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GENETIC VARIATION IN WOOD MECHANICAL PROPERTIES IN TEN-YEAR-OLD *ACACIA CRASSICARPA* GROWN IN VIETNAM

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Wood mechanical properties of *Acacia crassicarpa* were assessed at the age of ten years old in a progeny test at Cam Lo, Quang Tri Province, central Vietnam. A total of 208 trees from 52 open-pollinated families were selected for study. Height and diameter at breast height were measured for all selected trees and spiral grain was also measured at breast height on the standing trees using a Chalmers device, which measures the grain angle of the surface wood. Basic density and shrinkage were measured on one 12-mm bark-to-bark increment cores taken at breast height from each sampled tree. Microfibril angle was measured on fiber prepared from the core samples using polarized light microscopy. Genetic parameters of the wood and growth traits were estimated using individual-tree linear mixed models. High coefficients of additive genetic variation (CV_a, 17-34%) and high heritabilities (h^2 = 0.61-0.82) for all wood traits indicated that there is potential to improve basic density, wood shrinkage, grain angle and microfibril angle in the species in central Vietnam. The genetic correlation between DBH and shrinkage was positive and thus unfavourable, whereas correlations between DBH and both spiral grain and microfibril angle were negative and favourable. The Chalmers device appeared to be a reliable indirect method for investigating genetic variation in spiral grain in *A. crassicarpa*. Index selection, based on genetic parameters and economic weighting dependent on breeding objectives is suggested for development of seed orchards to deliver genetic gain for *A. crassicarpa* in central Vietnam.

Keywords: Basic density, shrinkage, spiral grain, microfibril angle, heritability, genetic correlation, gain

INTRODUCTION

Acacia crassicarpa A. Cunn. ex Benth. is a fast-growing tropical tree native to northern Queensland, Australia and the southern coastal lowlands of Papua New Guinea and adjacent Papua Province, Indonesia. It is suitable for planting on degraded sites in the seasonally-dry tropics and sandy soils (Pasieczni & McDonald 2016). The species tolerates a range of soil types, particularly those of low fertility. It is fire and strong wind resistant and competes well against weed species such as *Imperata cylindrica*. It produces a dense hardwood that can be used in wood pulp production, laminated wood, sawn or round timber for construction and fuelwood. The largest plantation estate is in Indonesia, where several hundred thousand hectares are grown for pulpwood production, primarily on peatlands (Nambiar et al. 2018). Vietnam has a much smaller plantation estate of 11,203 hectares, mostly on sandy soils in coastal and sub-coastal landscapes of the North Central and South-Central regions of the country (Ministry of Agriculture and Rural Development 2022). Pulp plantations of *A. crassicarpa* in Vietnam are managed on rotations varying in duration from five to eight years, while rotations for timber production may extend up to over 12 years (Nambiar et al. 2015).

Privous studies have generally found that Papua New Guinea provenances grow faster than those from north Queensland, and that within-provenance heritabilities for growth traits are low to medium, while those for stem straightness and forking are low (Arnold & Cuevas 2003, Dinh 2014, Hanchor et al. 2016).

However, additive genetic coefficients of variation (CV_a) of these traits were high (CV_a > 5%). If selected at 5%, genetic gain would achieve from 9.6–23.0% for growth traits and straightness (Dinh 2014).

Most modern forest tree improvement programmes aim to improve growth and stem form, tolerance of biotic and abiotic stresses and desired wood properties for desired end products (White et al. 2007, Nambiar et al. 2015). As short rotation of *A. crassicarpa* plantation, the proportion of juvenile wood will be higher. Besides wood density, shrinkage, microfibril angle (MFA < 20˚) and spiral grain (SLG < 5˚) have attracted much research interest in recent years, because of their effect on product recovery, shape stability and strength of lumber (Apiolaza et al. 2013, Dinwoodie 2000). Spiral grain is a helical orientation of the fibers in a tree stem, which is a popular trait of *A. crassicarpa* planting in degraded sites (i.e. sandy soil). However, microfibril orientation in the S_2 layer of cell walls is considered to be the most important factor determining wood stiffness, in the juvenile wood zone (Vanerek et al. 2017).

