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COMPARING WOOD DENSITY, HEARTWOOD PROPORTION AND BARK THICKNESS OF DIPLOID AND TRIPLOID *ACACIA* HYBRID CLONES IN VIETNAM

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Selected triploid *Acacia* hybrid (*A. mangium* × *A. auriculiformis*) clones grow at similar rates to commercial diploid *Acacia* hybrid clones planted widely in Vietnam. We compared wood properties at age 3.8 years of two promising triploid clones and two commercial diploid clones grown at Tan An, south Vietnam and Cam Hieu, central Vietnam, using discs from five trees per clone sampled at five heights above ground from 1.3 to 7.5 m. Heartwood proportions were calculated from disc diameters and heartwood–sapwood boundaries. Basic densities of triploid and diploid clones were similar at Tan An (434– 491 kg m^{-3} at breast height). At Cam Hieu, where tree growth was slower, all densities were lower, and the triploid clones had lower densities than the diploid clones (359 and 378 compared with 407 and 447 kg m^{-3}). Heartwood proportions at breast height (45 and 47%) and bark thickness (4.5 and 4.6 mm at breast height) of the two triploid clones were higher than those of the diploid clones (25 and 31%, and 3.7 and 3.7 mm respectively) at Tan An but triploids and diploids did not differ in these traits at Cam Hieu. Implications for wood processing and product value are considered.

Keywords: Ploidy, clonal variation, sample height, site, environment-by-clone interaction

INTRODUCTION

By 2017, the total area of *Acacia* plantations in Vietnam was approximately 2 million ha (VNForest 2017). These plantations are harvested on short (typically 5–8 years) rotations for export woodchips and in-country production of pulp, composite wood products and sawn timber (Nambiar et al. 2015). *Acacia mangium* and *Acacia* hybrid (*A. mangium* × *A. auriculiformis*) are the two most widely planted *Acacia* taxa; *Acacia* hybrid plantations total over 500,000 ha and are exclusively clonal. Vietnam's Institute of Forest Tree Improvement and Biotechnology (IFTIB) has developed superior diploid clones of *Acacia* hybrid selected from among spontaneous hybrids that grow faster than the two parental species (Son et al. 2018). Some individual *Acacia* hybrid clones have now been planted commercially for more than two decades. About 10 production clones are currently planted at commercial scale (Son et al. 2018).

Bark thickness, basic density and heartwood percentage are important stem and wood quality traits. Bark thickness affects the recovery of usable wood from a given standing volume. Basic density is important for pulpwood production because export woodchips are sold on dry-weight basis. For a given volume of harvested wood, higher basic density will result in higher return from woodchip sales. Basic density is also related to other important wood properties including stiffness and strength (Hai et al. 2010). A high proportion of heartwood is not advantageous for pulp production because heartwood contains more extractives and yields pulp with lower brightness compared with sapwood (Lourenço et al. 2008, Pometti et al. 2010). However, a high proportion of heartwood is desirable for sawn timber production because heartwood is typically more resistant to fungal and insect attack than sapwood, improving durability in external applications such as outdoor furniture (Pometti et al. 2010, Paques & Charpentier 2015).

Bark thickness, wood density and heartwood proportion vary with genotype, site conditions, tree age, growth rate and position within the stem (Pillai et al. 2013, Stängle et al. 2017, Wu et al. 2011). Plantation-grown wood of tropical acacia species typically has low to moderate basic density (Chowdhury et al. 2005, Hai et al. 2008). Heartwood proportion increases with tree age, as the cells of the inner wood layers die and become occluded with extractives. The heartwood zone progressively extends outward from the pith and upwards as the tree grows and ages (Walker 2006).

