EFFECTS OF AGE AND HEIGHT ON PHYSICAL AND MECHANICAL PROPERTIES OF BAMBOO

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KAMRUZZAMAN, M., SAHA, S. K., BOSE, A. K. & ISLAM, M. N. 2008. Effects of age and height on physical and mechanical properties of bamboo. Bamboo is an important raw material for housing, bridge construction and other purposes in Bangladesh. Due to acute scarcity of timber for housing, bamboo is important as a substitute both at the village and urban levels. A sufficient knowledge of the physical and mechanical properties of bamboo ensures safe design for materials used in service. In this study, some physical and mechanical properties (at different heights and three ages) of four bamboo species, *viz. Bambusa balcooa*, *B. tulda*, *B. salarkhanii* and *Melocanna baccifera*, grown in the southwestern part of Bangladesh were investigated. *Bambusa balcooa* had the highest moisture content in green condition. Moisture content at different height positions was different for all the bamboo species. However, moisture content was not different with age in all the species. Density for different age groups was only different for *B. salarkhanii* and *M. baccifera*. *Melocanna baccifera* had the highest density but the lowest shrinkage of culm wall thickness. Height and age had almost no effects on the modulus of elasticity (MOE) and modulus of rupture (MOR). The highest MOE and MOR were observed in *M. baccifera*.

Keywords: Culm, shrinkage, density, modulus of elasticity, modulus of rupture, Bangladesh

KAMRUZZAMAN, M., SAHA, S. K., BOSE, A. K. & ISLAM, M. N. 2008. Kesan usia dan ketinggian buluh terhadap ciri-ciri fizikal dan mekanik buluh. Buluh merupakan bahan mentah penting untuk pembinaan rumah dan jambatan serta kegunaan lain di Bangladesh. Disebabkan kekurangan kayu, buluh merupakan bahan pengganti utama untuk pembinaan rumah di kampung dan bandar. Pengetahuan mencukupi tentang ciri-ciri fizikal dan mekanik buluh memastikan keselamatan bahan semasa penggunaan. Dalam kajian ini, beberapa ciri-ciri fizikal dan mekanik empat spesies buluh yang tumbuh di tenggara Bangladesh iaitu *Bambusa balcooa, B. tulda, B. salarkhanii* dan *Melocanna baccifera* disiasat. Ciri-ciri ini dikaji pada ketinggian buluh yang berlainan dan pada tiga usia berlainan. *Bambusa balcooa* mempunyai nilai kandungan lembapan yang tertinggi pada keadaan basah. Pada ketinggian buluh yang berlainan kandungan lembapan adalah berbeza bagi semua spesies buluh. Namun, kandungan lembapan tidak berbeza dengan usia bagi semua spesies. Ketumpatan cuma berbeza dengan usia bagi *B. salarkhanii* dan *M. baccifera* sahaja. *Melocanna baccifera* mempunyai nilai ketumpatan yang tertinggi tetapi nilai pengecutan ketebalan dinding kulma yang terendah. Ketinggian buluh dan usia tidak mempengaruhi modulus kekenyalan (MOE) dan modulus kepecahan (MOR). *Melocanna baccifera* mempunyai nilai-nilai MOR dan MOE yang tertinggi.

INTRODUCTION

Bamboo is a versatile group of grass, belonging to the subfamily Bambusoideae of the family Poaceae. It contains more than 1250 species and 75 genera (Tewari 1993). Alam (1994) reported 27 taxa from 10 genera in Bangladesh together with their vernacular names and distribution. On the other hand, Lahiry (2001) reported 38 species in Bangladesh. As the morphology, structure and chemical components of bamboo differ from those of timber, the methods, technology and equipment for timber processing cannot be applied indiscriminately to bamboo utilization. Being a biological material, it is subjected to greater variability and complexity due to various growing conditions such as moisture, soil and competition (Latif *et al.* 1993).

Many factors, such as culm height, topography and climate, affect the properties of bamboo to a great extent and thus its utilization (Soeprajitno *et al.* 1988). Information on physical and mechanical properties of bamboo is necessary for assessing its suitability for various end-products (Sattar *et al.* 1990). The appropriate use of any material depends on its properties to

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a large extent. Being a universal raw material, the properties of bamboo need to be evaluated. The important physical properties include density, specific gravity, and shrinkage in diameter and wall thickness. On the other hand, mechanical properties include bending strength, tensile strength, compressive strength, shear strength, nail withdrawal resistance perpendicular to the face of the culm and fracture resistance.

