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ORIGINAL ARTICLE

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Possibility of improvement in fundamental properties of wood of acacia hybrids by artificial hybridization

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Abstract Growth, specific gravity, and wood fiber length of *Acacia mangium*, *Acacia auriculiformis*, artificial acacia hybrid clones, and combinations, which were planted in a trial forest in Bavi, Vietnam, in July 2001, were examined. The radial variations from pith to bark were investigated to clarify the effect of genetic factors on these traits. Superiority of hybrids over their parents ranged from 36.3% to 41.6% for diameter, from 20.0% to 25.3% for height, from 6.9% to 20.7% for specific gravity, and from 6.1% to 12.8% for wood fiber length. The hybrid possessed heterosis in diameter, height, specific gravity, and wood fiber length regardless of whether the female parent was *A. mangium* or *A. auriculiformis*. The profiles of wood fiber length and specific gravity in the radial direction were similar for all the trees investigated. Wood fiber length was initially 0.5–0.6 mm near the pith and then increased slowly, finally reaching 1.0–1.2 mm near the bark. The specific gravity of acacia increased from 0.49–0.58 near the pith to 0.63–0.74 near the bark. From a relative distance of 30% from the pith, the specific gravity increased slightly and seemed to be stable. The relations among tree diameter, specific gravity, and wood fiber length were fair and could be represented by positive linear regression formulas. Hybrids for which *A. auriculiformis* was the female parent and *A. mangium* was the male parent had a faster growth rate and longer wood fibers than the inverse hybrids.

Key words *Acacia mangium* · *Acacia auriculiformis* · Artificial acacia hybrid · Growth · Specific gravity · Wood fiber length

Introduction

Acacia is a large genus comprising around 1500 species, and belongs to the family Fabaceae. It is distributed in the warm and dry regions of the world, mainly in the tropical and subtropical zones. *Acacia mangium*, *Acacia auriculiformis*, and the hybrids between these two species are considered as important fast-growing species for plantations in many tropical countries, including Vietnam due to their rapid growth, rather high wood quality, and adaptation to many soil types with different pH values.[1] *Acacia mangium* and *A. auriculiformis* are natural species in Australia, Papua New Guinea, and Indonesia[2] and were introduced to other countries such as Vietnam, Malaysia, and Bangladesh in the sixteenth and seventeenth centuries.[1,3] The natural hybrids between *A. mangium* and *A. auriculiformis* were first discovered in Malaysia in early 1972, and have since been found in Papua New Guinea,[4] Thailand, and in Vietnam.[5] *Acacia mangium* was identified to be the female parent and *A. auriculiformis* was the male parent of the natural acacia hybrid.[3]

The plantation area of *A. mangium*, *A. auriculiformis*, and acacia hybrids has steadily increased over time in Asia. In Vietnam with an estimated area of 0.5 million hectares of plantation of these species, it does not only supply raw material for pulp, paper, and timber production but also plays an important role in protection of the environment. Some studies on growth and wood quality of these three species showed that the hybrids had a growth rate almost double that of their parents, at the same time producing wood with acceptable pulp yields and pulping quality.[6] The acacia hybrid has the potential for greater pulp yields, and the paper produced from its wood is superior to that produced from the wood of its parent species, or intermediate between the parents.[1] The pulp yield potential of acacia

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hybrid is also higher than other tree species such as *Eucalyptus urophylla*, *Eucalyptus exserta*, *Manglietia glauca*, and *Styrax tonkinensis*. The paper produced from the wood of acacia hybrid clones has better breaking strength and higher folding strength than that produced from the wood of the parental species or from *Eucalyptus camaldulensis*.[1] Additionally, acacia hybrid wood is suitable for production of particleboards and medium-density fiberboard (MDF).[7,8]

In recognizing the heterosis of acacia hybrid, controlled pollination (artificial hybridization) between plus trees of *A. mangium* and *A. auriculiformis* is very important. Recently, artificial hybridization was carried out at the Research Centre for Forest Tree Improvement in Vietnam, in order to investigate genetic stability and characteristics of hybrids and to select superior clones for plantation. However, there is no information on wood properties of artificial acacia hybrids. The purpose of this study is to clarify the difference in wood fundamental properties among *A. mangium*, *A. auriculiformis*, and the artificial hybrids and to discuss the possibility of improvement by artificial hybridization.