Vietnam exports more hardwood woodchips than any other nation. Most of these chips are sourced from acacia plantations (Midgley et al. 2017), although eucalypt plantations also make a small contribution to exports. However, Vietnamese woodchips fetch lower unit prices, per bone dry tonne, than most other exporting nations (R Flynn, personal communication 2019). Among the factors leading to low chip prices in Vietnam are the relatively low and variable wood quality of its acacia woodchips: much of the wood is being sourced from plantations harvested at ages of only 4–5 years. Increasing the rotation age is one obvious way to improve wood quality because wood density, fibre length and pulp yield typically increase with tree age. However, increasing the age of harvest may be difficult for many small growers since they wish to harvest as soon as possible to obtain a quick return on their investment (Midgley et al. 2017). Another option to improve wood quality is through genetic improvement—deploying clones or varieties which have higher density and pulp yield at any given harvest age than the genotypes previously planted. Improvements to chip production and screening in some Vietnamese chip mills to produce more uniformly sized chips could also increase the prices they receive.

Recently, polyploid breeding of tropical acacias has commenced in Vietnam (Griffin et al. 2015). Eight-year-old autotetraploid *A. mangium* trees had similar chip basic densities to those of diploid *A. mangium* from the same clonal planting in south Vietnam (mean of 652, compared with 659 kg m^{-3}) and Kraft pulp yields (mean of 50.2 compared with 50.5% at kappa 20). Wood fibres of the tetraploids were significantly longer and wider—traits which may be advantageous for paper making (Griffin et al. 2014). Triploid *Acacia* hybrid clones have subsequently been produced by controlled pollination between tetraploid *A. mangium* and diploid *A. auriculiformis* genotypes (Nghiem et al. 2018). Many triploid clones are now under field testing, but little is known of their wood properties.

The current study reports wood basic density, heartwood ratio and bark thickness of two promising triploid *Acacia* hybrid clones and two commercial diploid clones in field trials in south and central Vietnam. The trees under study had reached an age (3.8 years) and log size harvested by many Vietnamese smallholder growers, enabling the results to be considered in relation to market requirements for acacia wood.

MATERIALS AND METHODS

Study sites

Clone screening trials were established in 2014 at Tan An commune, Vinh Cuu district, Dong Nai province, south Vietnam and Cam Hieu commune, Cam Lo district, Quang Tri province, central Vietnam, to evaluate growth and adaptability of newly developed polyploid *Acacia* hybrid clones. Two commercially planted diploid *Acacia* hybrid clones were included as controls. The climate at Tan An, is tropical, with a wet season from May to November and dry season from December to April while Cam Hieu has a slightly lower mean annual temperature, a higher annual rainfall and a shorter dry season. Both sites are located in undulating terrain on ferric acrisols.

The clonal trials used randomised complete block designs with three replicates. Ten-tree line plots of each treatment were used at Tan An and 2 × 8-tree rectangular plots at Cam Hieu. Tree spacing was 3 m between rows and 2 m between trees within rows. Details of study sites and trial establishment are given in Table 1.

The trial at Tan An tested a total of 11 treatments and that at Cam Hieu tested 15 treatments. Here we report results for four fast-growing clones that were tested at both sites: two promising triploid *Acacia* hybrid clones (X101 and X102) and two commercially planted diploid *Acacia* hybrid clones (BV10 and BV16). Both triploid clones were selected from among the progeny of one controlled cross between a maternal diploid clone of *A. auriculiformis* and a single paternal tetraploid clone of *A. mangium*, these parents being superior selections from

Table 1 Study sites and trial details

Trial location	Tan An	Cam Hieu
Latitude (N)	11° 03'	16° 28'
Longitude (E)	107° 00'	106° 59'
Altitude (m asl)	50	50
Mean annual temperature (°C)	26.5	24.5
Mean annual rainfall (mm)	2400	3080
Soil type	Yellow-brown ferralitic grey soil/ Ferric acrisols	Yellow-brown ferralitic grey soil/ ferric acrisols
Site preparation	Manual	Manual
Planting time	August 2014	November 2014
Fertiliser per tree	2 kg organic fertiliser and 0.2 kg NPK (16:16:8)	2 kg composted cattle manure and 0.2 kg NPK (16:16:8)
No. of replicates	3	3
No. of trees per plot	10 (line plot)	16 (2 × 8 trees)
Planting espacement	3 m × 2 m	3 m × 2 m

Acacia breeding programs at IFTIB. The two diploid controls were outstanding clones selected and developed from among spontaneous hybrid offspring of one of the first *A. mangium* plantation in north Vietnam. The maternal plantation of the Daintree, Queensland provenance of *A. mangium* was adjacent to a plantation of the Darwin, Northern Territory provenance of *A. auriculiformis*, making the latter the likely paternal contributor to these diploid clones, as described by Kha (2001).