This study was aimed at evaluating some important physical and mechanical properties of four bamboo species: *Bambusa balcooa*, *B. tulda*, *B. salarkhanii* and *Melocanna baccifera,* available in the Khulna region of Bangladesh. The properties were assessed in relation to age and height position. The results may be helpful in identifying appropriate bamboo species for any particular purpose. Thus, this will ultimately increase the service life of bamboo in use and will help to conserve bamboo resources.

MATERIALS AND METHODS

Twenty bamboo samples from each species were collected from four villages in the Khulna districts of Bangladesh. All the sound culms were marked and from these, nine culms were randomly selected. Each species was divided into three age groups of two, three and four years old and samples were taken from each age group. The age of culms was determined by referring to morphological characters summarized by Banik (1993) and also by discussion with owners of the bamboo groves. Three samples from each age group were used for replication. Each sample was then divided into three portions: bottom, middle and top, of four feet long.

The size for moisture content and density determinations was 2.5 cm wide rings from each age and height position. The density was determined on the basis of green volume and weight. Moisture content was determined by the oven-dry method and volume, by the water-displacement method (Indian Standard 1970, 1979), not taking absorption into account, as experience has shown that absorption is negligible (Gnanaharan *et al.* 1995). The moisture content was measured by the formula (i).

$$MC(\%) = \frac{GW - ODW}{ODW} \times 100 \qquad \text{(i)}$$

where
MC = moisture content (%)
GW = green weight of bamboo
ODW = oven-dry weight of bamboo

Density was measured by formula (ii).

$$D = \frac{M}{V} \qquad \text{(ii)}$$

(ASTM 1983)

where
D = density
M = mass or weight
V = volume

The specimen size for shrinkage determination in wall thickness was 2.5 cm wide rings while the specimens for diameter shrinkage were the internodes of the culms bound by nodes at the extremity. Three rings and three internodal culms were cut for each of the height position and age. The shrinkage in wall thickness was determined from green to oven-dry condition and the diameter shrinkage from green to air-dry condition. The wall thickness was determined at four perpendicular positions to each other (Figure 1a) while the diameter shrinkage was measured along two diameters perpendicular to each other (Figure 1b). Wall thickness and diameter measurements were made with a slide caliper to the nearest 0.002 cm. Shrinkage was measured by formula (iii).

$$S = \frac{GD - ODD}{GD} \times 100 \qquad \text{(iii)}$$

(Panshin & de Zeeuw 1980)

where
S = shrinkage percentage
GD = green dimension
ODD = oven-dry dimension

The static bending test was performed on the split specimens of varying lengths with or without nodes. The width of the specimen was kept at least equal to twice the thickness. There were two span lengths depending on width and thickness of the specimens. A span length of 140 mm was used to represent calculated values ranging from 100–170 mm and 210 mm to represent values

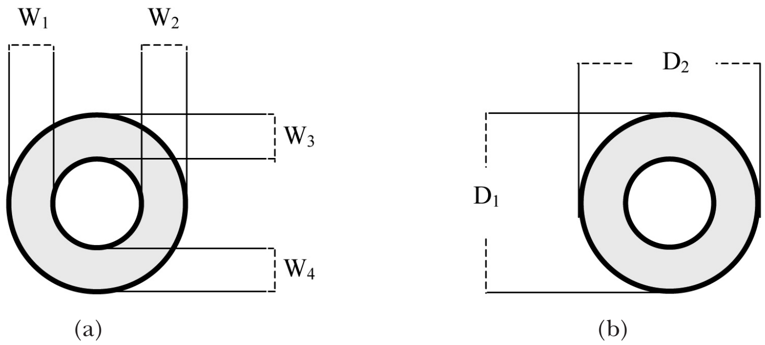

Figure 1 Position and direction of measurement: (a) Measurement for wall-thickness shrinkage (b) Measurement for diameter shrinkage (Talukder & Sattar 1980)

ranging from 180–300 mm. According to the Indian Standard (1976), the oven-dried split, short specimens from bottom, middle and top were tested under three-point loading. The tests were carried out in the Imal-IB600 Machine. The rate of deformation was kept at 6.5 mm min^{-1}. Both the supports had rollers. Small saddles and steel plates of 10 mm thickness were placed between the support rollers and the specimen. Load was applied through an iron plate and a loading saddle as well. No attempt was made to keep the nodal portion away from the loading point. The load and the deflection at the limit of proportionality were recorded. The maximum load at failure was also recorded. The nature of failure was observed and noted. The modulus of elasticity and modulus of rupture were computed according to Indian Standard (1970, 1976)