The assessment of wood quality for selection and breeding programmes normally requires investigation of a large number of families and a sufficient number of individuals per family. Traditional methods of assessment are costly and involve destruction of the sample trees and the loss of genetic material (Raymond 2002). Taking the measurement of core increment is the most common form of non-destructive sampling and it has long been used for investigations of basic density, shrinkage and microfibril angle (Ochir et al. 2021, Wessels et al. 2011, Pelletier et al. 2008). A method of measuring wood grain angle on standing trees using a mechanical device was successfully applied in the genetic testing of Scots pine and Norway spruce, developed at Chalmers Technical University in Sweden (Hannrup et al. 2003).

The current study assessed genetic variation in basic density, shrinkage, microfibril angle and spiral grain of *A. crassicarpa* families in a progeny test in Quang Tri province. The aim was to obtain genetic parameters to support the breeding of the species in central Vietnam.

MATERIALS AND METHODS

Experimental location

A total of 100 open-pollinated families of *A. crassicarpa* were planted in a progeny test in Quang Tri Province, central Vietnam. These families were sourced from two seedling seed orchards in Quang Tri and Binh Thuan provinces (30 and 58 unrelated families respectively) and from two seed production areas in Hanoi and Dong Nai provinces (12 and 3 families respectively). The test was conducted in 2010 and using a Row-Column incomplete block design generated using the software program CycDesigN, with 8 replicates and 4 trees per family row plot planted with initial spacing of 4 m × 2 m. The trial was thinned phenotypically at the age of 6 years, retaining the best two trees per plot and later at 10 years to retain the best tree per plot, selected for superior growth and stem/branch form and converted it into a seedling seed orchard.

The test site is located at Cam Lo in Quang Tri province (16˚ 78 N, 106˚ 98 E, altitude 50 m a.s.l.) located on the hill sites in the Northern central region of Vietnam. The soil is a shallow yellow ferralitic soil over decomposing parent material. The mean annual rainfall is about 2200 mm and mean annual temperature 25 ˚C. Hot dry southwest winds occur about 45 days per year, with maximum temperatures of 40˚C–42˚C and are considered to adversely affect local agricultural production.

Table 1 Number of sampled families from different seed sources

Seed source	Number of sampled families
Seed production areas	7
Seed orchard in Quang Tri	15
Seed orchard in Binh Thuan	30

Measurements and sampling

A total of 52 from the 100 families in the progeny test were selected at random for study (Table 1). All wood properties under consideration in this study (Table 2) were evaluated from a sample of 52 families at age of 10 years. On each of the sampled trees, one 12-mm bark-to-bark increment cores were taken from east to west direction at 1.3m above ground. Totally, 208 cores were used to determine basic density, shrinkage and microfibril angle.

Growth traits

Total tree height (H) and diameter at breast height over bark (DBH) were measured for all eight trees of each family in the test.

Wood density

Basic density was determined for each core. Green volume (V_1) was measured using an electronic densimeter MD-300S, with accuracy 0.001 g/cm^3. The cores were subsequently placed in a conditioning chamber at 20 ± 2 °C and 65 ± 5% relative humidity for 45 days until they reached the equilibrium moisture content (EMC) at air-dry condition (mean of EMC = 12.28 ± 0.01%). Wood cores were then reweighed (m_2), and volumes were re-measured (V_2). The cores were oven-dried at 103 °C for 8 days until a constant oven-dry weight was attained, and re-weighed (m_0) after cores had cooled to room temperature in a dry atmosphere maintained using silica gel in sealed containers. The basic density (Den) was calculated by Formula 1, as following:

$$Den = \frac{m_0}{V_1} (g/cm^3) \quad (1)$$

Wood shrinkage

Each of 12 mm core was marked with indelible pencil at each end for radial measurement and at four positions (60% and 80% of core length) along the radial length for tangential measurement (four measurements per core,

