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Variation in physical properties of *Artocarpus heterophyllus* Lam. wood grown in Thrissur district, Kerala

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Abstract
The study physical properties of jack wood plays an important role providing its strength and durability and also for its utilization in various aspects. The properties like the colour parameters (L* value, a* value and b* value), texture, moisture content, green specific gravity, oven dry specific gravity and shrinkage (volumetric, tangential and radial) were taken into account. The analysis revealed significant differences between the zones for shrinkage (volumetric, tangential and radial) between three zones while rest of the properties showed non-significant results between the three zones and girth classes within these zones. The strength and durability of the woods obtained from different zones are thus being analysed and the data could be further used for utilization of jack wood.

Keywords: Wood, specific gravity, strength

1. Introduction

Artocarpus heterophyllus Lam. popularly known as jackfruit or Ceylon Jack tree belonging to the family Moraceae is one of the important and commonly found trees in the homegardens of certain parts of India and Bangladesh (Bose, 1985). The place of origin of jack tree is unknown, however it is believed to be indigenous to the rainforests of the Western Ghats (Morton, 1987). It is a medium-sized, evergreen tree that typically attains a height of 8m–25m and a stem diameter of 30cm–80 cm. The canopy shape is usually conical or pyramidal in young trees and becomes spreading and domed in older trees. It is monoecious and both male and female inflorescences are found on the same tree (Bose, 1985; Morton, 1987). The assessment of the timber quality may involve the consideration of a large number of physical, chemical, anatomical and mechanical properties of wood. Though the jackfruit wood has been used extensively, little information is available on its properties. Thus the study of wood physical properties of jackfruit wood is important and very timely for the further effective utilization in future.

2. Materials and Methods

The present study was aimed at the collection trees of *Artocarpus heterophyllus* Lam. from three different zones based on altitudinal classes which are divided into Lowland, Midland and Highland of Thrissur district, Kerala (ENVIS, 2017). The samples were collected from the local markets based on three different girth classes i.e. 30cm-60cm, 60cm-90cm and 90cm-120cm. Three samples of each girth classes from different sites were collected which constitute 27 wood samples. Further studies on wood properties were conducted in the department of Forest Products and Utilization, College of Forestry, Kerala Agricultural University, Vellanikkara. Wood specimens of size 2 cm ×2 cm ×2.5 cm were made out from each sample assessing wood basic density, moisture content and heartwood colour (ISI, 1986).

i) Basic Density and Specific gravity

The basic density of wood is determined by using immersion method. This is the ratio between the dry weights of wood and the green volume of the same wood. Wood specimens of size 2 cm ×2 cm ×2.5 cm were made out from the wood samples collected from the zones. Green volume of the sample was estimated using the immersion method. A container capable of holding the sample was filled with water and placed on a digital balance of precision 0.0001 g. The samples were then carefully sunk in the water, such that the surface water should coincide with the surface of wood. The container should not be completely filled with water. The samples should not contact the sides or bottom of the container, and it should be forced under water with a thin needle.

The samples were then oven dried at 103±2ºC until the weight became constant for the determination of oven dry weight using a precision electronic balance (Shimadzu AUY 220) and were weighed correct to 0.001 g (Plate 4). Basic density (standard specific gravity) of wood specimens were calculated and by dividing it with density of water we get specific gravity of wood.

$$\text{Basic density (g/ cm}^3\text{)} = \frac{\text{Oven dry weight}}{\text{Green volume}}$$

$$\text{Specific gravity} = \frac{\text{Basic density of wood obtained}}{\text{Density of water}}$$

ii) Moisture Content

In order to determine moisture content, the samples were weighed to an accuracy of 0.001 g in a weighing balance (Shimadzu AUY 220) and then dried in a hot air oven at a temperature of 103±2°C till a constant weight. The final weight has been taken as oven dry weight. The moisture per cent of the samples was calculated by using the formula given by Desch and Dinwoodie (1996) [4].

$$\text{Moisture content (\%)} = \frac{\text{Mi} - \text{Mo}}{\text{Mo}} \times 100$$