Tree growth and sampling for wood property studies

At each site, five ramets of each of the four clones were felled at age 3.8 years to collect wood samples. Height and diameter over bark at breast height (DBH) of each sampled tree were measured. Discs 5 cm in thickness were cut from the felled stems at heights of 1.3 and 3.0 m, then at 1.5 m intervals until stem diameter over bark was less than 5 cm. Wood discs were stored immediately in closed zip-lock plastic bags in a cooled, insulated container to prevent drying and associated shrinkage and transported to the laboratory within 3 days for further processing.

Bark thickness

Bark thickness was measured on the cut discs at four positions corresponding to N, S, E and W orientations using electronic callipers with a precision of 0.01 mm. The mean of the four values was taken to be the bark thickness.

Basic density

Wood density was then determined using an adaptation of the water displacement method (TAPPI 2006). Discs were re-cut using a fine-toothed saw. The bark was removed and discs were soaked in clean water for 12 hours to ensure they were fully hydrated. They were then fully immersed in a weighed water bath while suspended on a needle mounted above the bath, and the mass of water displaced by the submerged disc was determined. Discs were oven-dried for about 48 hours at 105 °C to constant mass and then re-weighed. Basic density was calculated as oven-dry mass/volume of water displaced, assuming a water density of 1 g cm^{-3}.

Heartwood percentage

Heartwood percentage was determined on the water-soaked discs after the estimation of green volume described above and prior to oven-drying. The boundary between sapwood and heartwood on each disc was identified by the colour change, which was obvious (Figure 1).

Disc diameters and the positions of heartwood-sapwood boundaries were measured in N–S and E–W directions, and the total cross-sectional

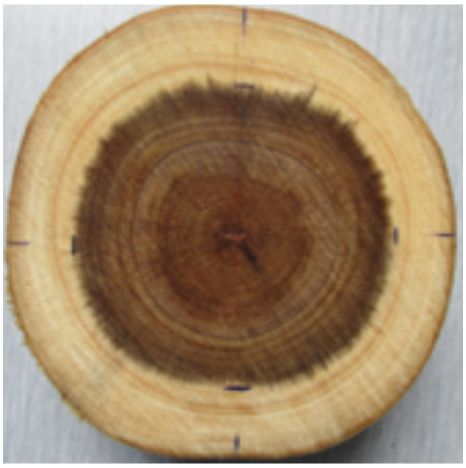

Figure 1 Sample disc for measuring heartwood

under-bark wood area and the area of heartwood calculated as the respective ellipses (Pillai et al. 2013). Heartwood proportion of each disc was calculated as the area of heartwood divided by the total cross-sectional area, expressed as a percentage.

Statistical analysis

A data set representing discs from all sample heights up to 7.5 m from the 40 trees sampled at age 3.8 years was assembled for statistical analysis of wood properties. Restricting sample height to 7.5 m avoided the inclusion of missing data points for the uppermost sample heights of 9.0 and 10.5 m, for which smaller trees, particularly at Cam Hieu, had stem diameters below 5 cm and were not sampled. Analysis of variance was carried out for each wood property variate, with site, disc height and clone as treatment effects in factorial combination and no blocking structure. Plots of residual versus fitted values were inspected to check that assumptions of normality were satisfied. Analyses were conducted using Genstat software, Release 18 (VSN International). To estimate trait variability within clones, the coefficients of variation (standard deviation/mean) for tree height, DBH and basic density, heartwood proportion and bark thickness for the discs sampled at 1.3 m were calculated for each clone at each site.

RESULTS

Trees sampled at Tan An were substantially larger, with overall mean height of 16.4 m and DBH of 13.9 cm compared with 11.8 m and 11.3 cm respectively at Cam Hieu (Table 2). The sampled trees of the triploid clones were larger than those of the diploid clones at Tan An, while mean DBH of all four clones at Cam Hieu were within 1 cm of one another.

