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Variation in wood properties of six natural acacia hybrid clones in northern Vietnam

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Abstract Wood properties of six 8-year-old natural acacia hybrid clones between *Acacia mangium* and *Acacia auriculiformis*, planted in Bavi, Vietnam, were studied. The hybrid clones possessed obvious heterosis in growth and in some wood properties. The characteristics of growth, air-dry specific gravity, lengths of fibers and vessel elements, S_2 microfibril angle, green moisture content, and shrinkage were examined to clarify the variation among clones. From the results, the differences among the clones in growth and in some wood properties were significant. The pattern of distribution of specific gravity showed that there were low and high specific gravity zones in the stem. Specific gravity at stump height or at 3.0 m was useful for prediction of specific gravity in the whole tree stem. Moreover, clones with high specific gravity can be predicted at a young age. There was no significant correlation between diameter growth and specific gravity. Of the six clones studied, clone BV5 was selected as the best based on its growth ability and specific gravity.

Key words Natural acacia hybrid · Growth · Wood properties · *Acacia mangium* · *Acacia auriculiformis*

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Introduction

Natural acacia hybrids in Vietnam were first detected growing at Bavi Research Station in 1991. The parents of these natural acacia hybrids were identified to be *Acacia mangium*, provenance Daintree, Queensland (Australia), and *Acacia auriculiformis*, provenance Darwin, Northern Territory (Australia).[1] Acacia hybrids are harvested at shorter rotation and have significantly higher yields than their parent species. They are faster growing, less susceptible to disease, and more adaptable to poor soil types than their parent species. While hybrid stock increase by 22 $m^3\,ha^{-1}\,year^{-1}$, the parents grow only 12 $m^3\,ha^{-1}\,year^{-1}$ on average under similar growing conditions. In recent years, large areas of acacia hybrid plantation have been established in Vietnam, estimated to be 0.4 million hectares, and are beginning to replace the other acacia species. Acacia hybrids are fast gaining favor over *Eucalyptus* or S*tyrax tonkinensis* for commercial pulp and paper production due to their pulp yield potential.[2] On the other hand, the hybrids inherited the ability to fix atmospheric nitrogen by a symbiosis between nitrogen-fixing bacteria and the plant's roots from both acacia species, thus improving the physical and chemical properties of the soil. This could enhance the long-term sustainability of hybrid plantations grown in the same site and provide an economic benefit to subsequent rotations of acacia or other crops. The plantations of these hybrids have the potential to provide several other environmental benefits. In central Vietnam, for example, fast-growing acacia has been used to stabilize hill slopes, allowing agroforestry to be practiced on steep land where previous cultivation would have caused excessive soil erosion. Acacia plantations also have a role to reduce greenhouse gas in addition to providing wood for pulp or firewood.[3] The net contribution of acacia hybrids to stop global warming is dependent on the extent to which acacia hybrids help to increase reafforestation, act as a carbon stock, and resolve environmental problems.

However, acacia hybrids planted in Vietnam are harvested at a short rotation of around 10 years to supply raw material for pulp and fiberboard industries. In order to increase the value of acacia plantation trees in terms of both wood usage and environmental benefits, it is necessary to enlarge the tree diameter by increasing rotation age and examine its possible use as a solid wood. Some studies on wood anatomical characteristics and wood properties of natural acacia hybrid in Vietnam have been carried out.[2,4,5] Le[2] compared wood chemical components, pulp potential, and physical and mechanical properties between acacia hybrid and its parent species and found some wood properties of acacia hybrid were intermediate between *A. mangium* and *A. auriculiformis*. The ability of acacia hybrid to be used as material for particleboards was also reported.[2] However, there is no study on the effect of genetic factors on the wood properties of natural acacia hybrid. The purpose of this study was to clarify the differences in wood properties among popular natural acacia hybrid clones. We especially focused on specific gravity and growth characteristics and discuss the possibility of early selection.