RESULTS AND DISCUSSION

Moisture content

The moisture content of *B. balcooa* was substantially higher than the other three species (Figure 2). Sattar *et al.* (1990) found higher moisture content in *B. balcooa* compared with *M. baccifera*. Between the three age groups, the moisture content of *B. balcooa* varied from 133 to 119% for bottom, 122 to 108% for middle and 109 to 99% for top. Similar variation was also observed in *B. tulda*, *B. salarkhanii* and *M. baccifera*. The age factor did not greatly affect the moisture content in different portions of bamboos. Younger culms showed higher percentage of moisture content in all four bamboo species. For every species in each age group, the bottom portion contained the highest proportion of water while the lowest, the top portion. Moisture content decreased as the height of culm increased for all the four species. Similar findings were also noted by Sattar *et al.* (1990), Kabir *et al.* (1991) and Sattar *et al.* (1994).

The variation was significant along culm height for *B. balcooa* ($F = 7.57$, $df = 2$, $p < 0.05$), *B. tulda* ($F = 53.44$, $df = 2$, $p < 0.05$), *B. salarkhanii* ($F = 42.01$, $df = 2$, $p < 0.05$) and *M. baccifera* ($F = 50.25$, $df = 2$, $p < 0.05$). This variation may be associated with the decrease in percentage of parenchyma cell, which acts as the site of water storage (Liese 1987, Latif & Jusoh 1992), structural and chemical composition of bamboo, season of felling (Liese 1985, Soeprajitno *et al.* 1988) and the gravitational force (Islam *et al.* 2002). Variation in moisture content between the four bamboo species was also significant ($F = 11.53$, $df = 3$, $p < 0.05$).

Density

Melocanna baccifera and *B. salarkhanii* produced more volume. Highest density of 870 kg m^{-3} was found in the bottom portion of 4-year-old *B. salarkhanii* while *B. balcooa* produced the lowest density (595 kg m^{-3}) bamboo (Figure 3). Wall thickness reduced from base to top. This is mainly because the amount of fibre increases and the number of vascular bundles decreases from base to top (Gnanaharan *et al.* 1995). Fibre wall thickness of *Bambusa blumeana* and *Gigantochloa scortechnii* varied significantly with height and age of culms but insignificantly with species and site while vascular bundle size differed insignificantly with species and age but varied significantly with

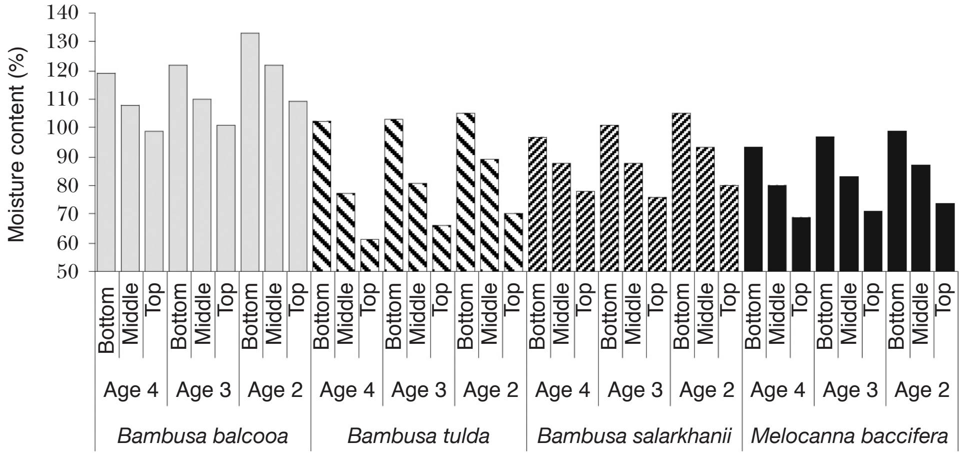

Figure 2 Moisture content of four bamboo species at different height positions and ages

