PHYSICAL AND MECHANICAL EVALUATION OF 8-YEARS-OLD ACACIA HYBRID (*Acacia mangium* x *A. auriculiformis*) CLONES FOR VARIOUS END USES

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PHYSICAL AND MECHANICAL EVALUATION OF 8-YEARS-OLD ACACIA HYBRID (*Acacia mangium* x *A. auriculiformis*) CLONES FOR VARIOUS END USES. Currently, clonal of forest tree is gaining importance due to the yield improvement and low variability in different wood characteristics. Hybrid trees from clonal forest are importantly characterized in term of wood quality for finding suitable uses. Accordingly, three clones (HD3, K47, H4) of 8-year-old Acacia hybrid (*Acacia mangium* × *A. auriculiformis*) were evaluated for inter-clonal comparison of its wood quality by evaluating their physical and mechanical properties as per Indian Standards. All tree clones were studied at breast high including diameter, heartwood content, and physical and mechanic properties. The Dbh of all three clones was around 30–35% and 60–70% greater than pure forms of *A. auriculiformis* and *A. mangium* of the same age, respectively. The volumetric shrinkage of all three clones was found to vary from 7.8 to 8.6%. The low shrinkage values may be attributed to higher dimensional stability of the wood of these clones. The data obtained in green and air-dry conditions were used to calculate 'suitability indices' with respect to teak (*Tectona grandis*) which was taken as a reference wood for comparison in India. All the suitability indices that these clones were either comparable or slightly lower than those of pure forms of *A. auriculiformis* and *A. mangium*. Less inter-clonal variation was observed in most of the suitability indices. Though, all the three clones were exclusively grown for their use in pulp and paper industry, but the comparative suitability figures for different end uses indicate that these clones could also be used for certain non-structural applications such as tool handles, light packing cases, pallets and light furniture.

Keywords: Acacia hybrid, clones, wood quality, mechanical properties, suitability figures

EVALUASI SIFAT FISIK DAN MEKANIK KLON ACACIA HIBRID BERUMUR 8 TAHUN (<u>Acacia mangium</u> × <u>A. auriculiformis</u>*) UNTUK BERBAGAI PENGGUNAAN AKHIR. Saat ini, pemanfaatan klon tanaman hutan merupakan hal penting karena variasi kualitas kayu yang bervariasi berdasarkan karakteristik kayu yang berbeda. Pohon hibrida dari hutan klon perlu dicirikan kualitas kayunya untuk menemukan yang terbaik dan sesuai penggunaannya. Untuk itu, tiga klon (HD3, K47, H4) dari akasia hibrida umur 8 tahun (*<u>Acacia mangium</u> × <u>A. auriculiformis</u>*) dievaluasi sebagai bentuk perbandingan antar klon terkait kualitas kayunya dengan mengevaluasi sifat fisik dan mekanik yang sesuai dengan Standar India. Contoh uji setinggi dada (dbh) dari ketiga klon dipelajari diameter batangnya, kandungan kayu teras, dan sifat fisik dan mekaniknya. Dbh dari ketiga klon itu sekitar 30-35% dan 60-70% lebih besar daripada bentuk murni* <u>A. auriculiformis</u> *dan* <u>A. mangium</u> *pada usia yang sama. Penyusutan volumetrik dari ketiga klon itu bervariasi dari 7,8 hingga 8,6%. Nilai penyusutan yang rendah dapat dikaitkan dengan stabilitas dimensi yang lebih tinggi dari klon kayu tersebut. Data yang diperoleh dalam kondisi segar dan kering udara digunakan untuk menghitung indeks kesesuaian mengacu pada kayu jati (*<u>Tectona grandis</u>*) yang diambil sebagai kayu referensi di India. Semua indeks kesesuaian dari klon ini dapat dibandingkan atau sedikit lebih rendah dari bentuk murni* <u>A. auriculiformis</u> *dan* <u>A. mangium</u>*. Tidak banyak variasi antar-klon yang diamati di sebagian besar indeks kesesuaian, walaupun ketiga klon tersebut secara eksklusif ditanam untuk industri pulp dan kertas, tetapi sifat-sifat kesesuaian secara komparatif untuk penggunaan akhir yang berbeda menunjukkan bahwa klon ini juga dapat digunakan untuk penggunaan non-struktural tertentu seperti gagang perkakas, kotak kemasan ringan, palet, dan perabotan ringan.*