Materials and methods

Clone of natural acacia hybrid

Natural acacia hybrids have been detected in many places from the north to the south of Vietnam. Hybrid trees occurred in *Acacia mangium* plantations raised from seed collected in *A. mangium* trial areas adjacent to *Acacia auriculiformis*. Plus trees of acacia hybrid were selected and shoots of these trees were collected to produce cuttings separately. Acacia hybrid clones were named (BV1, BV2 . . . or TB1, TB2 . . .) depending on the place of detection. Acacia hybrids possess heterosis in growth of both height and diameter and are slightly better in stem straightness; thus, their wood volume is much greater than that of their parents. In morphology, acacia hybrids have intermediate leaf size between *A. mangium* and *A. auriculiformis*. The phyllode of *A. mangium* has four main veins, *A. auriculiformis* has two or three main veins, and the hybrids have three or four veins. Crown shape and color of the bark of acacia hybrid are also intermediate between the parents but closer to *A. auriculiformis*. After several stages of selection and clonal testing, some acacia hybrid clones with the best ability of growth and superior stem form were recognized as new varieties for plantation. These studies were under the control and management of the Research Centre for Forest Tree Improvement, Forest Science Institute of Vietnam.

Materials

A natural acacia hybrid clone trial plantation is located in Bavi, Ha Tay (21°07′ N, 105°26′ E), northern Vietnam. The soil is a yellow lateritic hill soil developed on sandstone with hard conglomeration, is poor in nutrients, and is shallow with depths not exceeding 50 cm. Six clones designated as BV5, BV10, BV16, BV29, BV32, and BV33 were selected for this study. Saplings from propagated branches cut from natural acacia hybrid were prepared for planting. Each clone was planted in 500 m^2 with spacing of 2.5 × 2.5 m. A total of 18 trees (3 trees per clone) were harvested at 8 years of age. Each tree was measured for tree height and diameter at breast height after felling. Five disks with 5 cm thickness from 0.3, 1.3, 3.0, 4.5, and 6.0 m above the ground were cut to examine specific gravity and green moisture content. A 20-cm-thick disk was also collected from each tree at a height of 1.3 m for measurement of other properties.

Green moisture content

A fan-shaped specimen was cut from each disk and divided into heartwood and sapwood immediately; green moisture content was then calculated gravimetrically.

Specific gravity

Pith-to-bark strips (radius × 30 × 20 mm) were cut from each disk after air drying. The strip was divided into small pieces at intervals of 1 cm from pith to bark with a razor blade and the specific gravity was measured with an electronic densimeter (MD-300S).

Lengths of fiber and vessel element and microfibril angle

Pith-to-bark strips (radius × 10 × 10 mm) were cut from the disks cut at 1.3 m for fiber length, vessel element length, and microfibril angle of the S_2 layer. The strips were then divided into small pieces at intervals of 1 cm from pith to bark with a razor blade. The pieces were macerated by dipping in a 1:1 solution of HNO_3 and aqueous $KClO_3$ (3 g/100 ml solution) for 5 days. The pieces were rinsed three times with distilled water. The lengths of 30 fibers and 20 vessel elements were measured by microscope and Winroof software. The small blocks (5 × 5 mm, L × R) at 1, 3, 5, 7, 9 cm etc. from pith to bark were also prepared from the strips. Radial sections of 8 μm thickness were cut by microtome and then cleaned in distilled water. The sections were dehydrated in 10% ethanol, and subsequently in an ethanol series of 30%, 50%, 80%, and 100% ethanol for 5 min each. The sections were then placed on a slide glass and immersed in a 3% solution of iodine–potassium iodide for 2–5 s. One or two drops of 60% HNO_3 were added and a coverslip was placed over the wetted specimen. Microfibril angles of 20 fibers per small block were measured by microscope and Winroof software.

Shrinkage

The specimens for measurement of shrinkage (30 × 30 mm, 5 mm thickness) were soaked in distilled water until saturated. The dimensions in the radial and tangential directions were measured with a digital micrometer CD-S20C (minimum scale: 0.01 mm). The specimens were then subsequently placed in a conditioned room at 20°C and 65%

