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The Potential for Using Stem and Branch of Bhadi (*Lannea Coromandelica*) As a Lignocellulosic Raw Material for Particleboard

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Abstract

This study presents the potentiality of stem and branch particles of bhadi (Lannea coromandelica) tree as a lignocellulosic raw material for particleboard. Three types of three layer particleboard i.e., stem particleboard (S_{PB}), branch particleboard (B_{PB}) and stem-branch mixed particleboard (SB_{PB}) were manufactured with 10% commercial urea formaldehyde (UF) resin. Physical properties i.e., density, moisture content (MC), water absorption (WA), thickness swelling (TS), Linear expansion (LE) and mechanical properties i.e., modulus of elasticity (MOE) and modulus of rupture (MOR) of the particleboards were investigated according to the procedure of ASTM D-1037 standard. Density of S_{PB}, B_{PB} and SB_{PB} were 932, 787.5 and 854.83 Kg/m^3, respectively. MOE of S_{PB}, B_{PB} and SB_{PB} were 2714 N/mm², 2010 N/mm² and 2509 N/mm², respectively. MOR of S_{PB}, B_{PB} and SB_{PB} were 23.31 N/mm², 14.65 N/mm² and 21.85 N/mm², respectively. Based on the particle types and percentage of particles in the formulation, the properties of bhadi particleboard varied. Among the three types of particleboard, S_{PB} and SB_{PB} particleboard met the minimum ANSI A208.1 requirements of physical and mechanical properties for H-2 grade particleboard. Also it was observed that, the properties of S_{PB} and SB_{PB} particleboard are comparable to the properties of commercial particleboard produced in Bangladesh.

Keywords: *Lannea coromandelica,* stem-branch particle mixture, three layer particleboard, physical properties and mechanical properties.

Introduction

Particleboard a very familiar and environmental friendly wood based composite product across the world. Since the early 1981s, wood-based particle board is produced in Bangladesh. Recently the demand of particleboards increased all over the world for house construction, furniture manufacturing and interior decoration (wall and ceiling paneling) etc. due to its strength and workability. Therefore, it is manufactured in great quantities which results in large quantities of lignocellulosic raw materials consumption by the processing industries causing a threat to the natural forest as well as to the environmental sustainability. In addition, deforestation and forest degradation caused an important raw material issue in the sector for a long time in Bangladesh[1]. So, the alternate source of lignocellulosic raw materials for particleboard production is village forest or homestead forest, which satisfies 85% of the total requirements of timber and fuel wood supply of the country. In Bangladesh, 183 tree species grown in the homestead and village groves[2]. Among them only 5 species including civit (*Swintonia floribunda*), garjan (*Dipterocarpus sp*), chapalish (*Artocarpus chaplasha*), narikeli (*Pterygota alata*), and pitali (*Trewia nudiflora*) are recommended for particleboard production. In addition, Kadam (*Anthocephalus chinensis*), Chatian (*Alstonia scholaris*), jute stick, etc. are utilized by the particleboard industries of Bangladesh. But the supply of these wood species has become very limited, causing a serious shortage of raw materials for the wood-based industries[3]. Thus, it is imperative to find an alternative source of lignocellulosic raw material to sustain the particleboard production in Bangladesh. The manufacture of three layer particleboard from the mixture of stem and branch particle of bhadi is perhaps one such approach.