Materials and methods

Artificial acacia hybridization model

Plus trees of *Acacia mangium* and *Acacia auriculiformis* were selected as parent trees. Reciprocal hybridization was applied to clarify the effect of the species used as a female parent in hybridization. The hybrids between these two species were produced according to controlled pollination.[9]

Trial forest

The trial forest was established in July 2001 by the Research Centre for Forest Tree Improvement (Forest Science Institute of Vietnam) in Cam Qui, Bavi (21°07'N, 105°26'E, subtropical climate with rainy season from April to October and dry season from November to March). The soil is a yellow lateritic hill soil developed on sandstone, with hard conglomeration, poor in nutrients, and is shallow with depth is not exceeding 50 cm. There is water shortage in the winter–spring season. Trees were planted at spacings of 3 × 3 m with initial plough and fertilizer being applied to each tree at planting. The trial was established in a randomized complete block design with three replications. For each replication, ten trees per clone/combination were planted in each row. Diameter and tree height were measured every year for all trees of clones/combinations.

Sample trees

Five clones/combinations were selected for this study: *A. mangium* for Am7, *A. auriculiformis* for Aa32, the two artificial hybrid combinations of *A. auriculiformis* × *A. mangium* for Aa32Am7 and *A. mangium* × *A. auriculiformis* for Am7Aa32, and one artificial hybrid clone (MA2-selected from Am7Aa32 combination, which was bred some years ago). A total of 15 trees were harvested at 3 years and 9 months of age. After felling, each tree was measured for tree height and diameter at 1.3 m height above the ground. A 20-cm-thick disk was cut at 1.3 m above ground height for laboratory studies.

Measurements

A pith-to-bark strip of wood [radius (R) × 3 (T) × 5 cm (L)] was cut from each disk after drying in air. The strip was subsequently separated into two strips: one strip [radius (R) × 3 (T) × 2 cm (L)] was used to measure specific gravity and the other was used to measure the lengths of wood fibers and vessel elements.

The strip for specific gravity measurement was then divided into five equal parts with a razor blade. The specific gravity of each part was measured using an Electronic Densimeter MD-300S. The strip used for measurement of lengths of wood fibers and vessel elements was divided and small pieces were taken at relative distances of 0%, 10%, 30%, 50%, 70%, 90%, and 100% from pith to bark because the growth rings in acacia were not distinct. The pieces were macerated by dipping in 50% HNO_3 plus $KClO_3$ (3% w/v solution) for 5 days. Thirty wood fibers and 20 vessel elements were measured for their length at each distance using a Nikon V-12 profile projector.

Data analysis

The basic measurements were used to determine the mean for various distances from pith to bark and for comparison with the mean clone value. Superiorities (in percent) of hybrids in growth, wood fiber length, and specific gravity were calculated as:

$$S = \frac{H - A}{A} \times 100\%$$

where S is superiority of hybrid; H is the value of hybrid; and A is the value of the male parent, female parent, or average value of the parents. Correlations among diameter, specific gravity, and wood fiber length in acacia wood were also examined to clarify the relationship between growth trait and wood properties.

Results and discussion

Superiority of acacia hybrid in growth, wood fiber length, and specific gravity

The hybrids had straight stems and grew faster than their parents (Table 1). The morphological characteristics were intermediate between both parents, that is, *Acacia mangium*

Table 1. Mean and superiority of diameter, tree height, wood fiber length, and specific gravity of clones/combinations for acacia species at 3 years and 9 months

Clone/combination	Diameter at 1.3 m		Height		Wood fiber length		Specific gravity	
	Mean (cm)	Super (%)	Mean (m)	Super (%)	Mean (mm)	Super (%)	Mean	Super (%)
A. auriculiformis parent	5.41 (0.57)	–	7.24 (0.65)	–	0.92 (0.10)	–	0.60 (0.07)	–
A. mangium parent	6.68 (1.28)	–	8.39 (0.70)	–	0.87 (0.09)	–	0.56 (0.09)	–
♀*A. mangium* × ♂*A. auriculiformis* F1	8.37 (1.40)	38.46	9.40 (0.53)	20.28	0.95 (0.12)	6.14	0.62 (0.05)	6.89
♀*A. auriculiformis* × ♂*A. mangium* F1	8.56 (1.26)	41.60	9.38 (0.37)	20.03	1.01 (0.12)	12.84	0.70 (0.09)	20.68
♀*A. mangium* × ♂*A. auriculiformis* clone	8.24 (0.63)	36.31	9.79 (0.27)	25.27	0.95 (0.11)	6.14	0.66 (0.06)	13.79

Standard deviations are given in parentheses
Super, Superiority of hybrids over parents

had wide leaves and *Acacia auriculiformis* had narrow leaves, and their hybrids had leaves of medium size. Comparing the artificial hybrids, the characteristics were a little closer to those of the female parent. For example, the hybrids for which *A. auriculiformis* was the female parent and *A. mangium* was the male parent had smaller leaves and thinner bark than the hybrids produced from the reverse cross. Heart root disease was not found in all sample trees at this age.