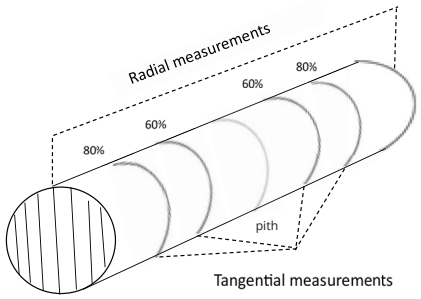

Figure 1 Position of radial and tangential measurements on bark-to-bark increment cores grain angle

Table 2 Phenotypic variations of wood properties between A. *crassicarpa* families at age of 10 years

Trait	Unit	Test mean	Variation	F-test
DBH	cm	24.2	20.87–28.17	<0.001
H	m	23.5	19.75–25.67	<0.001
Den	g cm^{-3}	0.50	0.38–0.61	<0.001
T_n	%	7.08	3.83–9.23	<0.001
R_n	%	3.01	1.81–5.82	<0.001
T_n/R_n	-	2.35	1.38–3.96	<0.001
GA	degrees	4.09	1.44–7.88	<0.001
MFA	degrees	8.58	4.95–13.93	<0.001

DBH = diameter at breasts height, H = height, Den = density, T_n = tangential shrinkage, R_n = radial Shrinkage, GA = grain angle, MFA = microfibril angle

Figure 1). Measurements were recorded using digital calipers with automatic data entry at 0.01 mm accuracy. The cores were first measured in the green condition (saturated). They were then dried in conditioning chambers as described in determination of wood density, and measured again when they reached 12% moisture content so that unit shrinkage could be calculated. Shrinkage was calculated for each position, and tangential shrinkage for each core was calculated by averaging the four measurements. All cores were also scanned at each stage of drying using a flatbed scanner. Cores were positioned on the scanner with the longitudinal direction at 90% from the line of scan so that the tangential dimension could be observed. The scanned images at 12% moisture content were assessed using the ImageJ software (National Institutes of Health, United States) to measure changes in radial length between the two tangential marks on each half of the cores, thus avoiding any distortion at the pith. Dimensional differences of cores were used to estimate total shrinkage (from fresh to oven-dry). Total shrinkage was estimated in the tangential (T_n) and radial (R_n) dimensions by Formula 2 and Formula 3, and these values were used to calculate the coefficient of anisotropy (T_n/R_n).

$$T_n = \frac{T_0 - T_1}{T_0} \times 100\ (\%) \quad (2)$$

$$R_n = \frac{R_0 - R_1}{R_0} \times 100\ (\%) \quad (3)$$

Grain angles

Grain angles (GA) on standing trees in the test were investigated by Chalmers device (Hannrup et al. 2003). This device pushes a wedge with an attached arm into the wood (Figure 2). When the arrow wedges of the device penetrate into the wood of the first annual rings closest to the bark, wedges are blunt to avoid cutting the fibers. GA measurements for each tree were done at two opposite radii and recorded by the arm that is attached to the wedge. The GAs were measured in the upper part of the internode closest to 1.3 m above ground of standing trees. Averaged measurements were then used to compensate for leaning stems and to obtain a measure of the grain angle relative to the axis of the stem. Positive and negative angles were used to designate left-handed and right-handed spirality, respectively.

Microfibril angle

For each core, the microfibril measurements were carried out on heartwood and sapwood parts. The microfibril angle (MFA) were measured by the method of Donaldson (1991) using a Pax-Cam microscope. The values of the MFA was determined by using the polarised light microscopy method by looking through the bordered pits in the cell wall to the other side of the cell wall. From heartwood and sapwood samples, the wood pieces were taken from the middle position of samples and longitudinal

Figure 2 Measurement device for measuring grain angle of standing trees; On the measurement scale "H" and "V" indicate right-handed and left-handed spiral grain, respectively

slices were prepared by a rotary microtome. These slices were then macerated in a solution of hydrogen peroxide and acetic acid in a 1:1 ratio. The solution was then heated for 24 hours at 60 °C to remove the pit membrane and to delignify the samples. After rinsing in distilled water, a single wood cell (tracheid) was placed on the glass microscope slide for polarised microscopy observation. The angle between the fibre axis and the maximum extinction position (MEP) was recorded by Pax-it software. This value is the average MFA of the cell wall, which is approximately the MFA of the S_2 layer, because S_1 and S_3 layers are thin relative to the S_2 layer.