Bhadi (*L. coromandelica*) is a medium size deciduous tree of anacardiaceae family and most widely distributed all over the Bangladesh due to its adaptability to various climatic conditions[2]. Its sapwood is pale colored while the heartwood is of reddish-brown. Sattar and Akhtaruzzaman found the density as 0.77 gm/cm^3 at 12% moisture content for *L. coromandelica* grown in village areas of Bangladesh[4]. In spite of having such density the wood is classified as non-durable or non-resistant to natural decay agents as resistance to natural decay depends on the higher extractive content rather than the higher density[5]. In addition, seasoning of this wood is very difficult or results in seasoning defects including severe split and warp due to the anatomical structure of wood as reported by Sattar and Akhtaruzzaman, which restricts its utilization in furniture manufacturing, house making and other structural purposes[4]. So, the fiber of lesser used bhadi tree could be a promising source of raw materials for the wood-based particleboard manufacturing industries. An extensive literature search did not reveal any information about the manufacturing of particleboard from the stem, branch and/or stem-branch mix particles of bhadi. Thus, the purpose of this study was to investigate potentiality and provide detailed information about the technical performance of bhadi particleboard manufactured through stem and branch particles. Specially, physical and mechanical properties of three types of three layer particleboard manufactured separately by using stem, branch and stem-branch mixed particles of bhadi were investigated.

Material and Methods

Panel manufacturing: *L. coromandelica* tree (age 7 year, height 9 m and average diameter 30 cm) was collected from the homestead of Khulna District of Bangladesh. Stem and branch were collected, debarked and chipped separately in the field by using traditional hand cutting tools. Subsequently, chips of stem and branch were separately reduced into particles in a hammer mill by using 8 mm screen. Particles were further screened through a 2 mm screen for the construction of three layer board, where fine particles were used as furnish for the face layer and the coarse particles were used for the core layer[6]. Particles were then dried to moisture content 2.5 % in a laboratory oven maintaining temperature 103 ± 2°C for 24 hours. After drying, coarse and fine particles were separately blended with 10% commercial urea formaldehyde (UF) resin (based on the oven dry weight of wood particle) in a drum type blender[7]. These particles were sent to the forming box for mat formation and mat forming was hand-performed. In the mat, the percentage of the weight of the top (face), core and bottom (face) layers were 20, 60 and 20%, respectively (table 1). The average thicknesses of the mats were 38 mm to produce 12 mm thick particleboard. All mats were hot pressed for 5 minutes at specific pressure 5.38 N/mm^2 and temperature 180 °C to produce 12 mm thick particleboards[8]. Three replications of each type of board having 40×25×1.2 cm dimension were manufactured. The boards were then trimmed to reduce the edge effect on the properties of particleboard.

Table - 1
The raw material formulation for three layer particleboards

Panel Types	Formulation	Top (Face)	Core	Bottom (Face)
		Fine particles (%)	Coarse particles (%)	Fine Particles (%)
S_{PB}	Stem particles only	20	60	20
B_{PB}	Branch particles only	20	60	20
SB_{PB} (Stem-branch mixture)	Stem particles	10	30	10
	Branch particles	10	30	10

Laboratory test: Before testing, the boards were conditioned at room temperature for 48 hours. For both physical and mechanical properties, room temperature and relative humidity was 23±2°C and 65±2%, respectively. According to the ASTM standard D-1037[9], all specimens were carefully prepared and tested to evaluate the physical and mechanical properties of each type of board. Six specimens were used for each type of panel for evaluation of physical and mechanical properties.

Physical properties: The density and moisture content of particleboard was measured based on the ovendry weight, which was obtained after drying the samples at 103±2°C until constant weight is reached. The weight of the samples of each board was measured by an electrical balance. The dimensions of each test sample were measured using a digital slide caliper, and thus volume of the samples was calculated by multiplying the length, width and thickness of the samples.

Density (D) was determined from the mass and volume of each sample by the following equation:

$$D = \frac{m}{v}$$

Where m is the mass v is the Volume of the particleboard sample.
Moisture content (mc) was calculated by the following equation:

$$mc(\%) = \frac{m_{\text{int}} - m_{od}}{m_{od}} \times 100$$

Where m_{int} is the initial mass (g) and m_{od} is the oven-dry mass of the particleboard sample (g).

In this study, 2 and 24 h water soak test determines the water absorption behavior of the panels and the effects of the absorbed water on panel thickness. The water absorption and thickness swelling was measured by the difference in weight and thickness of the samples respectively, before and after 2 and 24 hrs immersion in water. The water absorption (A) and thickness swelling (G) of the samples were calculated as percentages and are measured by using electrical balance and digital slide calliper respectively.
The water absorption was calculated by the following equation:

$$A(\%) = \frac{m_2 - m_1}{m_1} \times 100$$

Where m_2 is the weight of the sample after immersion in water and m_1 is the weight of the sample before immersion in water.

