WOOD AND PLYWOOD QUALITY CHARACTERIZATION OF NEW AND ALTERNATE SPECIES AMENABLE FOR COMPOSITE WOOD PRODUCTION

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Abstract. India is one of the robust consumers of engineered wood products, and the raw material demand for engineered wood production is increasing at an alarming rate. Currently, the plywood industry in the country depends only on a few species and demands screening of alternate species amenable for plywood production. Therefore, studies were conducted to characterize the physical and mechanical properties of eight different tree species, viz., *Toona ciliata*, *Chukrasia tabularis*, *Acacia* hybrid, *Neolamarckia cadamba*, *Acrocarpus fraxinifolius*, *Swietenia macrophylla*, *Casuarina equisetifolia*, and *Mitragyna parvifolia*, which are potential tree components in the agroforestry system. The physical properties such as density exhibited wider variation between the species. In general, all the species exhibited medium-to high-density values. Studies on veneer recovery indicated that barring *M. parvifolia,* all other species exhibited more than 50% veneer recovery and extended greater scope of adoption. Similarly, the veneer quality exhibited wide differences, and several species registered face veneer quality. The analysis of mechanical properties of plywood made out of all the eight species indicated that the MOE was well within the acceptable range and the MOR was on higher side, which indicated that these species could play a vital role in the manufacture of medium-to high-density plywood.

Keywords: Plywood, mechanical properties, veneer quality, alternate industrial wood, wood properties.

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INTRODUCTION

Forests played a significant role in India in meeting wood and wood product demand of the country until the recent past. However, with the enactment of Forest Conservation Act (1980) and further directives from Honorable Supreme Court in 1992, felling operations have been banned in natural forests, which resulted in rapid decline in supply of raw material resources from natural forest. There is growing wood demand due to population explosion, industrialization, and urbanization, and the existing forest resources are not adequate to meet the burgeoning demand (Parthiban and Fernandaz 2017). It is estimated that the country would need 152 million m^3 of wood from the year 2020 onward, which includes 87 million m^3 from short rotation species and another 65 million m^3 from long rotation species to meet the raw material requirement of various wood-based industries (FAO 2009). Among the wood-based industries, the plywood industry is very significant because of its role in the real estate sector and the associated house construction industries.

Plywood wood industries in the country have been established in the form of organized and unorganized sectors. Among them, the organized plywood sector alone demands more than 30 million m^3 of wood annually. This demand is predominantly met by only a few species such as eucalyptus and poplars (Parthiban et al 2014). Both these species are exotic in origin and are always criticized for their promotion in the agroforestry sector. The growing wood demand coupled with restricted supply from natural forest has ushered in a total mismatch between demand and supply and has suggested promotion of agroforestry deploying new and alternate species amenable for veneer and plywood productions. The National Agroforestry Policy (2014) also suggested incorporation of wide range of species with increased participation of wood-based industries. Against this backdrop, the present study has been carried out in eight different tree species and has assessed their suitability for veneer and plywood production.

MATERIALS AND METHODS

Materials

The experimental materials for this study consisted of eight species, viz., *Toona ciliata*, *Chukrasia tabularis*, *Acacia* hybrid, *Neolamarckia cadamba*, *Acrocarpus fraxinifolius*, *Swietenia macrophylla*, *Casuarina equisetifolia*, and *Mitragyna parvifolia*, selected from various research experiments established at the Forest College and Research Institute, Mettupalayam, India. The species are of the same age, ranging between 5 yr and 6 yr, and all of them have a cylindrical bole in nature and fast-growing ability and are amenable for incorporation in agroforestry.

Methods

The selected trees were felled and assessed for their growth attributes, and the results are presented in Table 1. The identified trees were felled and converted into logs of 52-inch length, which are used for making plywood, to analyze the plywood properties. The mechanical and physical properties were analyzed as per the standard method indicated in the following paragraphs.

Density

Density (D) was determined from the mass and volume of each sample using the following formula suggested by ASTM D2395-17 (2017).

$$D = \frac{m}{v} \ \left(\mathrm{kg/m^3}\right),$$

where m is the mass and v is the volume of the plywood sample.