Statistical analysis

The statistical analysis was conducted in two steps; the univariate analysis, where variance components for each trait were estimated and by bivariate analysis to estimate variances and covariances between pairs of characters. Row and column incomplete block effects within replicates were not modeled because the traits under consideration in this study were evaluated using a sub-sample of less than ¼ of the trees in the test. The following mixed linear model was used in the univariate analyses:

$$y = Xb + Zf + e \quad (4)$$

and the following bivariate model, which is an extension of model 3, was used in the two-trait analyses:

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} X_1 & 0 \\ 0 & X_2 \end{bmatrix} \begin{bmatrix} b_1 \\ b_2 \end{bmatrix} + \begin{bmatrix} Z_1 & 0 \\ 0 & Z_2 \end{bmatrix} \begin{bmatrix} f_1 \\ f_2 \end{bmatrix} + \begin{bmatrix} e_1 \\ e_2 \end{bmatrix} \quad (5)$$

where $[y_1]$ and $[y_2]$ are observation vectors of the traits; X_1 and X_2 are design matrices for fixed replicate effects; b_1 and b_2 are vectors of fixed replicate effects; Z_1 and Z_2 are design matrices for random family effects; f_1 and f_2 are vectors of random family within seed source effects; e_1 and e_2 are vectors of random residuals, and may be summarised as $f'=(f'_1,f'_1)$ and $e'=(e'_1,e'_1)$.

The random factors are assumed to be normally distributed with expected values of zero, leading to:

$$E \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} X_1 & b_1 \\ X_2 & b_2 \end{bmatrix} \quad (6)$$

and with the variance-covariance matrix assumed to be

$$Var \begin{bmatrix} f \\ e \end{bmatrix} = \begin{bmatrix} G \otimes I_f & 0 \\ 0 & R \otimes I_n \end{bmatrix} \quad (7)$$

Where G is the matrix with the family variances and covariances, R is the matrix with the residual variances and covariances, and I_f and I_n are identity matrices for number of families and trees, respectively. Finally, $\otimes$ symbolises the Kronecker product. Family variance (σ_f^2) and environmental variance (σ_e^2) for different traits were estimated using ASReml program (Gilmour et al. 2006).

Genetic parameters

The estimated variance components were used to calculate the narrow-sense heritabilities for the studied traits. Since open-pollinated families in the progeny test came from open-pollinated parent trees in seed production areas or seed orchards, the additive genetic variance (σ_e^2) was estimated as three times the family variance component. Because some degree of inbreeding (about 10%) was expected the coefficient of relationship was assumed to be 0.33, making heritability values more conservative than if a value of 0.25 was assumed (White et al. 2007). The additive genetic variance (σ_a^2), total phenotypic variance (σ_p^2) and individual-tree heritability ($\hat{h}^2$) estimates were calculated as follows:

$$\sigma_a^2 = 3\sigma_f^2 \quad (8)$$

$$\sigma_p^2 = \sigma_f^2 + \sigma_e^2 \quad (9)$$

$$\hat{h}^2 = \frac{\sigma_a^2}{\sigma_f^2 + \sigma_e^2} \quad (10)$$

Coefficient of additive variation (CV_a), additive genetic correlation ($\hat{r}_a$) between traits were estimated as:

$$CV_a = \frac{100\ \sigma_a}{\overline{X}} \quad (11)$$

$$\hat{r}_a = \frac{\sigma_{a_1 a_2}}{\sigma_{a_1 a_2}} \quad (12)$$

where $\overline{X}$ is the phenotypic mean, $\sigma_{a_1 a_2}$ is the genotypic covariance between two traits. σ_{a_1} and σ_{a_2} are the genotypic standard deviations of trait 1 and trait 2, respectively. Standard errors of the estimates of heritabilities, genotypic correlations were calculated using a standard Taylor series approximation implemented in the ASReml program (Gilmour et al. 2006).