The thickness swelling was calculated using the following equation:

$$G(\%) = \frac{A_2 - A_1}{A_1} \times 100$$

Where A_1 is the thickness before the test and A_2 is the thickness (mm) after the test.

The linear expansion was calculated using the following equation:

$$LE(\%) = \frac{l_2 - l_1}{l_1} \times 100$$

Where l_1 is the length before the test and l_2 is the length (mm) after the test.

Mechanical properties: MOE and MOR were measured following the three point bending test by using universal testing machine IMAL-IB600 according to the ASTM D 1037-93 standard[9]. Particleboards were cut into rectangular sections for determining MOE and MOR. The dimension of each particleboard sample was 240 mm × 50 mm × 12 mm. MOE and MOR were calculated using the following equations:

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

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

In both equations, b is the width of sample (mm); d is the thickness (depth) of sample (mm); P' is the load at proportional limit (N); Δ′ is the center deflection at proportional limit (mm); MOE is the modulus of elasticity (N/mm^2); MOR is the modulus of rupture (N/mm^2); L is the length of span (mm); P is the static bending maximum load (N)

Statistical analysis: A general statistical description (average and standard deviation) was determined for the different particleboard properties. Data analysis was performed by using the SAS statistical software package. The significance of different treatments was determined by variance analysis (ANOVA) and LSD (least significant difference) test ($\alpha \leq 0.05$).

Results and Discussion

Physical properties: The mean values of physical properties of S_{PB}, B_{PB} and SB_{PB} of *L. coromandelica* are given in table 2. From table 2 it is observed that the particleboards were in the high-density range (787.5 to 932 Kg/m^3)[10]. Statistical analysis illustrated significant difference of density among the three types of three layer particleboard. The result indicated that, S_{PB} showed maximum mean density (932 Kg/m^3), where as the B_{PB} and SB_{PB} showed mean density 787.5 and 854.83 Kg/m^3, respectively. Density of the S_{PB} is higher than those of B_{PB} and SB_{PB} particleboards which might be the result of the higher density of stem wood. Because the density of wood decreases from the base to upward within tree as a result of the higher proportion of heartwood formation[11]. It was also observed that, SB_{PB} manufactured from 50% stem and 50 % branch particles showed density of 854.83 Kg/m^3 which is significantly higher than the density of B_{PB} and lower than S_{PB} but remains in the range of ANSI A208.1 standard for high density particleboard. Thus, the results reflect the variation of density between the stem and branch wood, as the others parameter remains constant. All the board showed higher density compared to the commercial particleboard produced from *Anthocepalas chinensis*, *Bombax ceiba* and mixed particles as reported by Ashaduzzaman and Sharmin[3].