Kata kunci: Akasia hibrida, klon, kualitas kayu, sifat mekanis, angka kesesuaian

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I. INTRODUCTION

The short rotation plantation wood is emerging as a major raw material resource due to the ban on felling of trees in the natural forests. In the past, plantations had mainly been raised through seedlings. *Acacia auriculiformis* was introduced in India in 1946 and now it has naturalized in this part of the sub-continent (Rai, 1995), whereas *A. mangium* was introduced during 1984-85 (Damodaran & Chacko, 1996). These species were found to be well adapted in its better form and growth rate and adaptability to wider geo-climatic conditions. As most of the plantations were raised through seeds, the variability was very high resulting in low yield over the years. In order to minimize the variability in wood characteristics and to increase the yield per unit area, the clonal forest tree has been given an importance role. Moreover, to obtain better stem form, longer clear bole height with lighter branching, plantations of acacia hybrids through clonal material have also been raised as these hybrid trees could possess some outstanding intermediate characteristics of their parents. In order to find the suitability these hybrids clones of lower age for different value added applications, its wood quality parameters should be evaluated.

There is less work has been done in India on the aspects of finding its better utilization. Rokeya et al. (2010) have studied various physical and mechanical properties of hybrid acacia (*Acacia auriculiformis* × *A. mangium*) and reported that the wood of Acacia hybrid is suitable for making furniture and other household articles. Ismail and Farawahida (2007) have studied the physical and mechanical properties of *Acacia mangium* × *Acacia auriculiformis* hybrid planted in Malaysia and found that improvements of acacia hybrid are only confined to growth characteristics and heart-rot resistance but not wood properties. Some of the anatomical features of *A. mangium* × *A. auriculiformis* hybrid grown in Indonesia with regard to pulp yield and paper strength have been studied by Yahya et al. (2010). The anatomical wood properties, chemical composition and wood density acacia hybrid its parents, *A. mangium* and *A. auriculiformis*.

Acacia hybrids wood have been studied by various researchers. Tang et al. (2016) studied the potentials of these hybrids as an afforestation species for impoverished sand tailings in Malaysia. Kha (2000) reported that in Vietnam, the stem volume of acacia hybrids is 2-3 times greater than that of *A. mangium* and 3-4 times greater than that of *A. auriculiformis* of the same age. Similarly, plantations of some other hybrids of eucalyptus (*E. camaldulensis* × *E. grandis*) and poplar (*P. tomentosa* × *P. bolleana*) have also been raised and reported by various researchers. Loulidi et al. (2012) have studied various physical and mechanical properties of eucalyptus hybrid and compared the properties with its parental species. It was found that the wood of this hybrid has a rather important density classifying it among the mid-heavy wood, with strong nail withdrawal and it has interesting mechanical properties. Ma et al. (2015) have studied variation in the growth traits and wood properties of hybrid white poplar clones and recommended its utility as a raw material for pulp and paper making.

The Mysore Paper Mills (MPM) Ltd., Bhadravathi, a pulp and paper manufacturing industry in Shimoga District of India, has developed several clones of acacia and its hybrids and grown them under large-scale plantations on degraded forest land to meet its pulp wood requirement. These acacia hybrids originated from *A. mangium* as mother tree were designated as 'mangi-auriculis' (Amanulla et al., 2004). Various wood quality parameters of plantation grown *A. mangium* and *A. auriculiformis* have been studied and reported by many researchers (Kumar et al., 2006; Midon et al., 2002; Rao & Sujatha, 2004; Rao et al., 2007; Shanavas & Kumar, 2006; Sharma et al., 2011; Shukla et al., 2007a, 2007b). However, not much information is available on various wood properties and utilization potentials of clonal material for different end uses. This paper explores the possibility of using short rotation plantation trees obtained from clonal material, for different applications. In view of the above, various physical and mechanical properties of clones of acacia hybrid were evaluated in green and air-dry conditions as per Indian Standards to find their suitability for various end uses. The inter comparison of different suitability indices of the clones was also studied and reported.