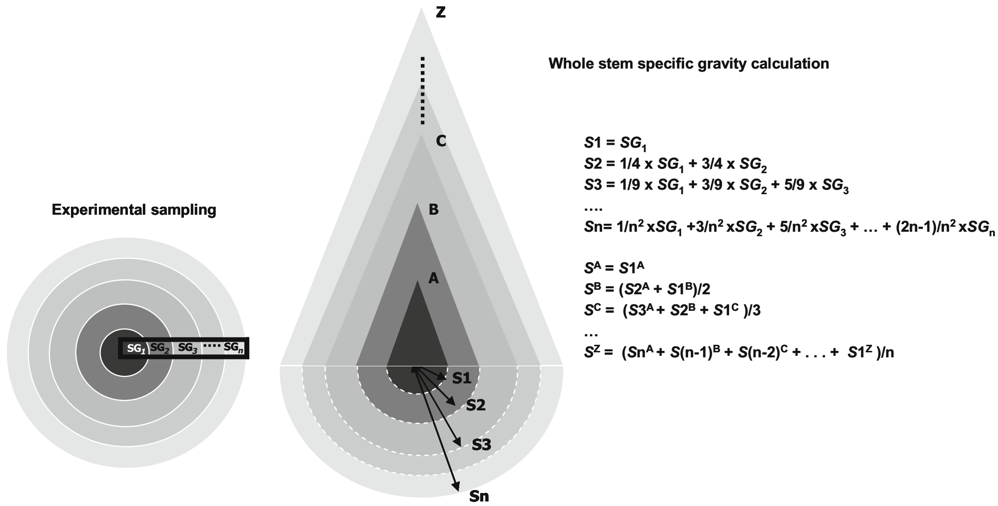

Fig. 1. Calculation method of specific gravity change with tree age. S1, S2, S3, . . . , S*n* are specific gravity of disk for diameters 2, 4, 6, . . . , *n* cm. S^A, S^B, S^C, . . . , S^Z are assumed to be specific gravity of the whole stem for diameters 2, 4, 6, . . . , *n* cm. $S1^A$, $S1^B$, $S1^C$, . . . , $S1^Z$ show S1 at height A, B, C, . . . , Z. For example, $S2^D$ shows S2 at height D

Table 1. Growth characteristics and wood properties of natural acacia hybrid clones

Clone	DBH (cm)	*H* (m)	Specific gravity	WF (mm)	VE (mm)	Green moisture content (%)		MFA (°)	Shrinkage (%)	
						Heartwood	Sapwood		R	T
BV5	14.67	14.17	0.67 (0.06)	0.90 (0.02)	0.23 (0.003)	74.81 (10.73)	89.25 (9.28)	15.46 (0.40)	3.46 (0.31)	7.29 (0.42)
BV10	12.70	12.67	0.69 (0.08)	0.86 (0.01)	0.23 (0.006)	75.02 (7.39)	75.03 (7.60)	16.43 (0.47)	3.23 (0.29)	7.43 (0.44)
BV16	13.47	13.20	0.66 (0.09)	0.86 (0.03)	0.24 (0.011)	77.69 (10.62)	83.08 (14.06)	16.02 (0.09)	3.44 (0.39)	7.54 (0.62)
BV29	13.97	13.53	0.68 (0.08)	0.93 (0.03)	0.24 (0.011)	73.59 (10.58)	78.85 (8.00)	15.49 (0.69)	3.36 (0.31)	6.93 (0.61)
BV32	15.33	14.50	0.61 (0.08)	0.92 (0.04)	0.24 (0.004)	85.37 (15.87)	90.06 (7.71)	14.44 (0.91)	3.34 (0.31)	6.89 (0.35)
BV33	14.33	13.60	0.62 (0.10)	0.93 (0.04)	0.25 (0.004)	78.65 (12.20)	82.50 (8.00)	15.76 (0.42)	2.96 (0.20)	6.51 (0.39)

Data other than DBH and H are shown as means with standard deviations given in parentheses
DBH, Diameter at breast height; *H*, height; WF, wood fiber length; VE, vessel element length; MFA, microfibril angle of S_2 layer; R, radial direction; T, tangential direction

relative humidity until they reached a moisture content of approximately 15%. The dimensions in two directions were measured again. Finally, the dimensions of the oven-dry specimens were measured.

Change of specific gravity with tree age

The data for specific gravity at each stem height was used to calculate the change of specific gravity with tree age. The method of calculation is shown in Fig. 1. First, the change of specific gravity with diameter growth of each disk was calculated as follows.

$$S1 = SG_1$$
$$S2 = 1/4 \cdot SG_1 + 3/4 \cdot SG_2$$
$$S3 = 1/9 \cdot SG_1 + 3/9 \cdot SG_2 + 5/9 \cdot SG_3$$
$$\ldots\ldots$$
$$Sn = 1/n^2 \cdot SG_1 + 3/n^2 \cdot SG_2 + 5/n^2 \cdot SG_3 + \ldots + (2n-1)/n^2 \cdot SG_n$$

where S1, S2, S3, . . . S*n* are specific gravity for disk diameters of 2, 4, 6, . . . *n* cm, respectively. Then the data from each stem height were combined along the growth layers. In this study, based on distance from the bark, growth layers at different heights were combined because the growth ring boundary was not distinct. Thus, the time series change of specific gravity for six clones was obtained.