Veneer and Plywood Properties

The logs were peeled to 1.5-mm target thickness in a veneer lathe with a knife angle at 91° to 15″ and the veneer yield and recovery were calculated as per Rahaman et al (2012). Veneer properties such as veneer quality were observed and noted.

Table 1. Biometric attributes of identified new and alternate species for plywood production.

S. no.	Species	Height (m)	Girth (cm)	Volume (m^2)	No. of logs	Bark thickness (mm)
1	*Toona ciliata*	7.00	67.10	0.1506	4	7.69
2	*Chukrasia tabularis*	8.00	83.10	0.2639	4	4.01
3	*Acacia* hybrid	7.50	63.50	0.1445	4	6.77
4	*Neolamarckia cadamba*	8.00	75.00	0.2150	3	6.39
5	*Acrocarpus fraxinifolius*	8.00	71.00	0.1926	3	3.05
6	*Swietenia macrophylla*	10.00	55.90	0.1493	2	6.22
7	*Casuarina equisetifolia*	14.00	65.50	0.2869	8	6.48
8	*Mitragyna parvifolia*	7.50	75.80	0.2059	3	14.54
Mean		8.75	69.61	0.2011	3.88	6.89

Plywood Manufacturing Process

The logs of different species were subjected to veneer-making process (peeling) with a veneer thickness of 1.80 mm. The green veneers (MC: 30-40%) were then dried to an MC of 6-8% by a hot air dryer at a temperature of 140-150°C for 15 min. Then, the dried veneers were conditioned for 48 h, and cross and panel cores were prepared for the plywood assembly. The thickness chosen was 12-152.4 mm × 76.2 mm with a 9-ply construction, including the face veneer. The veneers were alternatively placed wherein the phenol formaldehyde resin was applied to the alternative layers at a spread rate of 330 gm/m^2. After resin application, the ply construct was cold-pressed and then hot-pressed for 12 min at a temperature of 135°C, coupled with a pressure of 12 kg/cm^2. The final plywood panel was 12-mm (±5%) thick and trimmed to a size of 1840 mm × 920 mm with a circular saw and sanded with a 220-grade sandpaper in a wide belt sander. The final plywood was subjected to analysis of physical and mechanical properties as per ASTM D5456-1 (2019)/IS: 710-2010.

Mechanical Properties of Plywood

Plywood tests were conducted as per the Indian Standard Specification IS 1708 (Part 5): BIS (1986) by a universal testing machine at the laboratory of Century Plyboards (I) Ltd, Chennai, India, with the following parameters.

Boiling Test

The samples were subjected to soaking for 72 h in boiling water and noted as pass/fail based on the test results as suggested by IS 1659 (2004).

Static Bending Test

The strength and stiffness of samples were tested by using a static bending test. Here, applied force is increased very slowly and gradually until the specimen breaks. Plywood samples were cut into rectangular sections, and the dimension of each plywood sample was 240 mm × 50 mm × 12 mm. From the stress strain graph, the load at proportional limit and corresponding deflection were noted, and these values are useful to derive the MOE and MOR. The MOE and MOR were calculated as per ASTM D5456-19 (2019).

MOE. MOE was calculated using the following formula as suggested by ASTM D5456-19 (2019).

$$\mathrm{MOE} = \frac{P'L^3}{4\Delta' bd^3},$$

where MOE is the modulus of elasticity (N/mm^2), P' is the load at the proportional limit (N), L is the length of span (mm), Δ' is the center deflection at the proportional limit load (mm), b is the width of the sample (mm), and d is the thickness (depth) of the sample (mm).

MOR. MOR was calculated using the following formula as suggested by ASTM D5456-19 (2019).

$$\mathrm{MOR} = \frac{3\,PL}{2\,bd^2},$$

where MOR is the modulus of rupture (N/mm^2), P is the static bending maximum load (N), L is the length of span (mm), b is the width of the sample (mm), and d is the thickness (depth) of the sample (mm).

