNG possessed the lowest means at 3.97 and 3.38 cm, respectively (Table 3).

No clear diversity pattern was observed for either species between geographical regions based on DBH. In other words, we cannot conclude that provenances from a particular region were better than those from the others.

The species were significantly different as there were significant differences between the provenances of *A. mangium* and *A. auriculiformis* (Table 2). Both LS means and BLUP gave similar results but BLUP was significantly better in predicting the performance of the provenances. Among the provenances of *A. mangium* (Figs 1a and 2a) Claude River,

Table 3. Mean and ranking of each provenance for *Acacia mangium* Willdenow and *Acacia auriculiformis* A. Cunningham ex Bentham in terms of DBH

| Ranking | Provenances | DBH (cm) |
|---|---|---|
| ***A. mangium*** | | |
| 1 | Morehead, PNG | $8.94 \pm 1.32^{ab}$ |
| 2 | Claude River, QLD | $8.86 \pm 1.94^{ab}$ |
| 3 | Ellerback Road Cardwell, QLD | $8.62 \pm 2.22^{ab}$ |
| 4 | Northwest of Silkwood, QLD | $8.59 \pm 1.92^{ab}$ |
| 5 | West of Morehead, PNG | $8.47 \pm 1.46^{ab}$ |
| 6 | Kurrimine, QLD | $8.24 \pm 1.82^{ab}$ |
| 7 | Arufi Village Western Province, PNG | $7.91 \pm 2.23^{abc}$ |
| 8 | Syndicate Road Tully, QLD | $7.59 \pm 1.39^{abcd}$ |
| 9 | Balimo Aramia River, PNG | $6.35 \pm 1.06^{bcd}$ |
| 10 | Binaturi, PNG | $6.03 \pm 1.80^{cd}$ |
| ***A. auriculiformis*** | | |
| 1 | Mibini, PNG | $6.24 \pm 1.92^{ab}$ |
| 2 | Manton River, NT | $6.17 \pm 2.39^{ab}$ |
| 3 | Morehead River, QLD | $5.76 \pm 2.02^{ab}$ |
| 4 | Jardines Garden, QLD | $5.56 \pm 3.44^{ab}$ |
| 5 | Gerowie Creek, NT | $5.43 \pm 2.15^{ab}$ |
| 6 | Olive River, QLD | $5.21 \pm 2.53^{abc}$ |
| 7 | South Alligator River, NT | $5.11 \pm 2.41^{abc}$ |
| 8 | Douglas River, NT | $4.96 \pm 2.50^{abc}$ |
| 9 | Bensbach Western Province, PNG | $3.97 \pm 1.89^{bcd}$ |
| 10 | Pohaturi River, PNG | $3.38 \pm 1.65^{cd}$ |

Means designated with the same letter are not statistically significant at $P \leq 0.05$ as determined by Tukey's test

PNG – Papua New Guinea, QLD – Queensland, NT – Northern Territory

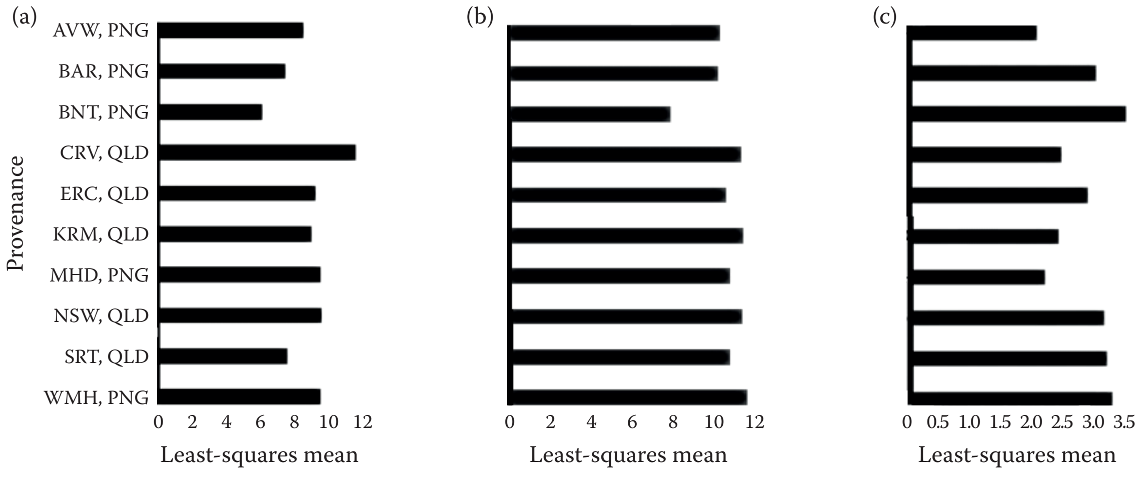


Fig. 1. Least-squares means analysis based on DBH (cm) (a), plant height (m) (b), tree form (c) for *Acacia mangium* Willdenow provenances. Values presented are least-squares means with 95% confidence limits. Claude River (CRV), Queensland (QLD) showed the best DBH whereas Binaturi (BNT), Papua New Guinea (PNG) had the lowest DBH. West of Morehead (WMH), PNG, Kurrimine (KRM), QLD were the tallest whereas BNT from PNG was the shortest provenance. BNT, PNG had the best tree form with a high frequency of trees that had straight bolls whereas Morehead (MHD), PNG had a high frequency of trees with crooked form