Results and discussion

Growth characteristics

The diameter at breast height and the tree height in six natural acacia hybrid clones are listed in Table 1. The diameter was 12.7–15.3 cm and the tree height was 12.7–14.5 m. The growth rate in this stand was less than other northern areas such as Xuan Mai-Hatay, Vinhphuc (17.4–25.4 cm in diameter and 14.5–18 m in height, 5- to 9-year-old stand) and much slower than in southern Vietnam (17.1–27.2 cm in diameter and 18.8–19 m in height, 5-year-old stand).[6] BV5, BV32, and BV33 showed the better diameter growth of the six clones.

Specific gravity

The mean values of air-dry specific gravity are listed in Table 1. Specific gravity showed a high group of 0.69 (BV10), 0.68 (BV29), 0.67 (BV5), and 0.66 (BV16) and a low group of 0.61 (BV32) and 0.62 (BV33). These values are higher than that reported by Le[2] (0.54 g/cm^3 at 5 years of age) and similar to those in reported by Nguyen[4] and Nguyen and Nguyen.[5]

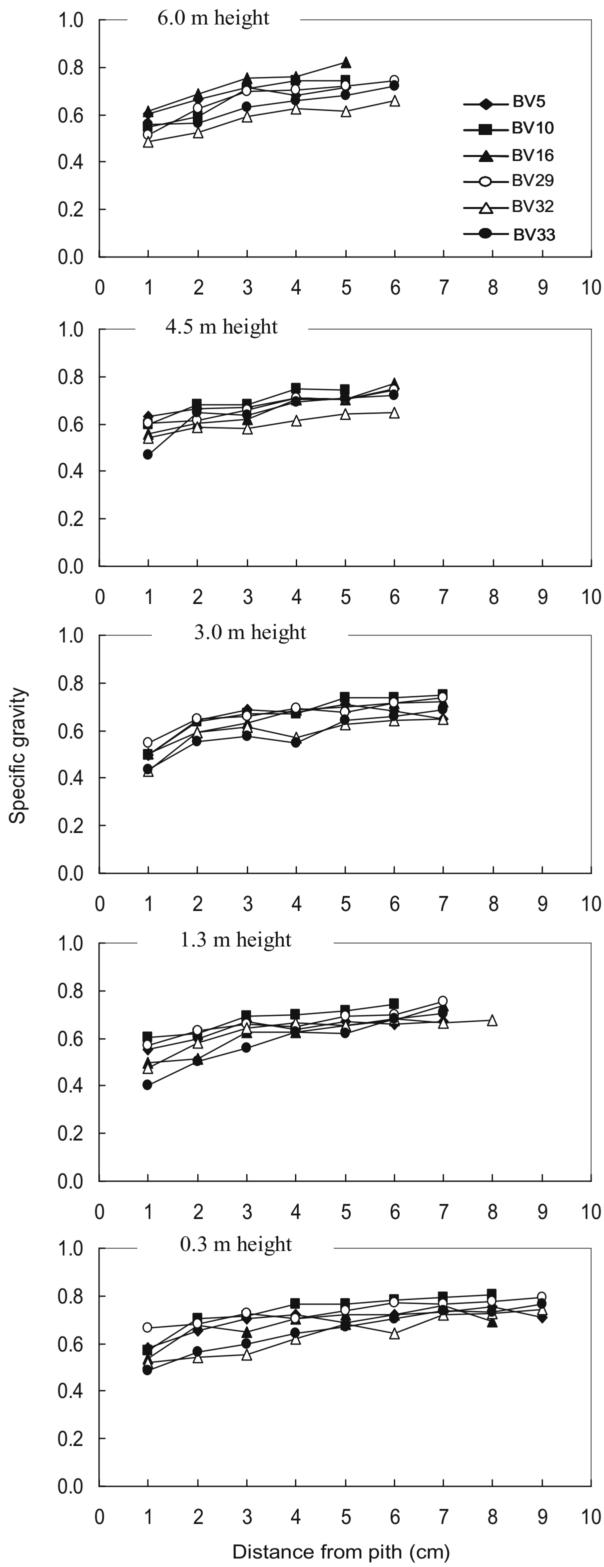

Fig. 2. Profile of specific gravity in the radial direction at different stem heights of natural acacia hybrid clones