Glue Shear Strength

The test samples were prepared, and saw cuts were made to allow the examination of each and every pair of glue lines in the plywood. Each test samples were gripped symmetrically at two ends in the jaws of a suitable testing machine and pulled apart. The distance between the notches on the test samples and the end of the gripping jaws of the testing machine were between 10 mm and 20 mm. The pull should be, as far as possible, in the center line of the central veneer. The grain of the center ply should be perpendicular to the direction of application of the load. The width of each sample and distance between the notches were measured to the nearest 0.025 cm to determine the shear area. During the test, the load was applied to the test specimens as uniformly as possible and adjusted so as to increase at a rate within the range of 1300 $\pm$ 500 N/min. The maximum load at the time of complete failure of each specimen was recorded and also checked to ensure whether the failure was due to wood or glue by visual examination of the area under shear. In case of wood failure, the percentage of wood failure should also be recorded IS 1734-1 to 20 (1983).

Water Absorption and Thickness Swelling

The water absorption and thickness swelling were analyzed with the 24-h water soak test that determines the water absorption behavior of the plywood and the effect of the observed water on plywood thickness. The samples were subjected to measures of water absorption and thickness swelling by the difference in weight and thickness of the sample before and after 24-h immersions in water.

The water absorption (A) was calculated by the following equation suggested by Rahaman et al (2012):

$$A(\%) = \frac{m2 - m1}{m1} \times 100,$$

where $m2$ is the weight of the sample after immersion in water and $m1$ is the weight of the sample before immersion in water.

The thickness swelling (G) was calculated by the following equation suggested by Rahaman et al (2012):

$$G(\%) = \frac{A2 - A1}{A1} \times 100,$$

where $A1$ is the thickness before the test and $A2$ is the thickness (mm) after the test.

RESULTS AND DISCUSSION

Biometric Attributes

Plywood is often recognized as the most significant and important engineered wood products which can overcome the major drawbacks of solid wood by their construction arrangement, material anisotropy, heterogeneity, and insufficient dimension stability due to changes in moisture (Král and Hrázský 2006). Although timber is a potential raw material for plywood production, all timber species are not amenable for commercial plywood production. The physical characteristics of timber coupled with its availability on larger volume and price factor are very significant in choosing timber for plywood production (Zaman 1982). Under such circumstances, the present study was carried out to identify new and alternate timber species amenable for plywood production. The species differed significantly in various growth attributes such as height, girth at breast height, volume, number of logs, and bark thickness, and the results are presented in Table 1. A wide range of species grown in homestead and agroforestry (Das 1990) have been found amenable for decorative plywood (Anonymous 1986), marine plywood (Anonymous 1985), general purpose plywood (Anonymous 1983), and chest board (Anonymous 1979), and this indicated that the species investigated in the present study can be useful for a wide range of plywood production.

The height of the identified tree species ranged between 7.00 m (*T. ciliata*) and 14.00 m (*C. equisetifolia*). Similarly, the GBH varied from 55.90 cm (*S. macrophylla*) to 83.10 cm (*C. tabularis*). The volume ranged between 0.1445 m^3 (*Acacia* hybrid) and 0.6441 m^3 (*Melia dubia*). Among the species studied, *C. equisetifolia* (0.2869 m^3) exhibited a higher volume followed by *C. tabularis* (0.2639 m^3). The trees were converted into 52-inch logs for plywood production. *C. equisetifolia* (8) registered the highest number of 52-inch logs converted, and other species varied from 2 to 4 logs. The bark thickness is one of the important parameters to reduce the wastage of residues in plywood production. Among the species studied, the bark of *A. fraxinifolius* (3.05 mm) exhibited a very low value followed by *C. tabularis* (4.01 mm).

Veneer and Plywood Properties

Density is a very significant property of wood, which plays a critical role in deciding the strength of plywood (Nazmul Alam et al 2012). In the present study, the evaluated species exhibited wide density variation which ranged between 907 kg/m^3 (*C. equisetifolia*) and 518 kg/m^3 (*S. macrophylla*). Except *C. equisetifolia*, all other species exhibited a medium density range and would be amenable for different grades of plywood production. The density of standard plywood ranged between 0.43 g/cm^3 and 0.79 g/cm^3 (Franz et al 1975), which thus attests that the species deployed in the present investigation are highly suitable for plywood production.