AVW – Arufi Village Western Province, BAR – Balimo Aramia River, ERC – Ellerback Road Cardwell, NSW – Northwest of Silkwood, SRT – Syndicate Road Tully

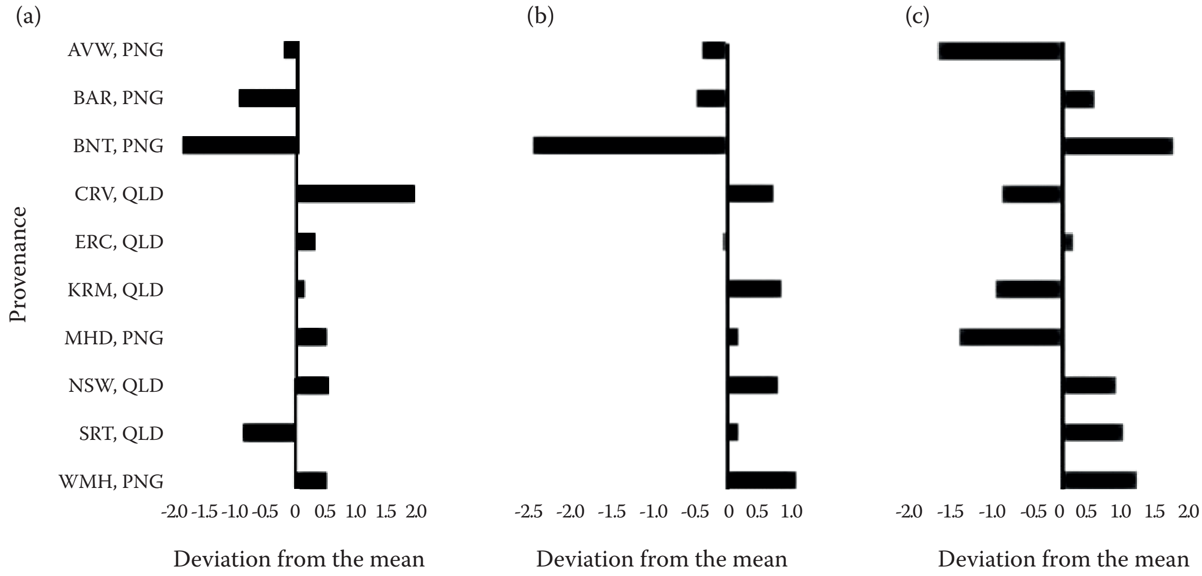


Fig. 2. Best linear unbiased predictors for DBH (cm) (a), plant height (m) (b), tree form (c) in *Acacia mangium* Willdenow provenances. Provenance Claude River (CRV), Queensland (QLD) showed superior DBH and the lowest was observed in Binaturi (BNT), Papua New Guinea (PNG). West of Morehead (WMH), PNG and Kurrimine (KRM), QLD showed similar plant heights whereas BNT, PNG were the shortest. BNT, PNG had the best tree form with a high frequency of trees that had straight bolls whereas Arufi Village Western Province (AVW), PNG and Morehead (MHD), PNG had a high frequency of trees with crooked form

BAR – Balimo Aramia River, ERC – Ellerback Road Cardwell, NSW – Northwest of Silkwood, SRT – Syndicate Road Tully

QLD was clearly the best with the predicted value of up to 200% of the mean value whereas Binaturi, PNG was the worst performer (Figs 1a and 2a). In case of *A. auriculiformis* (Figs 3a and 4a), Morehead River, QLD was 100% better performing than the mean and the lowest predicted DBH value was for Pohaturi River, PNG and Bensbach Western Province from PNG, respectively.