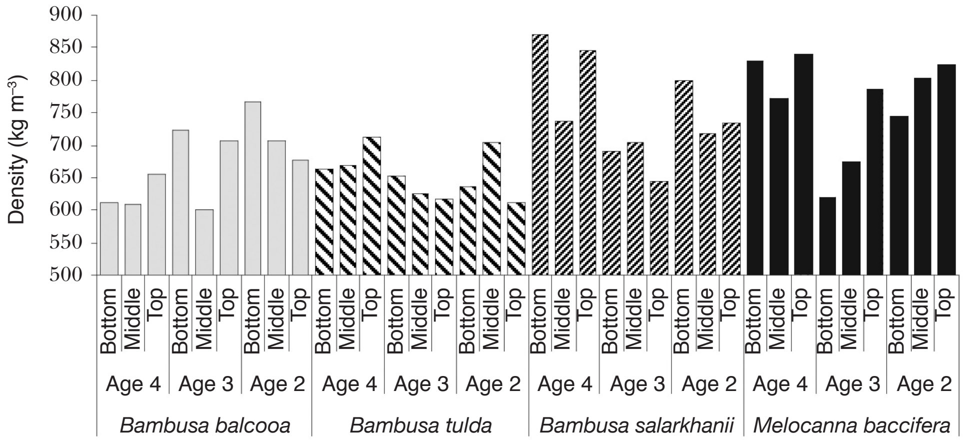

Figure 3 Density of four bamboo species at different height positions and ages

site and height of the culm (Latif & Liese 2001). The variation of density along culm height was insignificant for all the bamboo species. Variation in density in relation to age was found significant between 3- and 4-year-old culm of *B. salarkhanii* ($F = 42.01$, $df = 2$, $p < 0.05$) and *B. baccifera* ($F = 50.25$, $df = 2$, $p < 0.05$). Variation in density between the four bamboo species was significant ($F = 6.93$, $df = 3$, $p < 0.05$).

Shrinkage in wall thickness

The rate of shrinkage in wall thickness was decreasing from bottom to top, appreciably in each age group for all four species (Figure 4). The proportion of shrinkage in wall thickness was highest in *B. balcooa* while lowest in *M. baccifera*. In comparing between *M. baccifera* and *B. tulda*, there was not much difference in terms of shrinkage in wall thickness. The bottom portion shrinks more probably due to the presence of higher initial moisture content (Rehman & Ishaq 1947). Shrinkage in wall thickness in relation to age was insignificant for all the four bamboo species. The variations between all the three height positions were significant for *B. balcooa* ($F = 35.74$, $df = 2$, $p < 0.05$) and *B. tulda* ($F = 25.88$, $df = 2$, $p < 0.05$) and variation at bottom–middle and bottom–top positions were significant for *B. salarkhanii* ($F = 20.15$, $df = 2$, $p < 0.05$) and *M. baccifera* ($F = 6.59$, $df = 2$, $p < 0.05$). Shrinkage in wall thickness varied significantly between bamboo species ($F = 11.46$, $df = 3$, $p < 0.05$).

Shrinkage in culm diameter

The proportion of shrinkage in culm diameter was highest in *B. salarkhanii* and lowest in *B. tulda* (Figure 5). Bottom portion showed maximum proportion of shrinkage in culm diameter while the top portion, lowest. Highest shrinkage value of 9% in culm diameter was shown by *B. salarkhanii* and *B. balcooa* while lowest of 2% was shown by *M. baccifera*. In relation to age, the variations in values were insignificant for all the bamboo species. This is because shrinkage changes with age and it does not follow any definite trend (Sattar *et al.* 1990). Sattar *et al.* (1994) reported that shrinkage changes significantly along the culm height for *M. baccifera* and *B. balcooa*. Similar findings were found for *M. baccifera* ($F = 37.34$, df = 2, $p < 0.05$) and *B. balcooa* ($F = 3.93$, df = 2, $p < 0.05$). The variation in diameter shrinkage values for *B. tulda* ($F = 12.86$, df = 2, $p < 0.05$) and *B. salrkhanii* ($F = 7.55$, df = 2, $p < 0.05$) was significant. Variation in culm diameter shrinkage was significant ($F = 11.49$, df = 3, $p < 0.05$) between bamboo species.