The suitability of species for plywood production depends on economic veneer recovery. Currently, the predominant species used in plywood production is eucalyptus, and the veneer recovery ranged between 40% and 45% (Nazmul Alam et al 2012). Hence, all species with higher veneer recovery are amenable for plywood production. The recovery of veneer from the identified species varied from 43.09% (*M. parvifolia*) to 63.19% (*A. fraxinifolius*). Among the eight species investigated, *A. fraxinifolius* (63.19%) exhibited the highest veneer recovery followed by *Acacia* hybrid (59.29%). In case of shrinkage, *Acacia* hybrid (4.30%) registered very low shrinkage followed by *C. tabularis* (4.51%), *N. cadamba* (4.66%), and *S. macrophylla* (4.79%). *C. equisetifolia* (8.96%) registered very high shrinkage compared with all the species studied (Table 2). The veneer quality is the physical appearance combined with the esthetic appearance of the veneer. In the case of veneer quality, barring *C. equisetifolia* and *M. parvifolia*, the other six species exhibited acceptable veneer quality, and hence, they are amenable for veneer and plywood production. A similar study was conducted earlier in *Acacia* hybrid (Rahaman et al 2012); *Albizia richardiana* (Rahman et al 2014b) and *Gmelina arborea* (Tenorio et al 2011) lend support to the findings of the present study.

Mechanical Properties of Plywood

The characterization of plywood production indicated that all the species were tested positive at the 72-h boiling test. The mechanical properties of plywood made from various identified species are provided in Table 3. The average modulus of rupture (MOR) registered was 53.36 N/mm^2, and *Acacia* hybrid registered higher MOR (79.12 N/mm^2) and *M. parvifolia* registered low MOR (34.55 N/cm^3). The standard value for MOR ranged between 13.1 N/mm^2 and 68.9 N/mm^2 (ASTM D3043-87 1987). In the present study, all the species exhibited the MOR values within this range, and hence, they are amenable for plywood quality. Generally, MOR will be higher for high-density boards (Kwon and Geimer 1998; Ajayi 2002; Zheng et al 2007). In the present study, most species exhibited higher density coupled

Table 2. Wood quality studies for plywood production in identified new and alternate species.

S. no.	Species	Wood density (kg/m^3)	Sample volume (m^3)	Sample weight (kg)	Veneer (m^2)	Veneer yield (%)	Shrinkage (%)	Veneer quality
1	*Toona ciliata*	541.00	0.0829	72.90	26.66	57.92	6.12	Face quality
2	*Chukrasia tabularis*	715.00	0.1196	79.10	33.61	50.59	4.51	End cracks
3	*Acacia* hybrid	645.00	0.0657	64.20	21.65	59.29	4.30	Smooth surface
4	*Neolamarckia cadamba*	633.00	0.1010	88.70	29.27	52.16	4.66	Smooth surface and knotty holes
5	*Acrocarpus fraxinifolius*	607.00	0.0901	90.30	31.61	63.19	6.44	Fiber
6	*Swietenia macrophylla*	518.00	0.0630	49.10	19.97	57.01	4.79	Face quality
7	*Casuarina equisetifolia*	907.00	0.0792	87.10	25.17	57.19	8.96	Fiber and knotty holes
8	*Mitragyna parvifolia*	767.00	0.0900	97.80	21.55	43.09	5.10	Excessive cross fiber
	Mean	666.63	0.0864	78.65	26.19	55.06	5.61	—

with acceptable MOR, and hence, these species are potential alternate species suitable for various grades of plywood production.