Mean and superiority of diameter and height of five clones/combinations are listed in Table 1. Diameter and height reached 8.2–8.6 cm and 9.4–9.8 m, respectively, in hybrids while they were only 5.4–6.7 cm and 7.2–8.4 m in the parents (*A. auriculiformis* and *A. mangium*). Acacia hybrids grew 1.5 to 1.6 times larger in diameter and 1.3 to 1.4 times higher than *A. auriculiformis*. Acacia hybrids also grew faster than *A. mangium* but only 1.2 to 1.3 times larger in diameter and 1.1 to 1.2 times higher. These values were similar to those of natural acacia hybrid reported by Le,[1] who showed that 4-year-old natural acacia hybrid had a diameter of 10.3–12.9 cm and a height of 11.4–13.6 m, while they were 8.8 cm and 9.5 m in *A. mangium* and 5.1 cm and 6.3 m in *A. auriculiformis*, respectively. On average, the superiority of hybrids ranged from 36.3% to 41.6% for the diameter and from 20.0% to 25.3% for the height over their parents. This means that the hybrids can grow 2.2 to 2.4 times faster in volume than their parents.

Wood fiber length of hybrids was improved 3%–9% and 9%–16% in comparison with *A. auriculiformis* and *A. mangium*, respectively. Specific gravity of hybrids was 3%–17% and 9%–25% higher those of *A. auriculiformis* and *A. mangium*, respectively. Wood fiber and specific gravity of acacia hybrid clone in which *A. auriculiformis* was the female parent was 6% longer and 9% higher than clones produced from contrary hybridization (*A. mangium* as female parent). Superiority of hybrids ranged from 6.1% to 12.8% for wood fiber length and from 6.9% to 20.7% for specific gravity over that of their parents.

The prominent feature of hybrids between *A. mangium* and *A. auriculiformis* was the superiority in growth, wood fiber length, and specific gravity, which allowed the hybrids to outstrip their parents (true heterosis). In reciprocal hybridization, the hybrids possessed equivalent heterosis both in diameter and in height despite the female parent being *A. mangium* or *A. auriculiformis*. However, hybrids had a faster growth rate, longer wood fibers, and higher specific gravity when *A. auriculiformis* was the female parent and *A. mangium* was the male parent.

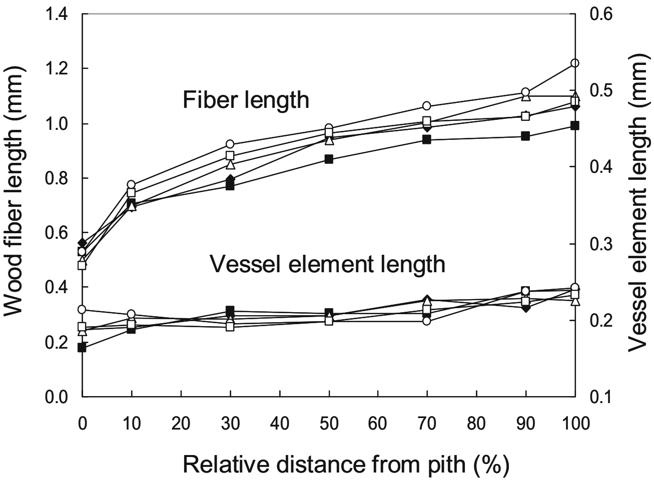

Fig. 1. Radial variation of wood fiber length and vessel element length of acacia species at 3 years and 9 months. Filled diamonds, *Acacia auriculiformis*; filled squares, *Acacia mangium*; open triangles, *A. mangium* × *A. auriculiformis*; open circles, *A. auriculiformis* × *A. mangium*; open squares, *A. mangium* × *A. auriculiformis* clone