Where,
M_i = Initial weight of sample (g)
M_o = Oven dried weight of sample (g)

iii) Colour

Colour of the heartwood has been investigated by C.I.E Lab colour system. Heartwood colour variation was quantitatively measured in reflectance mode as CIELAB colour co-ordinates (10° standard observer, D65 standard illuminant) using Hunter Lab Scan XE colorimeter (IWST, Bangalore, Karnataka) (Plate 5). CEILAB L*, a*, b* parameters were measured on each specimen and average value was calculated. In the CIELAB system, the L *axis represents lightness and a* and b* are the chromaticity coordinates (+a* is for red, -a* for green, +b* for yellow, -b* for blue).

iv) Texture

Wood texture describes the relative size as well as the amount of variation in size of the wood cells. It depends upon the size of the cells and its distribution and proportion of the various types of cells. Texture of *Tectona grandis* ranges from medium to coarse and was determined based upon the range of tangential diameters of vessels under four main classes (Peng *et al.*, 1988) [14] as given below:

Texture	**Mean tangential diameter of vessels**		
(a)	Very fine	:	<100 µm
(b)	Fine	:	100-200 µm
(c)	Medium	:	200-300 µm
(d)	Coarse	:	>300 µm

v) Volumetric Shrinkage

To estimate volumetric shrinkage, the specimen was initially weighed in the green condition with a precision of 0.00l g and the volume was determined by immersion method. A suitable vessel, half filled with water, was kept on the pan of a weighing balance and weighed correct to 0.001 g. The specimen was then completely dipped in water by means of a needle and weighed again. Care was taken such that no air bubble stick to the specimen and that the specimen was not touching the side of the vessel. The difference between the two readings is the green volume of the specimen. The specimen was then kept in a hot air oven at 103±2°C until constant weight is attained. After oven-drying, the specimen was again weighed and oven dried volume was determined by immersion as before. The percentage volumetric shrinkage was given by the formula,

$$\text{Volumetric shrinkage (\%)} = \frac{\text{Green volume} - \text{Oven dry volume}}{\text{Green volume}} \times 100$$

vi) Dimensional shrinkage

Dimensional shrinkage includes tangential shrinkage and radial shrinkage. To estimate dimensional shrinkage, the length of the specimen was measured correct to 0.01 cm by means of a digital vernier caliper. Centre and corners of specimen were marked to make subsequent measurements. The specimens were dried in an oven at 103±2ºC until a constant weight is attained. The specimens were then measured finally. The percentage dimensional shrinkage was given by the formula,

$$\text{Dimensional shrinkage (\%)} = \frac{\text{Initial length} - \text{Oven dry length}}{\text{Initial length}} \times 100$$

3. Results and Discussion

3.1 Colour and Texture

Wood is a natural and one of the most valuable raw materials with variations in properties of texture, colour, density and strength have been used for many purposes (Ates *et al.*, 2009). Colour is a crucial factor in hardwood appearance. It is often considered important in assessing aesthetic value of the wood product. Colour of the wood samples of jackfruit tree collected from different sites was taken to laboratory of Institute of Wood Science and Technology (IWST), Bangalore, Karnataka and variation was quantitatively measured in reflectance mode as CIELAB colour co-ordinates (10° standard observer, D65 standard illuminant) using Hunter Lab Scan XE colorimeter.

The table 1 shows the values for L* value, the highest value was found for 60 cm -90 cm girth class and lowest value for 90 cm -120 cm girth class *i.e.* 56.69. The highest zonal mean value of 60.35 was found for lowland and the lowest zonal mean value for midland *i.e.* 57.87. The analysis on the current data showed no significant variation between the zones and also girth within the zones. The importance of wood properties has been recognized throughout the history, as native people globally understood the unique properties of different tree species and used a particular tree species best suited for specific applications. Therefore, studies on wood properties help in promoting proper utilization of the wood for multiple applications. The colour variation within a species is influenced by many natural factors *viz.*, soil types, minerals, water levels, available sunlight, temperature and genetic composition.