II. MATERIAL AND METHOD

A. Sampling

Five trees each of three clones (HD3, K47 and H4) of acacia hybrid (*A. mangium* × *A. auriculiformis*), developed by MPM were selected for the study. These clones were grown at three nearby locations (HD3 at Heddur, K47 at Kanive and H4 at Halawani in Karnataka state of India) having an annual rain fall of 2000-3000 mm. All the clones were grown in deep red, loam and lateritic soil, with well drainage. The trees were felled and logs were collected from the same plantation sites for all clones.

B. Evaluation of Properties

The diameter at breast height (dbh) and heartwood percentage were determined for all clones immediately after tree felling. Various physical and mechanical properties such as specific gravity, shrinkage, bending strength, compressive strength and hardness were evaluated for each tree of all three clones. Small clear specimens were prepared and tested in both green and air-dry conditions as per standard procedure (Shukla et al., 2007b).

1. Heartwood content

The heartwood was identified based on colour differentiation from the sapwood. To estimate heartwood percentage, the total diameter and heartwood diameter of the discs were measured in four directions. Total area of the disc and heartwood portion was calculated separately and heartwood percentage was calculated using the ratio of the area of the heartwood portion to the total area of the disc.

2. Specific gravity

Specific gravity was measured using test specimens of 2 cm × 2 cm × 5 cm in green and air-dry conditions. Green volume and oven-dry weight was used for computing the green specific gravity while air-dry value of volume and oven-dry weight was measured for air-dry specific gravity.

$$\text{Spesific Gravity} = \frac{w}{v} \quad \text{.............................(1)}$$

where: w is oven-dry weight and v is green or air-dry volume of specimens.

3. Volumetric shrinkage

For the measurement of volumetric shrinkage, the specimen size was 2 cm × 2 cm × 6 cm. Specimens were weighed in green condition to 0.01 g accuracy and their volume was measured using the standard mercury displacement method. The specimens were initially air-dried and finally dried in the oven at 103±2ºC for 48 hrs and the weight and volume were again measured to compute the volumetric shrinkage (V).

$$V(\%) = ((V_1 - V_0)/V_1)*100 \quad \text{.............(2)}$$

where: V_1 and V_0 are volumes in green and oven-dry conditions respectively.

4. Static bending

The size of specimen was 2 cm × 2 cm × 30 cm with a span length of 28 cm. The loading was applied at a constant rate of 1 mm/min on the tangential surface of the sample. Various strength parameters viz. modulus of rupture (*MOR*) and modulus of elasticity (*MOE*) were computed using equations as follows:

$$MOR = \frac{3p'l}{2bh^2} \quad \text{.............................(3)}$$

$$MOE = \frac{pl^3}{4Dbh^3} \quad \text{.............................(4)}$$

where: *p* is load (*kN*) at the limit of proportionality, *p*' is maximum load (*kN*), *l* is span (mm) of the test specimen, *b* is breadth (mm) of the test specimen, *h* is depth (mm) of the test specimen and *D* is deflection (mm) at the limit of proportionality.

5. *Compression strength parallel to grain*

The size of specimen was 2 cm × 2 cm × 8 cm in length, and the rate of loading was 0.6 mm/min. The compression strength parallel to the grain (maximum crushing stress, *MCS*) was calculated by equation 5 as follows:

$$MCS = \frac{P'}{A} \quad \text{.......................(5)}$$

where: *p*' is maximum crushing load (kN) at break point and *A* an is area of cross section (mm^2) of the specimen on which force was applied.

6. *Compression strength perpendicular to grain*

The size of specimen was 2 cm × 2 cm × 10 cm. Load was applied at the 2 cm × 2 cm cross-section on the tangential surface at a rate of 0.6 mm/min. The compressive strength perpendicular to the grain (compressive stress at elastic limit - *CS* at *EL*) was calculated by equation 6 as follows:

$$CS \text{ at EL} = \frac{P}{A} \quad \text{.......................(6)}$$

where: *p* is load (kN) at the elastic limit and *A* is area of cross-section (mm^2) of specimen on which force was applied.

7. *Hardness under static indentation*

The size of specimen was 5 cm × 5 cm × 5 cm. The load (kN) required to penetrate into the specimen with an hemispherical steel ball of 1.128 cm diameter to a depth of 0.564 cm was recorded. Measurements were made at the centre of the radial, tangential and end faces; no splitting or chipping occurred. The rate of loading was kept constant at 6 mm/min.