Moisture content of S_{PB}, B_{PB} and SB_{PB} particleboards were 9.91, 15.03 and 12.2% respectively (table 2). Moisture content of particleboards varied may be due to the moisture content of raw materials (i.e., the position of the raw materials in the tree). Moisture content increases with the increasing height within a tree which has significant influence on the weight and properties of manufactured products[12]. Franz et al. reported that, moisture content of particle board after curing ranges between 8.5 and 11.0 %[13]. Except the S_{PB}, both B_{PB} and SB_{PB} showed slight variation in MC. This variation may be due to the lack of wax in UF resin, which results in quick moisture uptake. Therefore, it would be better to use wax and keep moisture content of particleboard within equilibrium moisture content. Because final properties of the board substantially affected by the distribution of moisture within the board as reported by Maloney[14]. WA and TS after 2 and 24 hours were investigated in this study and followed the order: $B_{PB} > SB_{PB} > S_{PB}$ particleboards. It was found that, WA by S_{PB}, B_{PB} and SB_{PB} particleboards were 13.19, 17.06 and 14.42% respectively after 2hrs; and 34.78, 48.86 and 41.87% respectively after 24 hrs of immersion in water (table 2). This variation in WA and TS may be due to the hygroscopic nature of wood particles, structural variation in stem and branch wood (i.e. cell types) and the absence of wax or hydrophobic additives in the UF resin. Compared to the commercial particleboard improved resistance to WA and TS was observed for S_{PB} and SB_{PB} particleboard and the results comply with the results for 24 hrs water soaking test of experimental boards manufactured from *Cassia siamea*, *Dalbergia sissoo*, *Gmelina arborea*, *Melia azedirach* and *Samanea saman* as reported by Ashaduzzaman and Sharmin[3]. It was also observed that, as branch particle content decreases from 100% to 50% in the formulation of SB_{PB} particleboards, WA and TS decreases significantly. Because in branch wood numerous vessels, rays lesser number of fibers and higher amount of hemicelluloses present while comparing with the stem wood and are responsible for the less resistant to TS[7]. Another reason behind such kind of variation is springback of the panels as they are soaked in water is transferred in less-dimensional stability as the UF resin is less resistant to water because of their amino methylene linkages[15]. Therefore, they go through decomposition with the effect of water absorption of particles[16]. Earlier researchers have reported that, addition of wax (from 0.5 to 1%) significantly decreases the WA and TS of the boards. The findings of this study are in agreement with those reported by Biswas et al.[17].

From table 2 it was observed that, with the increasing density of the boards from 787.5 to 932 Kg/m^3 the WA and TS decreases significantly for both 2 and 24 hrs immersion in water. This may be attributed to the low porosity on the board surface resulting from the higher density made diffusion of water difficult to the S_{PB} and SB_{PB} particleboard. Moreover, higher density affects correspondingly higher resistant to absorption and swelling properties[13]. Results of TS comply with the findings of Nemli et al.[18]. However, TS may be affected by WA of panel because thickness swelling of panel is high when WA is high for all the panels. Franz et al. also reported that the highest TS after two hours immersion in water should not exceed 6-10 % of the original thickness[13]. TS and WA may vary with the types of raw materials, particles size, binding materials used, and the gap between the particles. Thus, the result of this study indicated that the low-quality branch wood particles have potential influence on the WA and TS of the boards.

Table - 2
Average physical and mechanical properties, standard deviation and statistical analysis of bahdi (Lannea coromandelica) particleboards

Panel Types	Density (kg/m^3)	MC (%)	WA (%)		TS (%)		LE (%)		MOE (N/mm^2)	MOR (N/mm^2)
			2 hrs	24 hrs	2 hrs	24 hrs	2 hrs	24 hrs		
S_{PB}	932^A (48.66)	9.91^A (1.32)	13.19^A (2.76)	34.78^A (3.00)	5.85^A (1.49)	17.75^A (1.69)	0.32^A (0.1)	0.56^A (0.12)	2714^A (138)	23.31^A (1.43)
B_{PB}	787.5^C (18.87)	15.03^C (1.72)	17.06^B (0.68)	48.86^C (7.58)	9.46^C (2.94)	26.1^C (2.7)	1.04^B (0.21)	1.66^C (0.4)	2010^C (131)	14.65^B (1.54)
SB_{PB}	854.83^B (40.35)	12.2^B (1.84)	14.42^{AB} (2.83)	41.87^B (2.4)	8.21^B (2.1)	21.37^B (2.4)	0.48^A (0.2)	0.91^B (0.2)	2509^B (190)	21.85^A (2.03)

Values in parenthesis are standard deviation. Values within the same line column by different letters are significantly different