Variation in wood fiber length and specific gravity from pith to bark

General trends in wood fiber length and specific gravity in relation to relative distance from the pith to the bark are shown in Figs. 1 and 2. The profiles of wood fiber length and specific gravity in the radial direction were similar for all samples. Wood fibers were shortest (0.5–0.6 mm) near the pith and steadily increased toward the bark. The maximum value was 1.0–1.2 mm close to the bark. Wood fiber lengths of parents and hybrids increased 86%–89% and 111%–130%, respectively, from the pith to near the bark. The shortest mean wood fiber length (0.87 mm) and the shortest wood fibers at each relative distance were found in *A. mangium*. *Acacia auriculiformis* had longer wood fibers than *A. mangium*, but wood fibers of parents were usually shorter than those of the hybrids. Wood fibers of *A. auriculiformis* × *A. mangium* were the longest at each

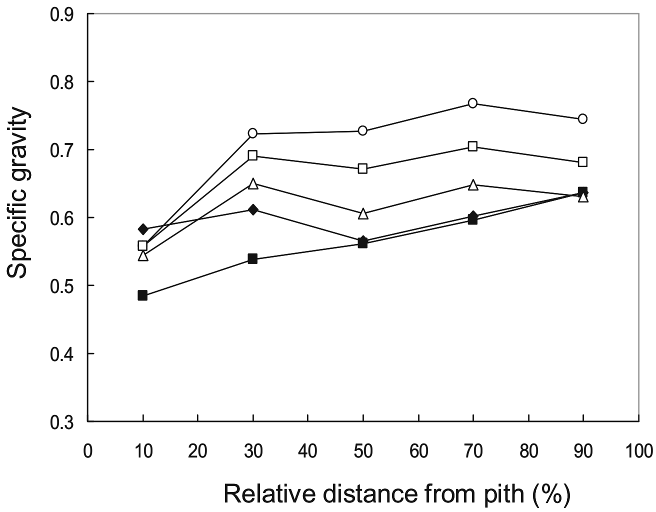

Fig. 2. Radial variation of specific gravity of acacia species at 3 years and 9 months

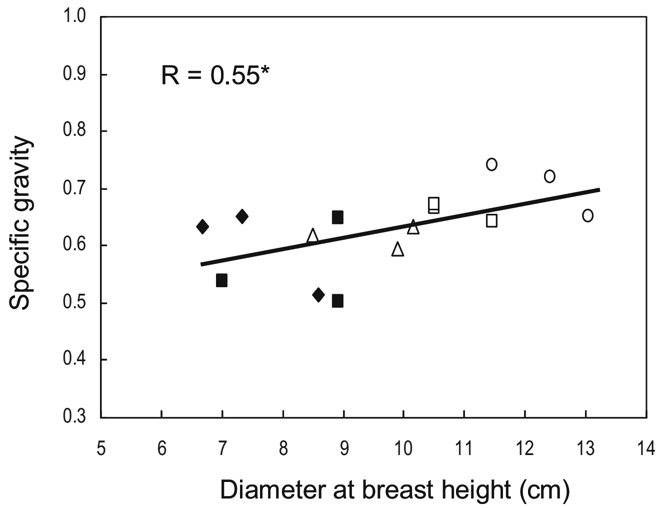

Fig. 3. Relationship between diameter at breast height and specific gravity for acacia species at 3 years and 9 months. *Asterisk*, significance at $P < 0.05$

relative distance except near the pith. Wood fibers did not appear to be stable in length at this age. These results agree with data for wood fiber length of *A. mangium* near the pith (0.4–0.6 mm) and near the bark (0.9–1.3 mm).[10] The data from this study are also similar to other results from studies on wood fibers of this species.[11–13] From the pith to the bark, vessel element length ranged from 0.16–0.21 mm to 0.22–0.24 mm (Fig. 1) and it can be assumed that there is little elongation of fusiform cambial cells with cambial age.

The specific gravity of acacia had a minimum value of 0.49–0.58 near the pith and it increased to 0.63–0.74 near the bark with average of 0.62. From a relative distance of 30%, the specific gravity went up slightly and seemed to be stable. *Acacia auriculiformis* × *A. mangium* combination had the highest specific gravity, subsequently *A. mangium* × *A. auriculiformis* clone and combination. *Acacia auriculiformis* and *A. mangium* had the lowest specific gravity. The mean values in this study were slightly higher than the mean values reported by Le[1] for *A. auriculiformis*, *A. mangium*, and natural acacia hybrid grown at the same site. These differences may be caused by plus tree selection for artificial hybridization. The between-tree variation of wood fiber length and specific gravity within a clone/combination was not large with the coefficients of variation below 10%. Wood fiber length and specific gravity are important traits because they have major effects on both yield and quality of pulp and wood products. Clone selection with combination of better growth and wood properties is the goal of tree improvement for commercial plantation.