Predicted genetic gain from selection was calculated according to Mullin et al. (1992) as:

$$R_y = i_{n,N} . \hat{h}^2_y . \sigma_{PY} \quad (13)$$

where R_Y is the predicted selection gain, and $i_{n,N}$ is the intensity of selection based on selection of n genotypes from N tested (10%).

RESULTS

Mean values of wood properties

Mean values of basic density, shrinkage, grain angle and microfibril angle among *A. crassicarpa* families are summarized in Table 2. Wood properties between families ranged widely, from 0.38 to 0.61 g cm^{-3} for basic density, 1.81 to 5.82% for radial shrinkage, from 3.83 to 9.23% for tangential shrinkage, and 1.38 to 3.96 for the ratio of T_n/R_n, 1.4° to 7.9° for grain angle, and 5° to 14° for microfibril angle.

Genetic parameters of wood properties

The heritabilities of all wood properties were estimated to be high (Table 3). Specifically, heritability of basic density, grain angle and microfibril angle reached up 0.61–0.82. The heritability and coefficient of additive variation (CV_a) of grain angle and microfibril angle were the highest. Wood shrinkages had lower heritabilities than density. But CV_a of wood

Table 3 Heritabilities, standard errors of heritabilities, coefficients of additive variation and genetic gain of wood properties within *A. crassicarpa* families at age of 10 years old

Trait	Heritability ($\hat{h}_2$)	CV_a (%)	R_Y (%)
Den	0.78 ± 0.16	16.8	28.4
R_n	0.61 ± 0.19	26.2	42.6
T_n	0.70 ± 0.11	21.0	39.0
GA	0.82 ± 0.28	34.4	59.4
MFA	0.79 ± 0.23	28.9	49.9

$\hat{h}_2$ = individual-tree heritability, CV_a = additive genetic coefficients of variation, R_Y = predicted selection gain; Den = density, T_n = tangential shrinkage, R_n = radial shrinkage, GA = grain angle, MFA = microfibril angle

Table 4 Genetic correlations and standard errors of correlations between growth traits and wood mechanical properties in the progeny tests of *A. crassicarpa* at at age of 10y

Trait	Den	R_n	T_n	GA	MFA
DBH	-0.38 ± 0.31	0.57 ± 0.16	0.54 ± 0.14	-0.52 ± 0.19	-0.45 ± 0.18
H		0.26 ± 0.31	0.10 ± 0.30	-0.07 ± 0.30	-0.06 ± 0.30

Den = density, T_n = tangential shrinkage, R_n = radial shrinkage, GA = grain angle, MFA = microfibril angle

shrinkages were higher than those of wood density.

Trait-trait genetic correlations between growth and wood properties at age 10 years are shown in Table 4. The correlation between height and wood properties was low and non-significant, with additive genetic correlation $\hat{r}_a$ = -0.07. Similarly, diameter was correlated weak and negatively or positively with basic density, but none of these relationships was significantly ($\hat{r}_a$ = -0.38 ÷ 0.34). However, there were moderate and positive genetic correlations between diameter and wood shrinkages ($\hat{r}_a$ = 0.42 - 0.57), and moderate and negative correlations between diameter and grain angle and microfibril angle ($\hat{r}_a$ = -0.45 ÷ -0.52).

Forward selection for the wood properties was shown to give a higher genetic gain at age of 10 years (Table 3). The genetic gain for wood properties ranged from 28.4% to 59.4%, higher than the gain for growth traits and stem quality (Toan et al. 2020).

DISCUSSION

Mean values

There are few literatures on wood mechanical properties of *A. crassicarpa*. Our basic density and shrinkage are similar to previous studies by Martins et al. (2020) and Maelim (2012). They found that the basic density, radial and tangential shrinkage of *A. crassicarpa* at age of 4.5 years ranged from 0.45–0.48 g cm^{-3}, 3.56% and 5.83%, respectively. Coefficients of anisotropy in the present study were larger than the ratio (1.14–1.66) reported for *Tectona grandis* (Dinwoodie 2000) and *Eucalytus globulus* (Yang & Evans 2003). The high transverse anisotropy also indicates that juvenile wood of some families may display instability and high distortion during drying, leading especially to the occurrence of cup and angular deformation in end products and the opening of large radial cracks (Dinwoodie 2000).