8. *Suitability indices and figures*

All the physical and mechanical properties evaluated in the green and air-dry conditions were used for computing the suitability indication (Rajput et al., 1996). The suitability figures of all the three clones were calculated using suitability indices for different industrial and engineering applications (Sekhar & Gulati, 1972).

9. *Statistical analysis*

The basic data on different physical and mechanical properties was subjected to basic statistical analysis for finding out the average values and standard deviations using SigmaStat software (Ver. 3.5). Analysis of variance was conducted out for finding the significant differences in various properties among the clones.

III. RESULT AND DISCUSSION

The average values of dbh, heartwood percentage, specific gravity and shrinkage of all the three acacia hybrid clones are shown in Table 1. Various mechanical properties of all the three clones in both green and air-dry conditions along with standard deviations are shown in Table 2. The comparative suitability indices of all the three clones along with the corresponding values of pure forms of *A. auriculiformis* and *A. mangium* (Kumar et al., 2006; Shukla et al., 2007b) are given in Table 3. The suitability figures of all the three clones for different industrial and engineering applications are listed in Table 4.

Table 2 indicates that air-dry values for most mechanical properties were substantially higher than corresponding green values. The analysis of variance shows that MOR in green condition, MOE in green and air-dry condition, MCS in green condition, CS at EL in air-dry condition and hardness in both conditions were significantly different among the clones. No significant difference was observed in average values of MOR and MCS in air-dry condition and CS at EL in green condition.

The green and air-dry values of different properties were used to calculate 'suitability indices', assigning a value of 100 toward teak as a reference (Rajput et al., 1996). The comparative suitability indices that all the three clones along with the corresponding values of pure forms of *A. auriculiformis* and *A. mangium* (Kumar et al., 2006; Shukla et al., 2007b) are given in Table 3. Due to lower shrinkage values in clones, the retention of shape for all three clones was higher than in pure forms.

Table 4 shows the suitability figures of all the three clones for different industrial and

Table 1. The average values of physical properties of three acacia hybrid clones

Clones	dbh (cm)	Heartwood (%)	Specific gravity		Volumetric shrinkage (%) (Green to oven-dry)
			Green (80±5%)	Air-dry (12±2%)	
HD3	48.96 (3.59)	57.9 (5.62)	0.445a (0.038)	0.486a (0.042)	8.6 (1.28)
K47	50.6 (2.62)	62.2 (5.42)	0.437a (0.039)	0.458ab (0.043)	8.1 (1.02)
H4	50.5 (5.01)	57.6 (2.76)	0.396b (0.029)	0.430bc (0.042)	7.8 (0.93)
P-value	ns	ns	< 0.001	< 0.001	ns

Remarks: Values in parenthesis are standard deviations; ns: non-significant; values within same column suffixed with different letters are significantly different at α=0.05

Table 2. The average values of mechanical properties of three acacia hybrid clones in green (80 ± 5%) and air-dry (12 ±2 %) conditions

Clones	MOR (MPa)		MOE (GPa)		MCS (MPa)		CS at EL (MPa)		Hardness (kN)	
	Green	Air-dry	Green	Air-dry	Green	Air-dry	Green	Air-dry	Green	Air-dry
HD3	58.4a (5.07)	78.0 (15.44)	8.6a (1.18)	10.7a (1.51)	26.2a (2.56)	43.4 (3.57)	3.7 (0.73)	6.1ab (1.12)	2.7a (0.30)	2.8a (0.54)
K47	54.0a (7.99)	76.6 (16.08)	7.7ab (1.66)	9.5ab (1.36)	25.9ab 2.93)	45.8 (4.21)	4.0 (0.90)	7.2a (1.22)	2.4b (0.41)	2.5b (0.42)
H4	46.9b (8.10)	73.6 (16.7)	6.6bc (1.48)	9.1bc (1.89)	22.6c 2.86)	41.7 (5.21)	3.1 (0.92)	5.5bc (1.01)	2.0c (0.27)	2.4bc (0.49)
P-value	< 0.001	ns	0.003	0.027	0.006	ns	ns	0.003	< 0.001	< 0.001

Remarks: Values in parenthesis are standard deviations; ns: non-significant; values within same column suffixed with different letters are significantly different at α=0.05

engineering applications. These figures were calculated by the method as described by Rajput et al. (1996) taking teak score 100 as standard in India for comparison of any timber for various applications. Clones HD3 and K47 are having similar suitability figures for different end uses whereas clone H4 showed lower values. Based on the suitability indices and composite suitability figures, the timber of clones HD3 and K47 could be used for tool handles, light packaging cases, pallets and light furniture. The clone H4 was found suitable for use as tool handles and light packaging cases.