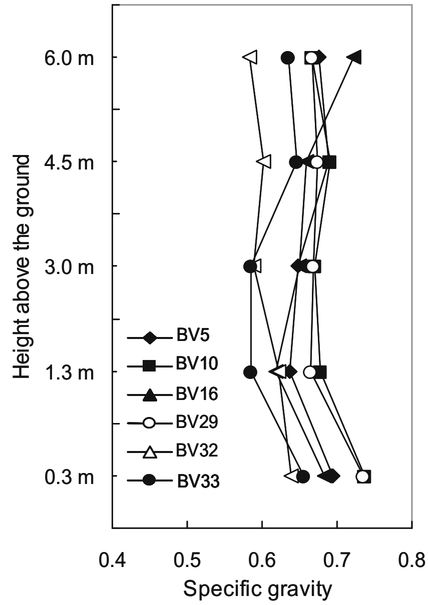

Fig. 3. Profile of specific gravity in the axial direction of natural acacia hybrid clones

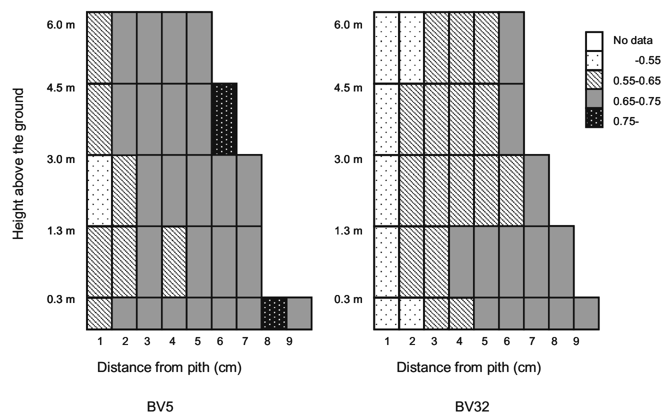

Fig. 4. Distribution image of specific gravity of natural acacia hybrid clones. *BV5*, belongs to high specific gravity group; *BV32*, clone belongs to low specific gravity group

The radial variation of specific gravity at each stem height is shown in Fig. 2. The specific gravity increased from pith to the bark in the six clones. This tendency is in agreement with the report by Ani and Lim[7] that stated that the specific gravity of *Acacia mangium* increased from the center to the outer region near bark. On the other hand, Lim and Gan[8] reported that for 14-year-old *Acacia mangium* the density increased from the pith to the intermediate region and decreased toward the bark. The axial variation of specific gravity is shown in Fig. 3. The specific gravity at the stump was the highest, tending to decrease and then increase toward the top. Lim and Gan[8] also reported that the density of *Acacia mangium* tended to decrease from about 10% of tree height to about 50% of the height before increasing toward the top. However, the specific gravity of 5-year-old *Acacia mangium* was reported to decrease with increasing height.[7]

Distribution images of specific gravity in stem are shown in Fig. 4. BV5 represented a high specific gravity group and BV32 a low specific gravity group. The images show that a

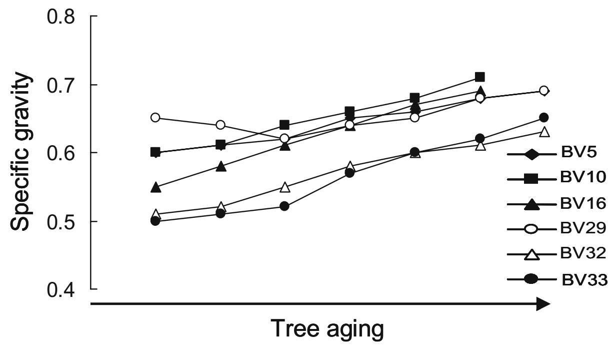

Fig. 5. Change of specific gravity with tree aging of natural acacia hybrid clones. Each plot was calculated as a three-point moving average

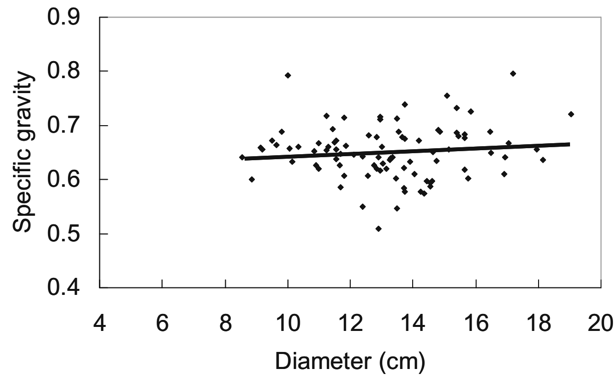

Fig. 6. Relationship between specific gravity and stem diameter of natural acacia hybrid clones

high specific gravity zone exists in the outer area of the stem and a low specific gravity zone in the inner area. A similar result was found in other clones. This means that the difference in mean specific gravity among the six clones is caused by the specific gravity in the intermediate area of the stem.