Correlations between diameter and specific gravity and wood fiber length

Tree-improvement programs by breeding for trees that are long-lived usually take many years to complete a cycle. In order to reduce the time of breeding and to extend a better tree/clone for plantation, tree selection at an early age is necessary. Understanding the relationship between growth and wood properties is important in the correct selection of clones. In a study on *A. mangium*, Wahyudi et al.[14] reported no relationship between growth rate and specific gravity, and Lowe and Greene[15] also noted that specific gravity was essentially independent of growth rate in green ash. No consistent relationship between specific gravity and ring width was found for eight important diffuse-porous hardwoods in the southern United States.[16] No correlation between wood density and tree growth was found in *Eucalyptus globulus*.[17] On the other hand, a negative relationship between growth rate and density was reported by Hendrix and Lowe[18] for green ash. However, Zobel[19] concluded that the relationship between specific gravity and growth rate in diffuse-porous hardwood varied from negative to positive correlation depending on species. In this study, a positive correlation between diameter at breast height and specific gravity was found ($r = 0.55$, $P < 0.05$, Fig. 3). On the other hand, positive correlations between wood fiber length and specific gravity ($r = 0.73$, $P < 0.01$, Fig. 4) and between diameter at breast height and wood fiber length ($r = 0.69$, $P < 0.01$, Fig. 5) were also found. This means that selection of fast-growing trees in the breeding program would not impact negatively on specific gravity and wood fiber length.

Conclusions

Artificial hybridizations were carried out between plus trees of *Acacia mangium* and *Acacia auriculiformis*, and the differences of wood properties among parents and F1 and hybrid clones were investigated. The significant superiorities of acacia hybrids in both growth and wood properties over their parents were clarified. Fair correlations between specific gravity and diameter at breast height, between

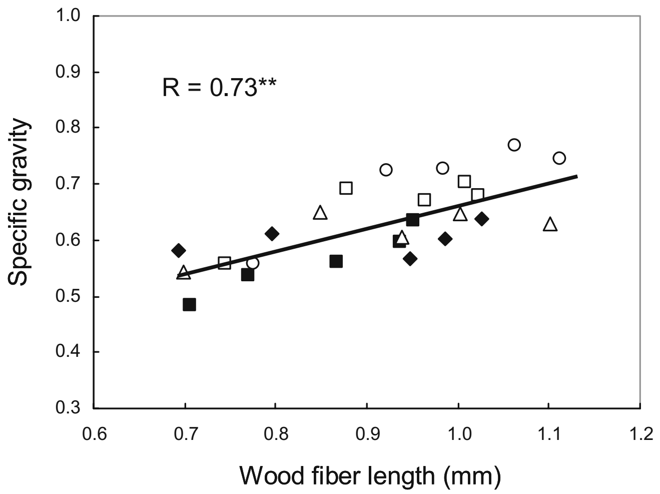

Fig. 4. Relationship between wood fiber length and specific gravity for acacia species at 3 years and 9 months. *Double asterisk*, significance at $P < 0.01$

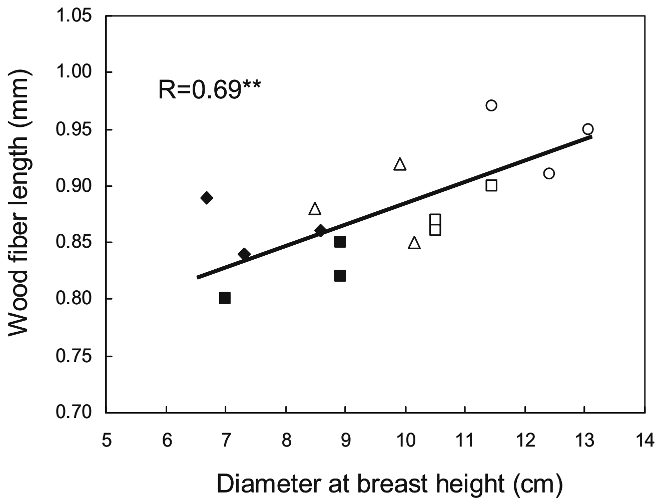

Fig. 5. Relationship between diameter at breast height and wood fiber length for acacia species at 3 years and 9 months. Double asterisk, significance at $P < 0.01$

wood fiber length and specific gravity, and between wood fiber length and diameter were found. Based on growth, wood fiber length, and specific gravity, artificial hybridization in which *A. auriculiformis* is the female parent and *A. mangium* is the male parent is expected to have a higher effect on wood improvement.

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