It could be seen from Table 1 that after 8 years, the average dbh of the trees was 49 cm in HD3 and 51 cm in case of K47 and H4. The diameter of all these clones was around 30-35% bigger than of pure forms of *A. auriculiformis* (Shukla et al., 2007b) and 60-70% bigger than pure forms of *A. mangium* (Kumar et al., 2006) of the same age. The sapwood was yellowish-white while heartwood was golden brown and was sharply distinct. The average heartwood was found to be 58% in HD3 and H4 and 62% in case of clone K47. As shown in Table 1, both dbh and heartwood percentages were not significantly different among the clones. The average specific gravity of HD3, K47 and H4 clones in green condition was found to be 0.445, 0.437 and 0.396, respectively, while air-dry specific gravity was 0.486, 0.458 and 0.430. The specific gravity was found to be significantly lower for all three clones compared to pure forms of *A. auriculiformis* and *A. mangium*

Table 3. Comparative suitability indices of clones and pure form of *A. auriculiformis* and *A. mangium*

Properties	Clones			*A. auriculiformis**	*A. mangium***
	HD3	K47	H4		
Weight at 12% MC	84	79	74	99	91
Strength as a beam	75	73	68	104	71
Stiffness as a beam	64	59	53	91	67
Suitability as a post	75	74	66	71	61
Shock resisting ability	67	64	57	89	74
Retention of shape	96	95	99	85	85
Hardness	56	56	45	72	68
Refractoriness	61	60	55	57	34

Souce: *Shukla et al. (2007b), ** Kumar et al. (2006)

Table 4. Suitability figure for various end uses taking teak as 100

End use	Clones		
	HD3	K47	H4
Suitability for tool handles	129	123	112
Suitability for light packing cases	89	88	83
Suitability for pallets	82	79	71
Suitability for furniture	75	72	63
Suitability for construction	74	70	65
Suitability for oars and paddles	72	70	64

Source: Rajput et al. (1996)

(Kumar et al., 2006; Shukla et al., 2007b). No definite trend was observed for specific gravity of acacia hybrids as compared to their parents. Rokeya et al. (2010) have reported intermediate values of specific gravity whereas Suffian (2011) has observed lower values of acacia hybrids. The analysis of variance showed that the specific gravity in green condition is significantly different among the clones. However, the difference was not significant between clone HD3 and K47. Similarly, the average values of specific gravity in air-dry conditions were also significantly different among the clones. The volumetric shrinkage was found to be 8.6, 8.1 and 7.8% for HD3, K47 and H4 respectively and was not significantly different among the clones. Rokeya et al. (2010) have reported the values of volumetric shrinkage in the range of 9.7–13% for acacia hybrid of 9–12 years old. The low values of volumetric shrinkage found in the present study indicate that the timber from all three clones is dimensionally stable and could be used for applications where this parameter is of prime importance.

IV. CONCLUSION

Various physical and mechanical properties of three 8-year-old acacia hybrid clones were studied and suitability indices were compared with pure forms of *A. auriculiformis* and *A. mangium* of identical age. Not much inter-clonal variation was observed in most of the properties. The dbh of all these clones was around 30–35% higher than that of pure form of *A. auriculiformis* and 60–70% bigger than pure form of *A. mangium*. However, the amount of heartwood was slightly lower compared to pure forms. The low values of volumetric shrinkage found in the present study indicate that the timber from all three clones is dimensionally stable and can be used for applications where this parameter is of prime importance. All the suitability indices of these clones were either comparable or slightly lower than those of pure forms of *A. auriculiformis* and *A. mangium*. Although, all the clones were exclusively grown for their use in pulp and paper industry, but comparative suitability indices show that these clones can also be used for application such as tool handles, light packaging cases, pallets and light furniture.

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