Correlations in specific gravity between each stem height and the whole stem were moderate and significant. High correlation coefficients were found at stump height (r = 0.908, P = 0.06) and at 3.0 m (r = 0.850, P = 0.01). The correlation between breast height (1.3 m) and the whole stem was moderate (r = 0.74, P = 0.07). These results show that specific gravity at stump height or at 3.0 m height is useful for prediction of specific gravity in the whole tree stem rather than the specific gravity at breast height.

Change of specific gravity in stem with aging

It is very important to predict stem density at harvest as early as possible when trees are young. Change in specific gravity in the whole stem with aging was calculated (Fig. 1). The time series change is shown in Fig. 5. Each plot in Fig. 5 was calculated by three-point moving average. It was clear that the specific gravity of the whole stem increased with age. Moreover, it is notable that the high specific gravity in clones (BV5, BV10, BV16, and BV29) was high when the tree was young. Conversely, the clones with low specific gravity (BV32, BV33) had low specific gravity when young. This means that it is possible to select clones with high density when a tree is young. This result is valuable for tree breeders who want to shorten tree improvement process. The correlations in specific gravity of whole stem between 8 years of age and younger were then examined in order to clarify a stage suitable for early prediction. The results are listed in Table 2. When the diameter at a height of 0.3 m was 2 cm, the correlation coefficient was 0.55 and a significant correlation at the 5% level was found. When the diameter became 6 cm, there was a significant correlation (r = 0.73) at the 1% level. We suggest that early selection of a clone with high specific gravity should be carried out when the diameter reaches 6 cm at 0.3 m height.

Table 2. Correlation coefficient in specific gravity of whole stem between 8-year-old and younger natural acacia hybrid clones

Diameter at 0.3 m height (cm)	Correlation coefficient (r)
2	0.55*
4	0.57*
6	0.73**
8	0.74**
10	0.82**
12	0.92**
14	0.96**
16	0.99**

* $P < 0.05$; ** $P < 0.01$

Relationship between growth rate and specific gravity

The relationship between diameter and specific gravity is shown in Fig. 6; there was no significant correlation (r = 0.07). This means that growth rate does not affect specific gravity. In order to improve wood quality, selection of clones with faster growth and higher density is important. In addition, it will be desirable to select clones with uniform wood and specific gravity because some end-users, such as processors and manufacturers of wood products, want acacia hybrids to have morphological uniformity.

Other wood properties

Mean fiber length was the longest in BV29 and BV33 (0.93 mm) and the shortest in BV10 and BV16 (0.86 mm). Fibers around 0.85–0.90 mm in length were also found in some studies on *Acacia mangium*.[8–11] The mean length of vessel elements ranged from 0.11 to 0.12 mm in the six clones (Table 1). The profiles of fiber length and vessel element length in the radial direction were similar for all clones (Fig. 7). The fiber length was 0.5 mm in the vicinity of the pith, reaching a maximum value of 1.1–1.2 mm close to the bark. Vessel element length in six clones increased slightly from 0.11 mm near the pith to 0.13 mm near the bark. The observed radial variation corresponds to results for *Acacia mangium* obtained in a Malaysian study.[9] Vessel element length was relatively constant in the radial direc-

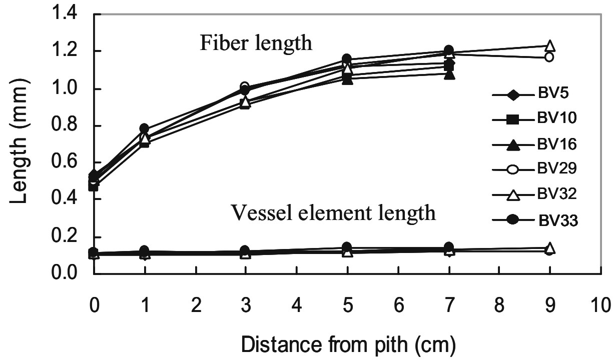

Fig. 7. Profile of lengths of fibers and vessel elements in the radial direction of natural acacia hybrid clones