Wood basic density

Site, clone, sampling height and site-by-clone interaction had significant ($p < 0.001$) influences on wood basic density, but other interactions were not significant (Table 3). For each of the four clones, density at Tan An was markedly higher than that at Cam Hieu. Density of triploid

Table 2 Diameter at breast height (DBH) and basic density, heartwood proportion and bark thickness at 1.3 m above ground for sampled trees at Tan An and Cam Hieu, showing associated coefficients of variation (CV)

Site	Tan An				Cam Hieu			
Clone	X101	X102	BV10	BV16	X101	X102	BV10	BV16
Height (m)	17.9	16.6	16.0	15.0	11.1	11.7	12.3	12.2
CV %	2.3	4.9	5.6	3.2	9.9	7.1	5.6	2.2
DBH (cm)	15.0	14.4	13.0	13.1	11.4	11.7	11.4	10.8
CV %	6.7	1.8	5.6	9.0	7.0	3.8	10.8	4.5
Basic density (kg m^{-3})	485	434	491	444	378	359	447	407
CV %	5.3	4.4	4.0	4.4	3.8	7.3	5.0	4.8
Heartwood proportion (%)	46.9	44.7	24.6	31.3	34	37.2	35.2	33.7
CV %	4.9	4.8	20.6	27.9	21.7	13.8	47.8	21.7
Bark thickness (mm)	4.50	4.60	3.66	3.68	3.84	4.18	3.48	3.42
CV %	8.3	11.6	7.4	8.9	15.8	8.4	13.2	9.6

Table 3 Analysis of variance for wood density

Source of variation	df	mv	vr	p-value
Site	1		673.9	< 0.001
Sampling height	4		17.8	< 0.001
Clone	3		92.9	< 0.001
Site × sampling height	4		1.6	0.174
Site × clone	3		17.3	< 0.001
Sampling height × clone	12		0.9	0.524
Site × sampling height × clone	12		1.1	0.366
Residual	158	2		
Total	197	2		

df = degrees of freedom, mv = missing values, vr = variance ratio

clones was significantly lower than that of diploid clones at Cam Hieu but not at Tan An (Figure 2). Density decreased slightly with increasing sample height for all clones at both sites. Clone BV10 exhibited the highest density and clone X102 the lowest density at both sites. Within-clone coefficients of variation for basic density at 1.3 m were low at both sites, ranging from 3.8 to 7.3% (Table 2). This low variation among ramets of each genotype indicated that basic density was being measured with high precision at both sites.

Heartwood proportion

Site, clone and sampling height significantly ($p < 0.001$) affected heartwood proportion and there was significant site-by-clone interaction (Table 4). Heartwood proportion of the triploid clones was greater than that of the diploid clones at Tan An but not at Cam Hieu (Figure 3). At age 3.8 years, the breast-height heartwood proportion of the two triploid clones at Tan An averaged 46%, while that of the two diploid clones averaged only 35% (Table 2). A pronounced decline in heartwood ratio with increasing sample height occurred for all four clones at both sites. Within-clone coefficients of variation for breast-height heartwood proportion were much higher and varied more than those for basic density, ranging from 4.8 to 47.7% (Table 2) reflecting the substantial variation in heartwood proportion from tree to tree for individual clones.

Bark thickness

Bark thickness showed a similar pattern of variation to the other two traits. Site, sampling height and clone significantly ($p < 0.001$) affected bark thickness and there was significant site-by-clone interaction (Table 5). The triploid clones had substantially thicker bark than the diploid clones at Tan An, particularly at the 1.3 m sampling height, but this difference was smaller at Cam Hieu. Bark thickness decreased with increasing sample height for all clones (Figure 4). The coefficients of variation for bark thickness within clones were low to moderate, ranging from 7.8 to 15.4% (Table 2).

DISCUSSION

This study enabled, for the first time, a comparison of three important wood properties—basic density, heartwood percentage and bark thickness—of young triploid and diploid *Acacia* hybrid trees growing in south and central Vietnam. Growth of these four clones in the trials was comparable to rates reported in nearby commercial plantations in central Vietnam (Harwood et al. 2017) and south Vietnam (Kha et al. 2012). Tree growth was more rapid at Tan An. Stem diameters of trees sampled for wood properties (Table 2) were similar to those harvested from many commercial plantations of *Acacia* hybrid. For example, Harwood et al. (2017) reported that the mean DBH at harvest of four 5-year-old plantations managed by smallholders near Cam Hieu ranged from 10 to 11 cm just before harvest.