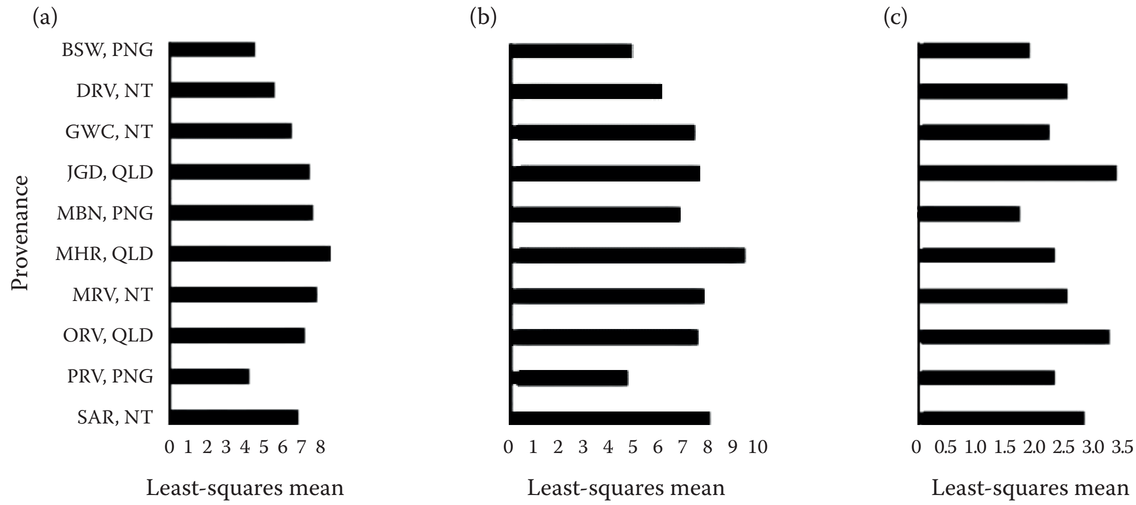


Fig. 3. Least-squares means analysis based on DBH (m) (a), plant height (b), tree form (c) for *Acacia auriculiformis* A. Cunningham ex Bentham provenances. Values presented are least-squares means with 95% confidence limits. Morehead River (MHR), Queensland (QLD) showed the best DBH whereas Pohaturi River (PRV) and Bensbach Western Province (BSW) both were from PNG had the lowest DBH. MHR, QLD provenance was the tallest whereas PRV, PNG had the shoetest height. Jardines Garden (JGD), QLD provenance had straight stem compared to very crooked and multi-stem bole in Mibini (MBN), PNG provenance

DRV – Douglas River, GWC – Gerowie Creek, MRV – Manton River, ORV – Olive River, SAR – South Alligator River

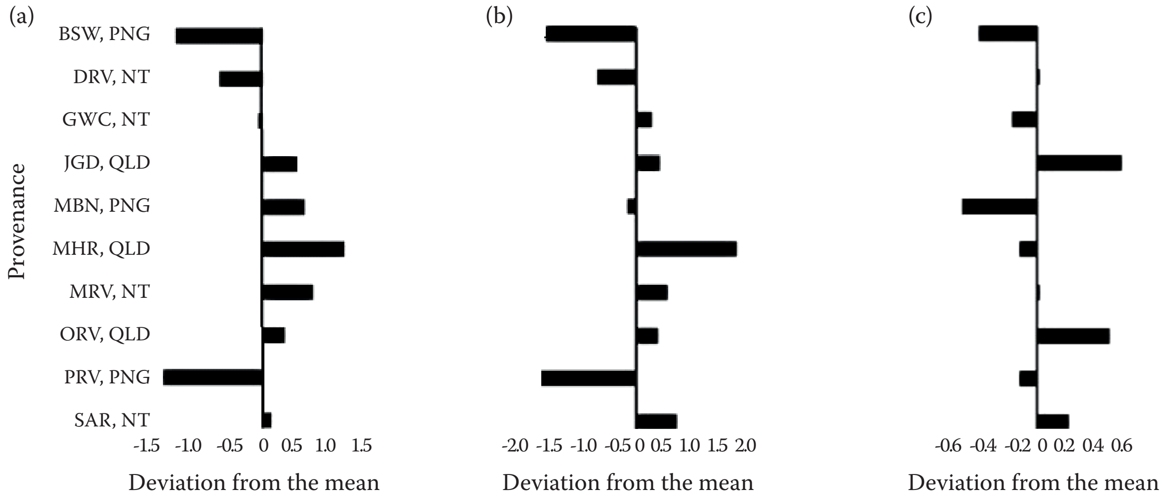


Fig. 4. Best linear unbiased predictors for DBH (cm) (a), plant height (m) (b), tree form (c) in *Acacia auriculiformis* A. Cunningham ex Bentham. Morehead River (MHR), Queensland (QLD) showed the best DBH whereas Pohaturi River (PRV) and Bensbach Western Province (BSW) from Papua New Guinea (PNG) had the lowest DBH. MHR, QLD provenance was predicted with 150% more mean height as compared to PRV, PNG and BSW, PNG with the shortest height. The best stem with straight bole and single stem were observed for Jardines Garden (JGD), QLD and Olive River (ORV), QLD provenances whereas the least desirable tree form was predicted for Mibini (MBN), PNG and BSW, PNG provenances

DRV – Douglas River, GWC – Gerowie Creek, MRV – Manton River, SAR – South Alligator River

## Plant height

Height is an important trait when selecting species or provenances, however, this depends on the main uses of the trees concerned. Apart from indicating productivity, height may also be seen as a measure of the adaptability of trees to the environment where tall trees/provenances usually thrive better than short provenances/trees. However, there have been cases where tall provenances are suddenly affected by stress and die-off of the plants, this interpretation need not always be true. Mean population height varied from 8 to 11 m for the best provenances (Table 4). The analysis of species differences supported the hypothesis of general differences in height between the two species (Table 4). The *A. mangium* shortest provenance was equal to the tallest provenance in case of *A. auriculiformis* (Table 4). Similarly the provenance effect was highly significant (Table 2). The best provenances were Claude River from QLD that had the highest value in terms of the overall ranking based on the mean of height followed by West of Morehead, PNG (11.03 m), Kurrimine, QLD (10.73 m), and Morehead, PNG (10.71 m). The provenance of Binaturi from PNG was the worst performing provenance in terms of height. Overall performances of provenances from QLD were better than those of PNG. Ten provenances of *A. auriculiformis* tested for height were found