Modulus of elasticity

The modulus of elasticity, in general, varied appreciably with the height of culm (Figure 6). Some deviations occurred due to the fact that the wall thickness did not uniformly decrease from the bottom to the top of the culm. The highest modulus of elasticity (498371.0 kg cm^{-2}) was observed in *M. baccifera* while the lowest, in *B. balcooa*. The difference in values varied significantly between *M. baccifera* and the other three bamboo species. There was no significant difference between *B. balcooa, B. tulda* and *B. salarkhanii*. This supports the findings of Sanyal *et al.* (1988) that the modulus of elasticity in bending decreased as the diameter of culm increased and vice versa. This may also be attributed to increasing specific gravity or density

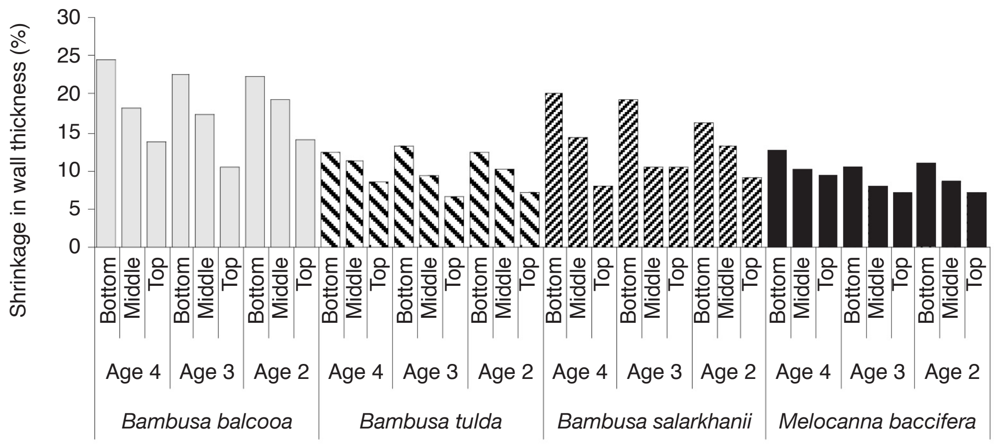

Figure 4 Shrinkage in wall thickness values of four bamboo species at different height positions and ages

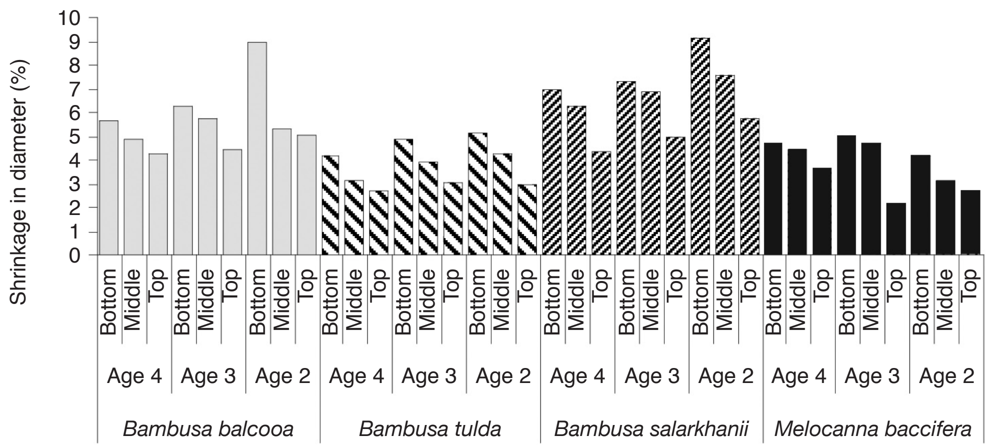

Figure 5 Shrinkage in diameter values of four bamboo species at different height positions and ages

along the culm as supported by Liese (1986). However, the values of modulus of elasticity varied insignificantly in relation to age and height position for all the four bamboo species except for *B. balcooa* where the values of bottom and top positions varied significantly ($F = 3.73$, df = 2 and $p < 0.05$). The modulus of elasticity between the four bamboo species varied significantly ($F = 81.12$, df = 3, $p < 0.05$).