With only two triploid and two diploid clones available for study it is inappropriate to draw general conclusions about the wood properties of triploid relative to diploid *Acacia* clones. Rather, the results provide a first indication of

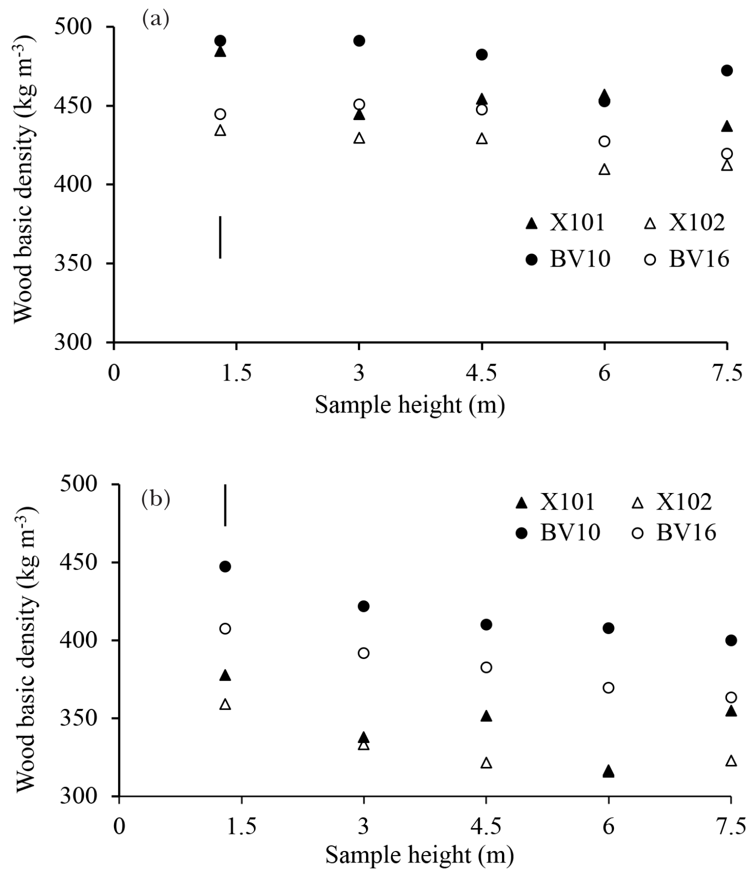

Figure 2 Wood basic density at (a) Tan An and (b) Cam Hieu; vertical bars show critical difference (p = 0.05) for comparing clones at each sampling height

Table 4 Analysis of variance for heartwood proportion

Source of variation	df	mv	vr	p-value
Site	1		53.6	< 0.001
Sampling height	4		97.3	< 0.001
Clone	3		37.5	< 0.001
Site x sampling height	4		1.9	0.109
Site x clone	3		24.0	< 0.001
Sampling height x clone	12		1.1	0.354
Site x sampling height x clone	12		1.1	0.359
Residual	156	4		
Total	195	4		

df = degrees of freedom, mv = missing values, vr = variance ratio

the wood properties of triploid *Acacia* hybrid clones and how these properties might affect their commercial potential. Diploid clones BV10 and BV16 have been studied in other field trials. Both these clones usually display above-average growth, and clone BV10 has above-average wood density, relative to other diploid *Acacia* hybrid clones, while BV16 typically has somewhat lower density than BV10 (Kha 2001, Kim et al. 2008, 2011).