Table 4. Mean and ranking of each provenance for *Acacia mangium* Willdenow and *Acacia auriculiformis* A. Cunningham ex Bentham in terms of height

| Ranking | Provenances | Mean height (m) |
|---|---|---|
| ***A. mangium*** | | |
| 1 | Claude River, QLD | 11.11 ± 1.10$^{abc}$ |
| 2 | West of Morehead, PNG | 11.03 ± 0.96$^{abc}$ |
| 3 | Kurrimine, QLD | 10.73 ± 0.97$^{abcd}$ |
| 4 | Morehead, PNG | 10.71 ± 0.91$^{abcde}$ |
| 5 | Northwest of Silkwood, QLD | 10.59 ± 1.12$^{abcde}$ |
| 6 | Syndicate Road Tully, QLD | 10.33 ± 0.75$^{abcde}$ |
| 7 | Ellerback Road Cardwell, QLD | 10.29 ± 1.53$^{abcde}$ |
| 8 | Arufi Village Western Province, PNG | 9.56 ± 1.90$^{bcde}$ |
| 9 | Balimo Aramia River, PNG | 9.43 ± 1.45$^{cdef}$ |
| 10 | Binaturi, PNG | 8.19 ± 2.06$^{ef}$ |
| ***A. auriculiformis*** | | |
| 1 | Morehead River, QLD | 8.33 ± 3.83$^{ab}$ |
| 2 | Mibini, PNG | 7.45 ± 2.05$^{abc}$ |
| 3 | Manton River, NT | 7.41 ± 2.43$^{abc}$ |
| 4 | Jardines Garden, QLD | 7.35 ± 4.59$^{abc}$ |
| 5 | South Alligator River, NT | 7.24 ± 3.31$^{abc}$ |
| 6 | Gerowie Creek, NT | 6.77 ± 3.24$^{bcd}$ |
| 7 | Olive River, QLD | 6.76 ± 2.65$^{bcd}$ |
| 8 | Douglas River, NT | 6.73 ± 3.40$^{bcd}$ |
| 9 | Bensbach Western Province, PNG | 5.32 ± 2.20$^{cde}$ |
| 10 | Pohaturi River, PNG | 4.61 ± 1.81$^{de}$ |

Means designated with the same letter are not statistically significant at $P \leq 0.05$ as determined by Tukey's test

QLD – Queensland, PNG – Papua New Guinea, NT – Northern Territory to be significantly different as indicated by their means (Table 4). The provenance of Morehead River from QLD had the highest value of 8.33 m. It was followed by Mibini (7.45 m) from PNG and Manton River (7.41 m) from NT. The two provenances with the lowest values of 5.32 and 4.61 m were Bensbach Western Province, PNG and Pohaturi River from PNG. Generally, *A. mangium* seemed growing faster as compared with *A. auriculiformis*. However, no correlation was observed between height and place of origin of provenances. Fast growth was observed within all provenances regardless of their place of origin. The provenances of *A. mangium* showed (Figs 1b and 2b) much more variation than the provenances of *A. auriculiformis* (Figs 3b and 4b). The best predicted provenance with almost 70% more height than the mean was West of Morehead, PNG with mean height of 11.03 m and 200% below the mean value was that of Binaturi from PNG with mean height of 8.19 m. In case of *A. auriculiformis*, Morehead River, QLD was 150% better than the mean with average height of 8.33 m and the least performer was Pohaturi River, PNG 160% below the mean and with a height of 4.61 m (Table 3).

## Tree form

The number of stems gives an indication of the growth habit of the species. Trees with a large number of stems are bushy, whereas trees with only one main stem have a more tree-like growth. The stem straightness was scored using a scale of four classes. Trees with almost straight stems with one or two small bends accounted for 48% of the total *A. mangium* (Table 5). This was followed by 27.8% of trees with slightly crooked stems. On the other hand, trees with very crooked stems and straight stems accounted for 24 trees each. Out of the total 24 trees with very crooked stems, 33.3% were from the provenance of Arufi Village Western Province, PNG followed by 29.2% from Morehead also from PNG, 12.5% from Kurrimine and 12.5% from Northwest of Silkwood, both from QLD (Table 5). In contrast, there were no trees from the provenances of Balimo Aramia River, PNG, Binaturi, PNG and Syndicate Road Tully from QLD with very crooked stems. This is a good indication of the provenances with good tree form.

As for the comparison between the regions, provenances from QLD made up about 47% of the

Table 5. Overall stem straightness of *Acacia mangium* Willdenow and *Acacia auriculiformis* A. Cunningham ex Bentham by provenances in response to the four classes