With regard to microfibril angle, our results found that *A. crassicarpa* families contained wood with a microfibril angle of less than 20˚, so it will not be an interest trait to improve the value (Vanerek et al. 2017). But the grain angle of the families ranged from 1.4˚ to 7.9˚ and 20 families (occupied 39% of number of studied families) had more than 5˚, therefore it should be possible to make a one-off selection of a new deployment population with an initial grain angle of below 5˚ by screening within the current breeding population.

Significant differences between families clearly indicated a potential for considerable improvement in density, shrinkages and grain angle of of *A. crassicarpa* through selecting among superior families identified in the progeny test. Six of a total of 52 families studied have a lower both coefficients of anisotropy and grain angle, and higher basic density than the mean values of the test but they were mostly medium-growing families, accounting for 84.2% (16 of the 19 families). Meanwhile six fast-growing families also have higher coefficients of anisotropy and grain angle or lower basic density compared to the mean values of the test.

Genetic parameters

High genetic variation in wood mechanical traits in this study is also consistent with result from previous studies of *Acacia* and *Eucalyptus* species. In *A. crassicarpa*, Dinh (2014) found that heritabilities and CV_a of basic density and cellulose content estimated in a first generation progeny test at the same site as the present study were quite high (with $\hat{h}^2$= 0.39–0.74 and CV_a= 4.7–14.1%). In *A. mangium*, Hai et al. (2015) and Firmanti et al. (2007) reported that the heritablities of wood mechanical properties ranged from 0.25 to 0.93 as well. Coefficient of additive variation (CV_a) values of most of wood traits studied exceeded 5%. In *A. auriculiformis*, Hai (2009) and Aggarwal et al. (2002) also noted that wood properties were highly heritable. In *E. nitens, E. dunnii* and *E. camaldulensis*, the heritablities of shrinkage or microfibril angle are often noted at moderate to high levels, $\hat{h}^2$= 0.35–0.75 (Kube & Raymond 2005, Hamilton & Pot 2007).

The present study contributed to the significant genetic variation of wood mechanical traits in the studied families originating from different provenances. Most of the families selected from the best provenances of Papua New Guines, including Bensbach, Bimadebun, Bituri prov WP, Dimisisi village, Gunbam Village, Morehead, Oriomo, Podari village, Serisa and Trans fly. Significant genetic variation

between different provenances of *A. crassicarpa* in wood mechanical properties was also reported in a previous studies and Samlleberr was the best provenance for mechanical properties (Dinh 2014).

High heritability and coefficient of additive variation of the wood properties in the Quang Tri test suggested that basic density, wood shrinkage and grain angle are strongly identified as potential traits to improve wood quality in *A. crassicarpa* in central Vietnam. Improvements to reduce shrinkage anisotropy and grain angle will become more important when the use of drying technology is more popular and commonly adopted (Walker 2006) in Vietnam. Estimates of genetic gains at selection intensity of 10% showed that genetic gain could reach from 28.4% to 59.4% for shrinkage and grain angle (Table 3).

Trait-Trait correlations

The regression of best linear unbiased predictions (BLUP) values of MFA on the values of grain angle was significant (Figure 3). Therefore, the strength of the relationships indicated that the grain angle measured by Chalmers device on standing trees could be an indirect and highly reliable method for investigating genetic variation in the microfibril angle in *A. crassicarpa*. Using Chalmers device in measurement of the grain angle has also been applied to some European pines (Hannrup et al. 2003).

In the present study, small sample size of only 52 families caused a large standard error to the genetic correlations and the correlations must therefore be interpreted with caution. However, diameter correlated positively and unfavorably with shrinkage, but negatively and favorable with grain angle and microfibril angle (Table 4). Consequently, decrease of wood shrinkage will affect growth of *A. crassicarpa*. In another progeny test of *A. crassicarpa* in Quang Tri site, Dinh (2014) found that there were weak and non-significant correlations between diameter and cellulose content and wood density. The same trend was also evident for the relationships between growth, basic density and shrinkage in *A. auriculiformis* (Hai et al. 2008). But positive correlations between shrinkage and diameter have been still reported in *Eucalyptus* species (Bandara 2006) and *Calycophyllum spruceanum* (Sotelo et al. 2007). There is now no report of the correlation between growth and grain angle and microfibril angle in *A. crassicarpa*. However, study on diameter was reported to correlate negatively with grain angle and microfibril angle in *Pinus radiata* (Jayawickrama 2001).