Basic density

The wood basic density for these 3.8-year-old acacia trees (means at breast height ranging from 360 to 490 kg m^{-3} for individual clones

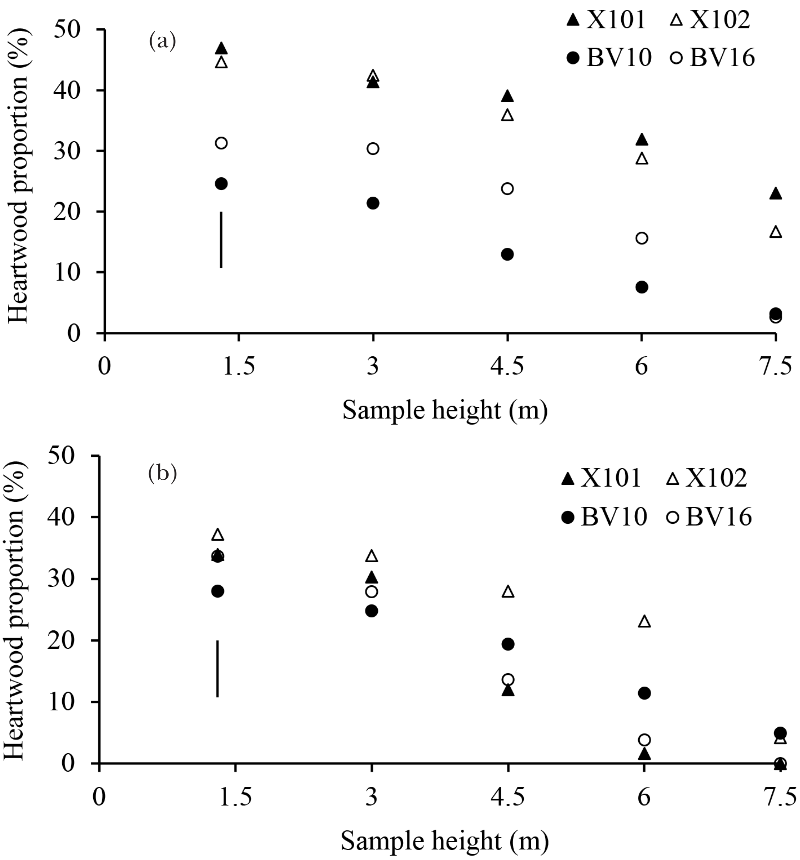

Figure 3 Heartwood proportion at (a) Tan An and (b) Cam Hieu; vertical bars show critical differences (p = 0.05) for comparing clones at each sampling height

Table 5 Analysis of variance for bark thickness

Source of variation	df	mv	vr	p-value
Site	1		13.2	< 0.001
Sampling height	4		58.0	< 0.001
Clone	3		8.7	< 0.001
Site x sampling height	4		0.3	0.556
Site x clone	3		2.0	< 0.001
Sampling height x clone	12		2.1	0.024
Site x sampling height x clone	12		0.7	0.812
Residual	156	4	13.7	
Total	195	4	96.0	

df = degrees of freedom, mv = missing values, vr = variance ratio

across the two sites, Table 2) was low, relative to most plantation-grown pulpwood. Whole-tree basic density of 5–9-year-old *Eucalyptus globulus* and *E. nitens* grown at nine sites across southern Australia ranged from 427 to 570 kg m^{-3}, with all but two sites exceeding 450 kg m^{-3} (Raymond & Muneri 2001). Older trees of tropical acacias species generally have higher density than observed in our study. For example, basic density of *A. mangium* in Malaysia at age of 5 years was in the rage 450–500 kg m^{-3} (Sulaiman & Choon 1993). Basic density of *A. mangium* grown in Bangladesh ranged from 500 to 620 kg m^{-3}, increasing with tree age from 10 to 20 years and declining slightly with increasing sample height (Chowdhury et al. 2005). Breast-height basic