| Provenance | Stem straightness frequency (%) | | | | Frequency (%) | Provenance mean |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | | |
| ***A. mangium*** | | | | | | |
| Claude River, QLD | 4.2 | 9.1 | 2.1 | 0.0 | 2.3 | 2.28 ± 0.66 |
| Northwest of Silkwood, QLD | 12.5 | 3.6 | 13.7 | 12.5 | 11.4 | 2.92 ± 0.89 |
| Kurrimine, QLD | 12.5 | 18.2 | 10.5 | 0.0 | 15.9 | 2.24 ± 0.71 |
| Syndicate Road Tully, QLD | 0.0 | 9.1 | 14.7 | 8.3 | 22.7 | 2.96 ± 0.59 |
| Ellerback Road Cardwell, QLD | 4.2 | 10.9 | 8.4 | 20.8 | 9.1 | 2.79 ± 0.82 |
| West of Morehead, PNG | 4.2 | 3.6 | 15.8 | 20.8 | 6.8 | 3.04 ± 0.72 |
| Morehead, PNG | 29.2 | 14.5 | 5.3 | 0.0 | 6.8 | 2.12 ± 0.92 |
| ArufiVillage Western Province, PNG | 33.3 | 14.5 | 6.3 | 0.0 | 13.6 | 1.92 ± 0.79 |
| Balimo Aramia River, PNG | 0.0 | 12.7 | 12.6 | 12.5 | 6.8 | 2.8 ± 0.69 |
| Binaturi, PNG | 0.0 | 3.6 | 10.5 | 25.0 | 4.5 | 3.24 ± 0.65 |
| ***A. auriculiformis*** | | | | | | |
| Morehead River, QLD | 20.0 | 11.9 | 7.9 | 6.9 | 0.0 | 2.2 ± 1.81 |
| Jardines Garden, QLD | 0.0 | 3.0 | 11.8 | 31.0 | 4.9 | 3.33 ± 1.39 |
| Manton River, NT | 3.3 | 16.4 | 10.5 | 6.9 | 22.0 | 2.4 ± 1.51 |
| Douglas River, NT | 3.3 | 10.4 | 10.5 | 10.3 | 17.1 | 2.73 ± 1.64 |
| Gerowie Creek, NT | 16.7 | 9.0 | 11.8 | 0.0 | 24.4 | 2.21 ± 1.75 |
| South Alligator River, NT | 0.0 | 16.4 | 11.8 | 10.3 | 12.2 | 2.68 ± 1.48 |
| Mibini, PNG | 30.0 | 10.4 | 1.3 | 3.4 | 4.9 | 2.0 ± 1.88 |
| Bensbach Western Province, PNG | 10.0 | 9.0 | 11.8 | 0.0 | 2.4 | 2.25 ± 1.55 |
| Pohaturi River, PNG | 16.7 | 6.0 | 9.2 | 10.3 | 4.9 | 2.5 ± 2.09 |

classes: 1 – very crooked stem with more than 2 serious bends, 2 – slightly crooked stem with 1 serious and/or more than 2 small bends, 3 – almost straight stem with 1 or 2 small bends, 4 – straight stem total number of *A. mangium* trees. Of these, about half of the trees had almost straight stems, 30.1% with slightly crooked stems, 10.8% with straight stems and eight trees with very crooked stems. Meanwhile, out of the 105 trees from PNG, 45.7% accounted for trees with almost straight stems followed by 25.7% of trees with slightly crooked stems, 15.2% of trees with very crooked stems and 14 trees with straight stems. Only 24 out of the 105 trees from PNG had straight stems.

Of the total 202 *A. auriculiformis* trees, 37.6% of trees had almost straight stems. This was followed by 33.2% of trees with slightly crooked stems. On the other hand, 14.9% of trees had very crooked stems whereas 29 trees had straight stems. The provenances of Jardines Garden, QLD and South Alligator River, NT accounted for 31 and 20.7% of the total number of trees with straight stems, respectively.

There were 84 *A. auriculiformis* trees from NT. Out of this number, 41.7% showed slightly crooked stems, 40.5% slightly straight stems, 9.5% straight stems and 8.3% had very crooked stems. Provenances from NT generally contained very few trees with the best stem straightness, where the provenance of Gerowie Creek, NT had no trees with straight stems.

Trees from the provenances of QLD accounted for 31.2% of the total *A. auriculiformis* trees. Of this, 39.7% had slightly straight stems, 27% had straight stems, 15 trees had slightly crooked stems and six trees from the provenance of Morehead River, QLD accounted for the 9.5% of trees with the worst stem straightness.

Meanwhile, trees from PNG, namely the provenances of Bensbach Western Province, Mibini and Pohaturi River accounted for 27% of the total *A. auriculiformis* trees. Four trees possessed straight stems whereas the rest of the three classes had an equal number of trees. Out of the 17 trees with very crooked stems, 52.9% was from Mibini. As for straight stem trees, three were from Pohaturi River whereas one was from the provenance of Mibini. Overall, the provenances from QLD had the best stem straightness followed by NT and PNG. The provenance of Jardines Garden from QLD had the best form. In addition, *A. mangium* had the better form than *A. auriculiformis*. More trees of *A. mangium* attained the score of 3 and 4 which indicates better stem straightness whereas the scores of 1 and 2 were more frequently received by *A. auriculiformis*.