Similarly, MOE is yet another significant mechanical property which implies that the deformation produced by low stress below the proportional limit is completely recoverable after the loads are removed. The standard range of MOE is from 2000.70 N/mm^2 to 4800.30 N/mm^2. In the present study, the average MOE recorded was 6395 N/mm^2 and the maximum MOE was registered by *C. equisetifolia* (9057 N/mm^2) followed by *C. tabularis* (8067 N/mm^2), *Acacia* hybrid (7554 N/mm^2), *N. cadamba* (6928 N/mm^2), and *S. macrophylla* (6384 N/mm^2). Most species exhibited higher MOE, and this indicates that these species could play a vital role in the manufacture of high-density plyboards as evidenced in ghora neem (Rahman et al 2014a), raj korai (Rahman et al 2014b), and eucalyptus (Nazmul Alam et al 2012).

In glue shear strength, the load varied from 1170 N (*C. equisetifolia*) to 700 N (*S. macrophylla*). The wood failures in glue shear strength were high in *Acacia* hybrid (78%) followed by *T. ciliata* (75%) and *S. macrophylla* (75%). It was found that after submerging for 24 h, the percentage of thickness swelling of plywood ranged between 3.0% (*Acacia* hybrid) and 4.5% (*C. tabularis*). Among the species investigated, *C. tabularis* (4.5%) and *Acacia* hybrid (3.0%) registered high and low values, respectively. Water absorption was high in *N. cadamba* (28.0%) and *C. equisetifolia* (28.0%) and very low in *Acacia* hybrid (15.0%).

Table 3. Plywood properties of identified new and alternate species.

			Static bending test (across grain)		Glue shear strength			
S. no.	Species	Boiling test (72 h)	MOR (N/mm^2)	MOE (N/mm^2)	Load (N)	Wood failure (%)	Water absorption (%)	Thickness swelling (%)
1	*Toona ciliata*	Pass	45.44	4790.97	1150	75	17.0	3.3
2	*Chukrasia tabularis*	Pass	58.50	8067.25	1010	50	18.0	4.5
3	*Acacia* hybrid	Pass	79.12	7554.28	875	78	15.0	3.0
4	*Neolamarckia cadamba*	Pass	56.63	6928.40	1000	60	28.0	3.5
5	*Acrocarpus fraxinifolius*	Pass	43.50	4357.50	1100	25	21.0	4.2
6	*Swietenia macrophylla*	Pass	45.85	6384.44	700	75	20.0	3.8
7	*Casuarina equisetifolia*	Pass	63.26	9057.73	1170	28	28.0	4.0
8	*Mitragyna parvifolia*	Pass	34.55	4026.15	895	42	23.0	4.3

The thickness swelling is independent of the panel size and thickness of veneer (Kelly 1994). Among the species evaluated, the thickness swelling is higher in *C. tabularis* (4.5%) and lower in *Acacia* hybrid (3.0%). High density and low water absorption may lead to a decrease in thickness swelling as evidenced in eucalyptus (Nazmul Alam et al 2012). In the present study, all the species exhibited high density and low water absorption, which could be the reason for the low thickness swelling. The average water absorption capacity of plywood in the present study is 21.20%, with the maximum in *N. cadamba* and *C. equisetifolia* (28%) and minimum in *Acacia* hybrid (15%). This variation indicated that this could be attributable to differences in the holocellulose content of the studied veneer species which are responsible for water absorption (Wardrop 1957).

CONCLUSION

Eight fast-growing tree species, viz., *T. ciliata*, *C. tabularis*, *Acacia* hybrid, *N. cadamba*, *A. fraxinifolius*, *S. macrophylla*, *C. equisetifolia*, and *M. parvifolia*, incorporated in various agroforestry systems were characterized based on their suitability toward veneer and plywood production. The study identified that all the species exhibited variations because of density which ranged from medium to high. All the eight species exhibited higher veneer yields coupled with acceptable shrinkage, and these species could play a vital role in plywood production. Plywood properties revealed that all eight species tested positive for the boiling test. The mechanical properties of plywood such as MOE and MOR showed that the plywood made out of the tested species exhibited accepted values. In this holistic analysis, barring *M. parvifolia*, the other seven species are recommended as a potential species for commercial plywood production of different grades.

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