Modulus of rupture

Modulus of rupture varied insignificantly for all the bamboo species in relation to age and height position (Figure 7). No definite trend was found from the base to the top of the culm. The highest modulus of rupture (2400 kg cm^{-2}) was found in *M. baccifera* while the lowest (1400 kg cm^{-2}), *B. balcooa*, which is opposite to the findings of Limaye (1952) who reported that this property was positively correlated with wall thickness. The difference in values was found significant between *M. baccifera* and *B. balcooa* while the difference was not really significant between *B. balcooa*, *B. tulda* and *B. salarkhanii*. The use of oven-dried split bamboo specimen may be a reason for this difference compared with the findings of other researchers. For round bamboo, the bottom had the strongest modulus of rupture while the top, the lowest (Sattar *et al.* 1990, Kabir *et al.* 1991). However, the MOR values of split specimens from culm top were higher than that of base (Gnanaharan *et al.* 1995). Li and Li (1983) also reported that MOR increased from base to top for split specimens. Significant variation ($F = 6.95$, df = 3, $p < 0.05$) was found between the four bamboo species in relation to modulus of rupture.

CONCLUSIONS

In Bangladesh, diminishing timber favoured the extensive utilization of bamboo for household construction to making toys. In the south-western

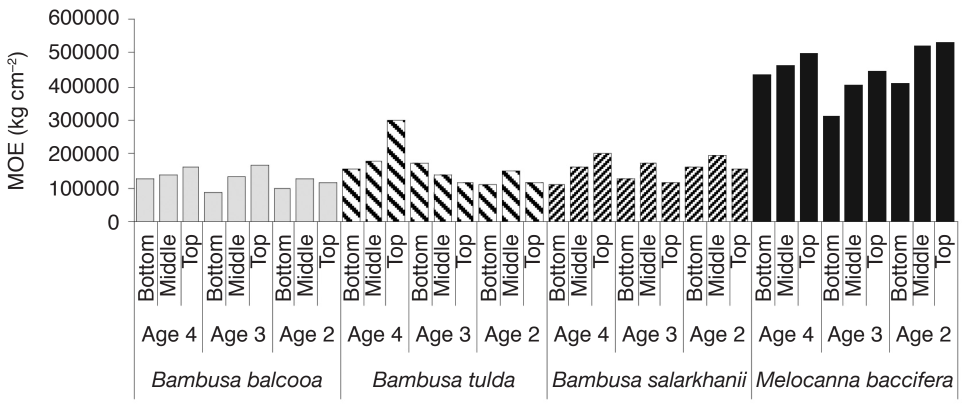

Figure 6 Modulus of elasticity (MOE) of four bamboo species at different height positions and ages

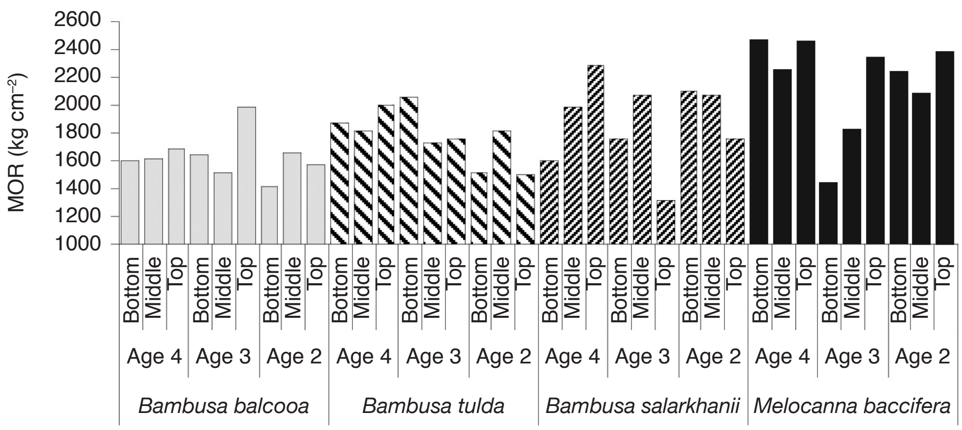

Figure 7 Modulus of rupture (MOR) of four bamboo species at different height positions and ages

region of the country, the major bamboo species include *B. balcooa*, *B. tulda* and *B. salarkhanii*. In some homestead areas, *M. baccifera* is also being cultivated. As their efficient utilization depends on their inherent physical and mechanical properties, some of them were studied. The study revealed that *B. balcooa* has the highest moisture content at green condition. *Melocanna baccifera* had higher density than that of other bamboo species but lower shrinkage in culm wall thickness. Shrinkage in wall thickness and diameter at different height positions were significantly different for each species. Bamboo behaves differently in round and in split forms. In split form, it behaves more like solid wood.

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