There were 44 *A. mangium* trees of which Syndicate Road Tully accounted for 22.7% of these multi-stemmed trees. The provenances of Kurrimine and Arufi Village Western Province had the second and the third highest number of multi-stemmed trees with seven and six trees, respectively. Trees from QLD accounted for about 61% of the total number of multi-stemmed trees whereas the rest of the 17 trees were from PNG. As for *A. auriculiformis*, multi-stemmed trees accounted for 41 or about 20% of the total number of trees. Out of this, 24.4% were from the provenance of Gerowie Creek, nine trees belong to the provenance of Manton River whereas seven trees were from Douglas River. All the ten provenances had multi-stemmed trees except for the provenance of Morehead River. Provenances from the region of NT had the highest number of multi-stemmed trees at 31. The rest of the multi-stem *A. auriculiformis* trees were from PNG and QLD with five trees each. In conclusion, there was an equal number of multi-stemmed trees for both species of *Acacia*.

The most desirable tree form for *A. mangium* (Figs 1c and 2c) was predicted for Arufi Village Western Province, PNG almost 70% better than the mean and the least desirable tree form was observed for Binaturi, PNG (Figs 1c and 2c). The tree form in case of *A. auriculiformis* (Figs 3c and 4c) provenance Mibini, PNG was multiple percent better than the mean and Jardines Garden from QLD was observed with very crooked multiple stems (Figs 1c and 2c).

### Lignin and tree form

Total lignin and its components, i.e. syringyl (S), guaiacyl (G) and S/G ratio like lignin structures, were analysed for tree form, mid branching (forking) and base branching (multiple) for both *A. mangium* (fork = 22.54 ± 0.746, multiple stem = 20.27 ± 0.982) and *A. auriculiformis* (fork = 30.60 ± 2.15, multiple stem = 25.25 ± 0.855). Total lignin contents were significantly different for both traits in both species. S was low in multistem trees [17.40 ± 3.13 (*A. mangium*), 18.25 ± 3.69 (*A. auriculiformis*)] and high in forked stems [44.91 ± 11.74 (*A. auriculiformis*) and 48.2 ± 5.19 (*A. mangium*)]. G was high in *A. mangium* (fork = 48.2 ± 5.19 and multiple leader = 48.5 ± 6.96) and for *A. auriculiformis* (fork = 44.91 ± 11.74 and for multiple leader = 34.93 ± 6.19). S and G were significantly different in *A. auriculiformis* whereas they were similar in *A. mangium*. Generally the S/G ratio was higher for forked trees than for multiple leader stems in both species.

## Correlation and multivariate analyses

Highly positive significant correlations were observed between DBH and plant height in both species. These results indicated that growth characteristics are closely related to one another in *Acacia* trees. Furthermore, DBH is a suitable criterion in *Acacia* breeding programs for selecting trees with high wood yield. A negative weak correlation was observed between tree form and DBH and/or height in both species (Table 6). This correlation was high in *A. mangium* compared to *A. auriculiformis* due to relatively large DBH, tall trees and lower number of crooked trees.

The PCA included all the variables analysed in the univariate analyses except for lignin content because a large proportion of the trees had not been assessed due to difficulty involved in processing a large number of samples (Figs 5a, b). The analyses were performed on mean values per provenance. In the analysis the first two variates were significant, accounting for a total of 96.6% for *A. mangium* and 98.1% for *A. auriculiformis*. A plot of the scores for the first and second principal components is shown in Figs 5a, b using the provenance names for both species. Provenances that are far apart were interpreted as being very different and therefore it is likely that the two provenances in reality have different properties.

Table 6. Loading values for *Acacia auriculiformis* A. Cunningham ex Bentham and *Acacia mangium* Willdenow from the principal component analysis of stem diameter, tree height and tree form

| Characteristics | PC1 | PC2 | PC3 |
|---|---|---|---|
| ***A. auricculiformis*** | | | |
| DBH | –0.704 | 0.061 | 0.708 |
| Height | –0.702 | 0.094 | –0.706 |
| Tree form | 0.109 | 0.994 | 0.023 |
| Proportion of variance | 0.652 | 0.329 | 0.019 |
| ***A. mangium*** | | | |
| DBH | –0.619 | 0.416 | 0.667 |
| Height | –0.651 | 0.202 | –0.731 |
| Tree form | 0.439 | 0.887 | –0.146 |
| Proportion of variance | 0.719 | 0.247 | 0.034 |

PC – principal component

The provenances appeared to cluster in five groups (Figs 5a, b). This would also be expected from the univariate analyses where Claude River, Kurrimine and Morehead had much higher values and superior traits than the other provenances. Whereas West of Morehead, Northwest of Silkwood, Syndicate Road Tully and Ellerback Road Cardwell group was the next group of provenances with superior traits. The provenances with least de-