It is very difficult to select families having both fast growing and good wood quality. Selection of *A. crassicarpa* for timber plantations in the future is necessary to be selected by index selection (Ivkovic et al. 2006). Index selection, based on genetic parameters and economic weighting dependent on breeding targets (Raymond 2002), may provide significant benefits in breeding. Bioeconomic models of *A. crassicarpa* growing and processing systems in Vietnam need to be studied to identify the most important breeding targets and determine relative economic weighting for appropriate traits, as was done for *Pinus radiata* in Australia (Ivkovic et al. 2006).

The relationships reported here were based

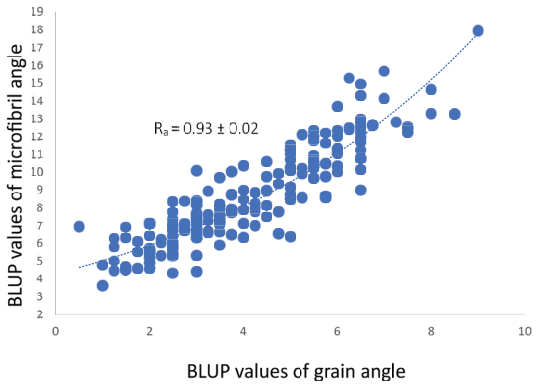

Figure 3 The relationship between grain angle measured on standing trees and microfibril angle
BLUP = best linear unbiased predictions

on juvenile wood. In Vietnam, a typical rotation of most *Acacia* species is about 5–8 years for pulpwood and 7–15 years, depending on sites for sawn-timber production, so the sawn-timber industry in Vietnam is largely based on juvenile wood. Using juvenile wood, important economic parameters are often identified as utilisation of wood, dimensional stability, wood durability, and post-drying defects (Raymond 2002). So, interest traits of *A. carssicarpa* to select the most reasonable families for timber product may be yield, stem straightness, basic density, coefficient of anisotropy and/or grain angle.

Acacia crassicrapa is difficult to propagate and tested individual clones because of maturation problems (White et al. 2007). So deployment of clones of this species is not possible to implement. Nevertheless, the progeny test reported here was designed for multiple roles and could be classified as breeding seed orchards (Hai et al. 2015). In such breeding seed orchards, family testing, selection, breeding and seed production can all occur with the one stand (White et al. 2007). Firstly, selective thinnings to be carried out at a later age to a single tree per row plot within 25% of the establishment stocking. Each tree will be surrounded by a group of unrelated neighbours, facilitating outcrossing and minimising cross-pollination between related trees. Secondly, additional thinnings based on rigorous selection of superior families and individual trees within-families, should be provided for significant genetic improvement. Such thinnings will be heavy, both between and within families, to improve growth performance of seed obtained. Selection for grafted clonal seed orchards can be at higher intensity to deliver greater gain from the clonal seed orchard relative to the seedling seed orchard. Meanwhile, selection of superior trees for inclusion in advanced-generation breeding programmes can also be carried out in the breeding seed orchard.

CONCLUSIONS

Significant variations in basic density, shrinkage, microfibril angle and grain angle were found between fast-growing families of *A. crassicarpa* at 10 years of age in Quang Tri test samples. These results, together with high heritability levels and coefficient of additive variations show that there is potential to improve these traits through selective breeding. Genetic correlations also indicate that stem diameter correlated positively and unfavorably with shrinkage, but negatively and favorable with grain and microfibril angle. The grain angle measured by Chalmers device on standing trees could be an indirect and highly reliable method for investigating genetic variation in the grain angle in *A. crassicarpa*. Index selection, based on genetic parameters and economic weighting dependent on breeding targets and development of breeding seed orchards or clonal seed orchards would be suggested to provide significant benefits in *A. crassicarpa* breeding.

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