Table 1: Variation in Colour parameter (L*) of *Artocarpus heterophyllus* Lam. wood from three different zones

Girth classes	**Zones**		
	Lowland	**Midland**	**Highland**
30cm-60cm	59.78 (2.91)	58.31 (2.97)	59.27 (1.46)
60cm-90cm	59.96 (4.18)	58.61 (6.41)	61.44 (2.46)
90cm-120cm	61.32 (1.26)	56.69 (6.81)	57.98 (4.52)
Zone mean	60.35 ^{a}	57.87 ^{a}	59.56^a
F value	2.98 ^{ns} (Zones)	0.29 ^{ns} (Girth classes within zones)	

*Value in parenthesis is standard deviation; (*) significant at 0.05 level; (ns) non significant at 0.05 level

The results from the study of Haygreen and Bowyer (1982) [6] had shown variation in colour of different coniferous species from different locations which may be due to natural chemical extractives found in the wood. The hues produced through these deposits cover a wide range and are traceable to four spectral colours *viz*., red, orange, yellow and violet. Other natural influences, such as fungi, may also contribute to some colour variations. The colour characteristics of wood depend on the chemical components that interact with light. Typical molecules having chromophore bindings in wood are lignin, below the wavelength of 500 nm, and phenolic extractives such as tannins, flavonoids, stilbenes and quinines, above the wavelength of 500 nm (Hon and Minemura, 2001) [7]. Within a species wood colour can vary due to the genetic factors (Rink and Phelps, 1989 and Mosedale *et al.*, 1996) [17, 12] and environmental conditions (Phelps *et al.,* 1982; Wilkins and Stamp, 1990) [15, 22].

Table 2 shows the data for values for a* value for which the wood belongs to 90 cm -120 cm girth class has the highest value 11.81 and the lowest value 9.69 for 60 cm -90 cm girth class . When taking the zone mean, the highest value is for wood belongs to midland *i.e.* 11.14 and the lowest value of 10.20 for lowland. There was no significant variation observed between the zones and girth within zones.

Table 2: Variation in Colour parameter (a*) of *Artocarpus heterophyllus* Lam. wood from three different zones

Girth classes	Zones		
	Lowland	**Midland**	**Highland**
30cm-60cm	9.83 (0.43)	10.49 (1.19)	10.85 (0.29)
60cm-90cm	10.68 (0.42)	11.19 (1.64)	9.69 (0.66)
90cm-120cm	10.08 (0.18)	11.75 (1.39)	11.81 (1.49)
Zone mean	10.20 a	11.14 a	10.78 a
F value	1.21ns (Zones)	1.66 ns (Girth classes within zones)	

Value in parenthesis is standard deviation; (*) significant at 0.05 level; (ns) non significant at 0.05 level

The b* value from the table 3 shows the highest value 41.62 for the wood which belongs to 90 cm -120 cm girth class from lowland and the lowest for 90 cm -120 cm girth class *i.e.* 37.07 which belongs to highland. When it comes to the zone mean value, the highest value 39.97 was found highest for the wood which belonged to lowland and the lowest zonal mean value for highland wood *i.e.* 38.73. There was no significant variation observed between the zones and girth within zones. Hon and Minemura (2001) [7] have shown that the interaction of chemical components with light is responsible for colour characteristics of wood. They have also obtained that lignin is the chromophore binding molecules in wood along with phenolic extractives such as tannin, flavonoids, quinines etc. In the present study, heartwood colour showed no significant variation across the zones of Thrissur.

Table 3: Variation in Colour parameter (b*) of *Artocarpus heterophyllus* Lam. wood from three different zones

Girth classes	Zones		
	Lowland	**Midland**	**Highland**
30cm-60cm	40.08 (1.62)	38.90 (3.96)	38.71 (2.53)
60cm-90cm	38.23 (4.15)	38.80 (3.29)	40.42 (2.78)
90cm-120cm	41.62 (2.44)	40.02 (2.23)	37.07 (5.32)
Zone mean	39.97a	39.25a	38.73a
F value	0.57 ns (Zones)	0.56 ns (Girth classes within zones)	

*Value in parenthesis is standard deviation; (*) significant at 0.05 level; (ns) non significant at 0.05 level

This can be comparable to the findings by Thulasidas *et al.* (2006) [20] who observed that no significant difference existed between teak samples collected from dry and moist area. But our finding is contrary to information given by Knust (2009) [8] that there was significant difference of L*, a* and b* value across the agro-ecological regions of Ghana. This difference can be attributed to geographical locations and soil properties of the two research sites.