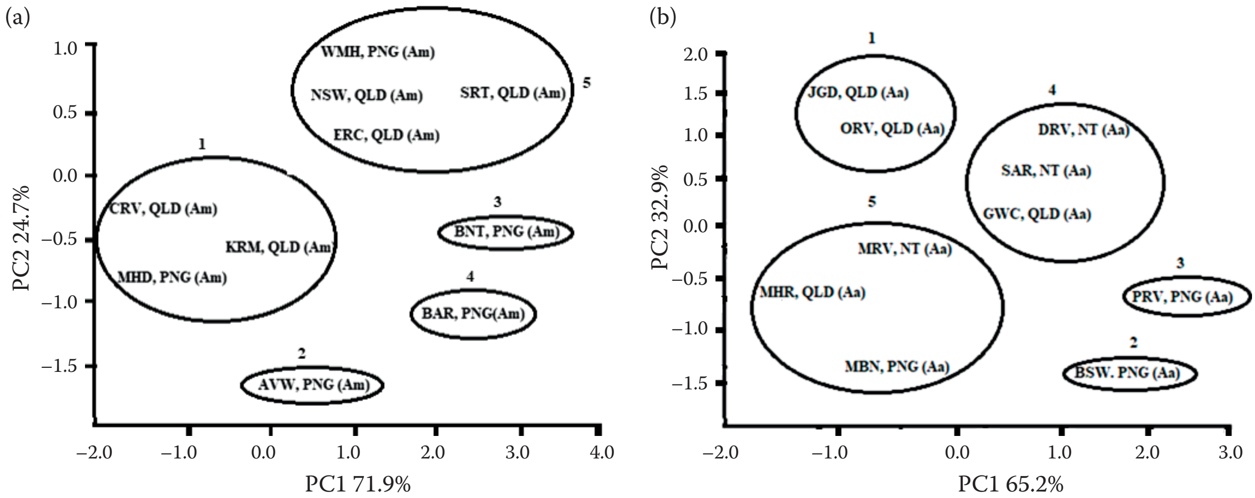


Fig. 5. Score plot of the first (PC1) and the second (PC2) principal component (10 sites) for *Acacia mangium* Willdenow (Am) (a), *Acacia auriculiformis* A. Cunningham ex Bentham (b) provenances. The variables plant height, DBH and tree form were included in the analysis. Each provenance is marked at the mean value. Provenances were grouped into 5 groups based on DBH, plant height and tree form

QLD – Queensland, PNG – Papua New Guinea, NT – Northern Territory, AVW – Arufi Village Western Province, BAR – Balimo Aramia River, BNT – Binaturi, BSW – Bensbach Western Province, CRV – Claude River, DRV – Douglas River, ERC – Ellerback Road Cardwell, GWC – Gerowie Creek, JGD – Jardines Garden, KRM – Kurrimine, MBN – Mibini, MHD – Morehead, MHR – Morehead River, MRV – Manton River, NSW – Northwest of Silkwood, ORV – Olive River, PRV – Pohaturi River, SAR – South Alligator River, SRT – Syndicate Road Tully, WMH – West of Morehead sirable traits were Arufi Village Western Province, Binaturi and Balimo Aramia River (Fig. 5a).

Similar patterns were observed for *A. auriculiformis* provenances, where provenances with superior traits, i.e. Manton River, Morehead River, Mibini, were grouped together followed by South Alligator River, Douglas River, Gerowie Creek and the least were Bensbach Western Province and Pohaturi River (Fig. 5b). The absolute values of loading values for PC 1 were higher in DBH and height, while that loading value for PC 2 was higher in tree form, indicating that DBH, plant height characteristics and tree form contribute to PC1 and PC2 in the provenances of both species. DBH was reported to be positively correlated with plant height. Thus, these two traits contribute to PC1. On the other hand, tree form was negatively correlated with both DBH and height and contributed to PC2.

## DISCUSSION

The results showed marked differences between provenances in their performance in terms of height, DBH and tree form. These differences are associated with inter- and intra-variations from the three main geographic regions, viz. QLD and PNG in case of *A. mangium* and QLD, NT and PNG in case of *A. auriculiformis* where both species naturally occur. The variations observed between both species indicate the presence of genetic diversity within its distributional range.

*A. mangium*, *A. auriculiformis* and their hybrid are the most important species for pulp industry. Tree species with a wide geographical distribution exhibit considerable provenance variation. The relative contribution of genetics and environment to variation may be evaluated by raising seedlings from various seed sources under relatively uniform conditions. The main objective of provenance trials is to locate as quickly and as economically as possible those provenances yielding well-adapted and productive forests. This was the first study in Malaysia where provenances from both species were evaluated simultaneously under similar environmental conditions compared to previous studies which were conducted separately on *A. auriculiformis* (Nor Aini et al. 1994) and *A. mangium* (Baharuddin 1987). Large significant differences observed in plant height, DBH and tree form between and within provenances were in concordance with Baharuddin (1987), Minquan and Yutian (1991), and Nor Aini et al. (1994). The present phenotypic evaluation of diverse germplasms has successfully shown that the growth performance and stem straightness of *A. mangium* were clearly better than in *A. auriculiformis*. A selection of provenances from QLD, Australia, generally performed better than from PNG in case of *A. mangium* whereas for *A. auriculiformis* the provenances from QLD and NT performed better and provenances from PNG were the least performer. The best performing provenances of *A. mangium* in terms of DBH and height were Claude River, QLD and West of Morehead, PNG whereas the worst were Balimo Aramia River, PNG and Binaturi, PNG. As for *A. auriculiformis*, the best performer was Morehead River, QLD whereas the worst were Bensbach Western Province, PNG and Pohaturi River, PNG. More trees of *A. mangium* attained the score of 3 and 4 which indicates better stem straightness whereas the score of 1 and 2 was more frequently received by *A. auriculiformis*. However, there were no clear differences between the regions where the provenances originated. As for the formation of multiple leaders, both *Acacia* species had an equal number of multi-stemmed trees. Growth performance of provenances from the region of QLD was slightly better than that of NT and PNG. The growth performance of each provenance will differ as the genetic constitution of the seed is different. This was in line with the findings of Pinyopusarerk et al. (1996), who found a similar mixed relationship with regard to the ranking of provenances from QLD and PNG. While two PNG provenances were the top performers and one of their counterpart was at the bottom group. Significant growth differences were observed: (*i*) between provenances at four sites, (*ii*) between the sites, (*iii*) between provenances within regions. These findings were supported by Ryan et al. (1986), Hardwood and Williams (1991), Bhumibhamon (1992), Awang et al. (1994), and Tuomela et al. (1996). In these studies, there were clear differences between the regions. Provenances from PNG continuously and consistently outperformed their counterparts from QLD. But the good growth rate attained by Claude River was comparable to that of Vuokko et al. (1992) though the growth assessment was done at the age of 61 months in this study.