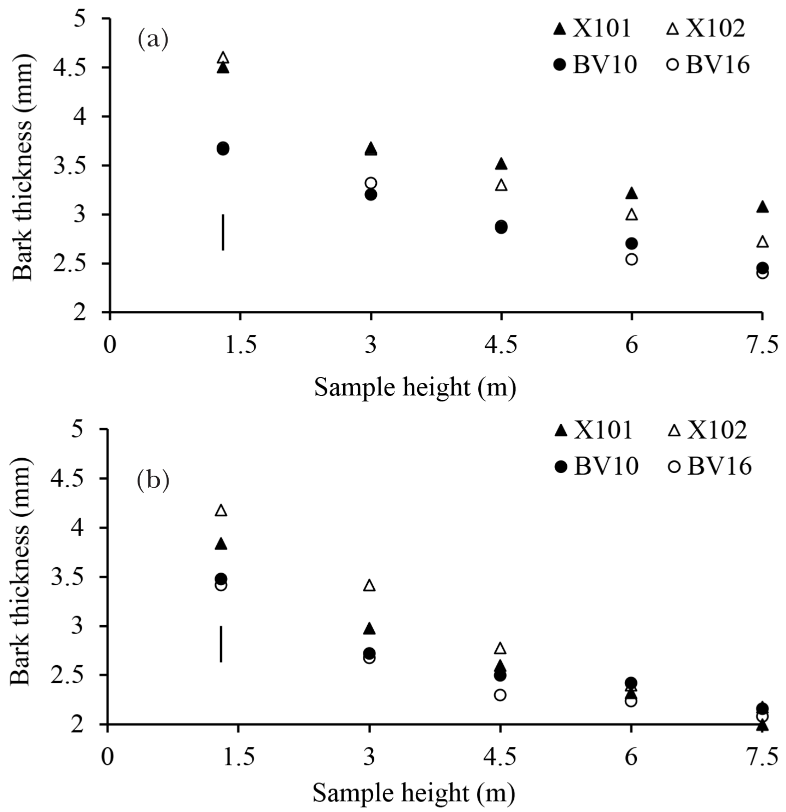

Figure 4 Bark thickness at (a) Tan An and (b) Cam Hieu; vertical bars show critical differences (p = 0.05) for comparing clones at each sampling height

density of *A. auriculiformis* grown in northern Vietnam was 560–590 kg m^{-3} at age 8 years (Hai et al. 2008). Radial profiles of air-dry density of 8-year-old *Acacia* hybrid reported by Kim et al. (2008) showed a consistent increase in density from pith to bark at sampling heights from 0.3 to 6 m, indicating that the older wood laid down in later years had higher density. This trend was also observed for *A. auriculiformis* by Hai et al. (2008).

The significant influences of genotype, site and sampling height on basic density observed in our study were also reported in earlier investigations of the wood properties of 7-8-year-old clonal *Acacia* hybrid (Kim et al. 2008, 2011), but there were differences in the specific patterns of variation observed. These authors reported air-dry specific gravity (i.e. density of air-dry wood) rather than basic density, which complicates comparisons with the current study. They found that slower-growing trees in north Vietnam had significantly higher air-dry density than that of the same clones grown in south Vietnam (Kim et al. 2011), while we observed that the faster-growing trees in the south had higher basic density than the slower-growing trees in central Vietnam. Wu et al. (2011) reported that wood basic density of a set of 19 eucalypt clones grown at three trial sites in southern China was lowest at the site where growth was fastest. In the current study, DBH included as a covariate did not have a significant effect on the analysis of variance, showing that after accounting for site and clone differences, DBH of individual clonal ramets did not significantly influence basic density (analysis not shown). However, given the small sample size (only five ramets per clone, at each site) and the modest range of DBH sampled, as indicated by the low coefficients of variation for DBH of sampled trees (Table 2) a subtle influence of DBH on density would not be easily detectable. Further study is needed to fully understand and account for the influences of site and growth rate *per se* on wood density of *Acacia* hybrid.

Air-dry specific gravity of trees grown in north Vietnam declined substantially with increasing height from 0.3 to 1.3 m and was then constant with further increase in sampling height up to 6.0 m (Kim et al. 2008), whereas in our study a slight ongoing decline in basic density with increase in sampling height from 1.3 to 7.5 m was evident in both south and central Vietnam. Interestingly, an opposite trend of increasing basic density with increasing sample height was reported for 5–9-year-old trees of *E. globulus* and *E. nitens*; such a trend is typical for plantation-grown eucalypts (Raymond & Muneri 2001).