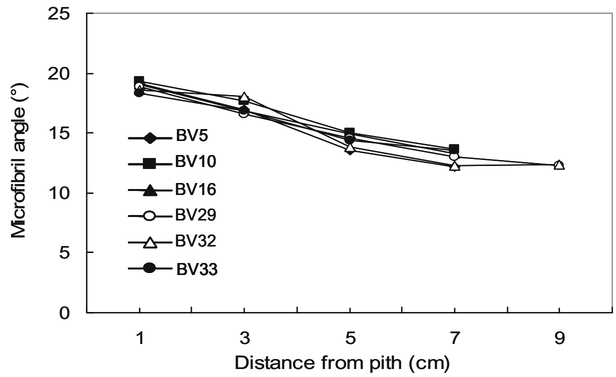

Fig. 8. Profile of microfibril angle in relation to distance from the pith of natural acacia hybrid clones

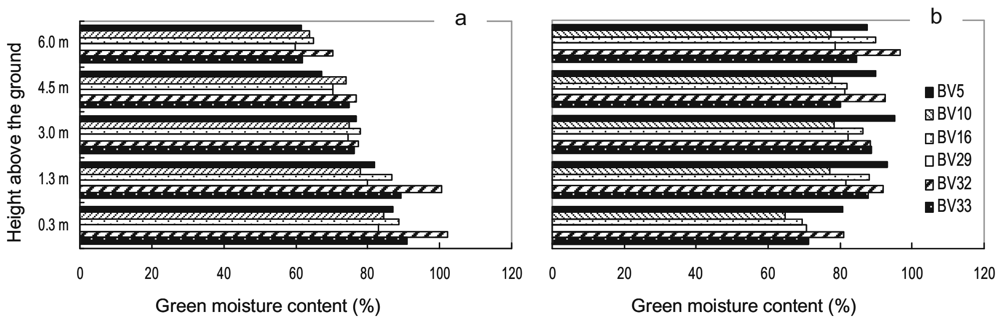

Fig. 9a, b. Vertical variation of green moisture content in **a** heartwood and **b** sapwood of natural acacia hybrid clones

tion and it can be assumed that there is little elongation from fusiform initials with cambial aging.

Microfibril angle interacts with strength and stiffness of clear wood[12] and differences in microfibril angle have a profound effect on the properties of wood, in particular its stiffness.[13] Microfibril angle was the smallest in BV32 with 14.4° and the largest in BV10 with 16.4° (Table 1). The profiles of microfibril angle in the radial direction are shown in Fig. 8. The mean microfibril angle was 19° near the pith and 13° near the bark, indicating a 30% reduction. There was little difference in radial variation of microfibril angle among the six clones.

Green moisture content varied among the clones and ranged from 73.59% to 85.37% in heartwood, and from 75.03% to 90.06% in sapwood (Table 1). Yamamoto et al.[6] reported the green moisture content of acacia hybrid grown in the same area and that value was slightly higher than the result in this survey. Green moisture content decreased with increasing stem height in heartwood, while in sapwood it was the lowest in the bottom of the stem (Fig. 9).

Total shrinkage ratio was the smallest in BV33 (2.96% and 6.51% in radial and tangential directions) and the largest in BV5 (3.46% in the radial direction) and in BV16 (7.54% in the tangential direction) (Table 1). The mean value in the six clones was 3.1% and 7.1% in radial and tangential directions, respectively. These values are comparatively small in spite of the high density. According to the grading standard of physical properties in tropical wood species, the value was classified as grade II.[14]

Conclusions

There were significant differences in growth and wood specific gravity among six natural acacia hybrid clones planted in Bavi, Vietnam. However, there was little difference in the lengths of fiber and vessel elements, microfibril angle, green moisture content, and shrinkage. BV5 was the outstanding clone with strong points in both growth and wood specific gravity. The pattern of distribution of specific gravity showed that there were low and high specific gravity zones in the stem. The calculation of change in specific gravity with tree aging suggests that clones with high specific gravity can be selected at an early stage. Growth rate does not affect specific gravity. Growth rate and specific gravity are the main traits to consider in clone selection to improve wood quality in natural acacia hybrid.

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