The trait-trait correlations between DBH and height were consistently positive with a wide range. Low and negative correlations were observed between tree form and both DBH and height. In an early evaluation of the species in four provenance trials, Khasa et al. (1995) found that tree height and DBH were not generally correlated to survival, number of stems, tree form, branch angle and wood density. Nevertheless, positive correlations between growth and stem quality (e.g. straightness and branch number) were also reported from low to high in other tropical species, such as *A. crassicarpa*, *A. mangium*, *Acacia nilotica* (Linnaeus) Willdenow ex Delile, *Eucalyptus grandis* W. Hillebrand ex Maiden and *Eucalyptus camaldulensis* Dehnhardt (Arnold, Cuevas 2003; Gapare et al. 2003; Ginwal, Mandal 2004; Hai 2008). The estimated correlated responses in the present study were based on a single test site making them upwardly biased because the provenances were not tested on multiple sites. However, the results obviously indicated that there would be an important benefit from using the growth traits as selection traits together with tree form to increase productivity.

These preliminary results are important as they provide the basic information which may be used to determine suitable provenances for future breeding programs. In addition, growth performance observed in both species reinforces the idea that *A. auriculiformis* has a similar potential to be used for industrial planting like *A. mangium*. Although the results indicate that there were some clear differences in provenance means for various traits, we assume that there is a great potential for future breeding programs within individual provenances as well. It would be prudent to select and retain superior individuals not only from the good provenances but also from the poor ones. This would prevent the exclusion of other desirable traits such as straight tree form, low lignin content, fibre length, wood density and disease resistance. *Acacia* interspecific hybrids from both species were proven to be very successful, therefore provenances carrying various desirable characteristics can be used in future hybrid breeding programs in meeting the need of different end uses.

PCA was useful in the grouping of provenances with similar phenotypic traits for both *A. mangium* and *A. auriculiformis*. QLD provenances showed better phenotypes compared to PNG and NT provenances. All provenances were planted on a single site under similar conditions. Phenotypic variation was not distributed according to the geographical origin. The performance of the *Acacia* provenances has been shown to be varied considerably with the site conditions (Sim, Gan 1988). Both species were previously shown to be well adapted to Malaysia. Hybrids from both species are commercially planted for pulp and paper industry. Hybrids are found superior to the parental species for pulp yield and quality, however to fulfil industry demands a further improvement in traits like low lignin content, high wood density, longer fibre and disease resistance is desired. Conventional breeding in *Acacia* is slow whereas the utilization of DNA markers in MAS breeding required QTL linkage maps developed on pedigreed populations. Development of pedigreed populations is difficult, therefore natural populations can be utilized in the association mapping approach. In *Acacia* however, no association mapping studies have been conducted because the necessary genomic tools have only recently begun to emerge (Wong et al. 2012). For association mapping to be utilized in *Acacia* it is important to test the population for trait stability and performance under different environmental conditions to reduce the probability of false positive associations. Two groups for *A. mangium* provenances from PNG and QTL were found to be similar. West of Morehead (PNG), Northwest of Silkwood (QLD), Syndicate Road Tully (QLD) and Ellerback Road Cardwell (QLD) were grouped together indicating they are genetically similar, thus they can be pooled and can be treated as a single population for association mapping studies. Seed families from these provenances can be pooled and treated as a single population for association mapping. For *A. auriculiformis* two groups each containing three provenances Douglas River (NT), South Alligator River (NT), Gerowie Creek (QLD) and the second group Manton River (NT), Morehead River (QLD) and Mibini (PNG) were similar and can be used to raise hybrid families. Most of the phenotypic traits are under genomic control and the variation can be explained through heritability estimates, however the "second code" governed by epigenetic mechanisms has emerged as the potential culprit of phenotypic changes in crops (The EPIC Planning Committee 2012). Epigenetic regulation is mainly governed by environmental factors, therefore screening provenances to different environments would better explain the epigenetic variance. It is concluded that the provenances from both species should be screened under different climatic conditions to have better understanding of the genotype x environment interaction and epigenetic effects.

Most of the provenances showed high survival and superior growth traits suggesting their suitability for growing under local conditions; however, owing to the soil conditions under the present studies it would be interesting to investigate them in more detail whether there are any other geographical gradients in the adaptation of provenances to the site, as well as to include more local provenances.

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