Heartwood percentage

The very young age and relatively small DBH of the trees in this study makes any conclusions about heartwood provisional at best. The development of heartwood in triploid and diploid *Acacia* hybrid clones will need to be re-examined when older and larger-diameter trees become available for sampling. Nonetheless, it is apparent that in south Vietnam, fast-growing triploid clones develop more heartwood at an early age than did diploids. A smaller proportion of heartwood was laid down in the slower-growing trees in central Vietnam. As for basic density, DBH of individual trees included as a covariate in the analysis of variance did not significantly influence heartwood proportion.

Site conditions can influence heartwood formation. Pérez Cordero and Kanninen (2003) researched heartwood and sapwood proportions of 17 *Tectona grandis* plantations from 11 sites covering different climate zones in Costa Rica and found that trees in wet sites produced less heartwood than those on dry sites. A positive effect of diameter growth on heartwood proportion was recognised in *E. globulus* (Morais & Pereira 2007, Miranda et al. 2009), and *Tectona grandis* (Moya & Perez 2008). Effects of genotype in heartwood proportion are also well-recognised, for example in *E. globulus* where Miranda et al. (2014) reported heritability values of 0.32 for heartwood diameter and 0.23 for heartwood proportion.

The observed decrease of heartwood ratio with increasing stem height at both sites was consistent with expectation, given that a higher proportion of the cross-sectional area at increasing height will be sapwood laid down at later ages. Previous studies have also recorded similar results with many other hardwood species (Moya & Muñoz 2010, Githiomi & Dougal 2012, Pillai et al. 2013).

Bark thickness

The thicker bark observed at Tan An was a consequence of the greater tree size there, since the ratio of bark thickness to DBH was actually slightly higher at Cam Hieu (mean of 3.3%, compared with 3.0% at Tan An). Bark thickness of the two triploid clones was clearly greater than that of the diploid clones at Tan An. Again, this greater bark thickness of the triploids was in part a consequence of their greater DBH, which exceeded that of the diploid clones by over 1 cm at this site (Table 2). Polyploidy may in itself be associated with thicker bark. Autotetraploid *A. mangium* trees had significantly thicker bark than diploid trees 26 months after planting, even though their DBH was slightly smaller, on average (Harbard et al. 2012). The difference in bark thickness between triploid and diploid clones was greatest at the lowest sampling height of 1.3 m. The bark morphology of the triploid clones was rougher and more similar to that of *A. mangium* on the lower stem while the bark of the diploid clones was smoother at this height. The triploid clones had a higher proportion (2/3) of their genome derived from *A. mangium* than did the diploid clones (½) (Nghiem et al 2018) and this may have resulted in more *A. mangium*-like bark.

Implications for wood markets

As well as providing an initial insight into the wood properties of two newly developed *Acacia* hybrid triploid clones relative to commercially planted diploids, the results are relevant to the challenges Vietnamese growers and wood processers face in increasing the value of the country's *Acacia* plantations. Wood harvested from 3.8-year-old *Acacia* hybrid trees had a range of basic density that was low, relative to typical values for the international hardwood chip market. Other studies of *Acacia* wood density suggest that extending the rotation age will significantly increase density at harvest. The greater bark thickness observed for the triploid clones will need to be considered when predicting wood recovery from standing stem volume. The particularly low basic density of triploid clone X102 suggested that basic density of promising new triploid clones should be carefully evaluated before final adoption of clones for commercial planting. The higher proportion of heartwood observed in the triploid clones would be an advantage for sawn timber applications. Further study is required to determine the effect of heartwood on pulping properties. Evaluation of other economically important wood properties of the triploid clones, including fibre characteristics and wood stiffness and strength, is currently under way and will be reported elsewhere.

CONCLUSIONS

Wood basic density of two 3.8-year-old triploid *Acacia* hybrid clones was significantly less than that of diploid *Acacia* hybrid clones in central Vietnam but not in the south, where tree growth was faster and densities were higher. Heartwood proportion and bark thickness of triploid clones was significantly greater than that of diploid clones in the south but not in central Vietnam. Declining trends of wood density, heartwood proportion and bark thickness with increasing stem height were observed for all four clones at both sites. While these triploid clones appear to be acceptable in these wood and stem traits, it will be important to consider wood basic density and bark thickness when ranking new clones for commercial deployment.

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