Table 2 shows the average LE of the three types of particleboard for 2 and 24 hrs and followed the same order to increase as stated for WA and TS. Particleboard made from stem particles (S_{PB}) exhibited higher resistance to LE compared to branch particles (B_{PB}) and stem-branch mixed particles (SB_{PB}) and ranges from 0.32 to 1.04% for 2 hrs and 0.56 to 1.66% for 24 hrs. Statistical analysis (ANOVA and LSD) showed there was a significant difference of LE for 24 hrs among the particleboards. Though, for 2 hrs immersion in water, LE of S_{PB} and SB_{PB} were not significantly different but LE of B_{PB} was significantly different. This is attributed to the absence of wax and random orientation of grain of the particles within the particleboard. Gatchell et al. reported that, with the increasing random orientation of the grain, linear expansion of the particleboard increased[19]. The results of this study also indicated that, the duration of exposure also has influences on the result obtained for the test particleboards. The findings of this study are in good agreement with Lehmann's research results[20].

Mechanical properties: The average, standard deviation and statistical analysis of mechanical properties of S_{PB}, B_{PB} and SB_{PB} particleboards are summarized in table 2. Based on the statistical analysis significant difference was determined for the MOE and MOR properties of the particleboards. MOE and MOR of the S_{PB}, B_{PB} and SB_{PB} particleboards followed the same trend of density and the order: $S_{PB} > SB_{PB} > B_{PB}$ particleboards. S_{PB} particleboard showed the highest mean value of MOE and MOR (2714 and 23.31 N/mm^2 respectively) where as the B_{PB} particleboard showed lower MOE and MOR values (table 2). Therefore, both MOE and MOR value varied among the different types of particleboards due to the density of raw materials as well as with the source of particles in the tree. Franz et al. reported that, higher density of wood affects correspondingly higher bending strength of manufactured board[13]. It is also reported that, the cell thickening in high density wood i.e., stem wood makes wood itself much stronger which provides high strength to the particleboard[21]. In addition, inferior mechanical properties of B_{PB} particleboards may be due to the lesser number of fiber cells in branch wood. Kelly reported that, MOE and MOR of particleboard increases with increasing board density[22]. In addition, lower fiber length of branch wood than wood of the stem may be another reason for the lower MOE and MOR of B_{PB} particleboards[23, 24]. The findings of this study comply with the properties of stem and branch particleboards of Douglas-fir[25], loblolly pine[26] and black locust[18]. The SB_{PB} particleboard showed modified MOE and MOR properties when compared with the S_{PB} and B_{PB} particleboards. In another word, the addition of 50% branch particles in the board formulation to produce SB_{PB}, reduces the MOE and MOR properties compared with S_{PB} boards. Again, this variation due to the variation in properties of the raw materials i.e., stem and branch wood which modify MOE and MOR properties of SB_{PB} particleboards. The findings of MOR of this study are comparable to the commercial particleboard produced in Bangladesh and much higher than the results of MOR of experimental particleboards as reported by Ashaduzzaman and Sharmin[3]. MOE and MOR of S_{PB} and SB_{PB} particleboards were found to be within the range of ANSI A208.1 requirements for high density particleboard of H-2 grade. But the values of MOE and MOR of B_{PB} did not meet the ANSI A208.1 requirement for H-2 grade particleboard. Moreover, the MOE and MOR properties of particleboards also varies depending on the surface density, surface particle alignment and adhesive content[22].

Conclusion

This study investigated the potentiality of using stem and branch particles of bhadi in the manufacture of three layer particleboard. On the basis of physical and mechanical properties, production of S_{PB} from stem particles only and SB_{PB} from a mixture of 50% stem and 50% branch particles are technically feasible and are comparable to the commercial particleboard produced in Bangladesh. From the results and discussion following conclusion can be drawn – i. Particle types (stem or branch particle) have significant influences on the physical and mechanical properties of bhadi particleboard. ii. Depending on the percentage of particles i.e., stem or branch particle in the formulation, physical and mechanical of bhadi particleboard varies.

Though the particleboard production only from the stem particles and mixed particles i.e., 50% stem and 50% branch particles are feasible, it would be better to try to mix as much as possible higher percentage of branch particles with stem particles by maintaining adequate physical and mechanical properties. Thus, it will ensure the proper utilization of *L. coromandelica* as a lignocellulosic raw material for particleboard manufacturing.

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