In-significant variation in wood properties contributed to genetic factors as wood colour within species varies due to genetic factors (Rink and Phelps, 1989; Mosedale *et al*., 1996) [17, 12]. Tadashi *et al*. (2003) showed that teak wood colour is darker in wetter region than drier area. Knust (2009) [8] also explained that soil properties are associated with wood colour of teak independent from effects of tree age as observed by Nelson *et al*. (1969) [13] for walnut wood. The fact behind this was explained by Knust (2009) [8] that availability of more soil minerals to wood that eventually interact with its chomatophores in such a way as to absorb more light, thus reflecting less light and hence the wood appearing darker.

Table 4 shows the texture that has been observed from every wood which was procured from different zones. All the wood samples from the different girth classes within different zones had the medium texture wood.

Table 4: Variation in texture of *Artocarpus heterophyllus* Lam. wood from three different zones

Girth classes	Zones		
	Lowland	**Midland**	**Highland**
30cm-60cm	Medium	Medium	Medium
60cm-90cm	Medium	Medium	Medium
90cm-120cm	Medium	Medium	Medium

Safdari *et al.* (2008) [18] identified and studied the important commercial wood species *Fagus orientalis, Acer insigne, Carpinus betulus, Alnus glutinosa, Diospyros lotus, Juglan regia, Tilia rubra, Sorbus torminalis, Prunus avium, Parrotia percia, Ulmus glabra, Quercus castaneaefolia, Gledistschia caspica* and *Fraxinus excelsior* in Iran based on the texture, colour and vessel arrangement with presence or absence of tyloses. Similarly, Toong *et al.* (2014) established a predictive relationship between the material properties and anatomical characteristics of common commercial Malaysian timbers. They studied relationship of anatomical characteristics with wood texture, porosity, density, radial shrinkage, modulus of elasticity and compression parallel to grain.

3.2 Moisture content (%)

Wood is hygroscopic in nature and extent of its hygroscopicity depends upon the cellular components of wood. The water in wood is held in cellular cavities and cell wall. The water in cell wall is of more concern as it influences various wood properties including shrinkage and swelling. The moisture content and maximum moisture content in living trees vary by species and also due to sapwood and heartwood contents. The presence of moisture in wood makes it dimensionally unstable and it also indicate the degree of porosity in wood. The data related to moisture content of jackfruit wood collected from different sites are presented in Table 5. The maximum moisture content of 44.55% was observed for wooden samples collected from lowland which belongs to 60 cm -90 cm girth class and the minimum moisture content 35.65% was found in sample procured from midland which belongs to 30 cm -60 cm. The highest zonal mean value of 41.79% was observed for wood procured from lowland and the lowest zonal mean value for highland *i.e.* 38.89%. There was no significant variation observed between the zones and girth within zones.

Table 5: Variation in moisture content (%) of *Artocarpus heterophyllus* Lam. wood from three different zones

Girth classes	Zones		
	Lowland	Midland	Highland
30cm-60cm	40.15	35.65	37.22
60cm-90cm	44.55	41.63	41.71
90cm-120cm	40.68	40.20	37.75
Zone mean	41.79 [a]	39.16 [a]	38.89 [a]
F value	1.72 [ns] (Zones)	0.15 [ns] (Girth classes within zones)	

Value in parenthesis is standard deviation; (*) significant at 0.05 level; (ns) non significant at 0.05 level

Wood moisture generally vary within stems, commonly peaking towards the outer edges in the radial direction and declining toward the heartwood, leading to different moisture contents between heartwood and sapwood (Raczkowski *et al*., 2000; Spicer and Gartner, 2001) [16, 19]. The moisture content variables have shown significant variations among core samples collected from different populations of *Dipterocarpus indicus* (Nageeb *et al*., 2010). The similar results have been reported by Sharma and Sharma (2005) in *Robinia pseudoacacia* and Raj *et al.* (2010) in Chir pine. The studies by Sunny *et al.,* (2019) on wood properties of *Dalbergia sissoo* found that maximum moisture content of (20.17%) was observed in the wood samples of Nalagarh site, highest maximum moisture content (68.33%) found in the samples from Nalagarh site.

Tsoumis (1991) [21] showed that the equilibrium moisture content of the wood varies according to location, as the temperature and relative humidity of air varies. Brough *et al.* (1986) [3] have reported that the moisture content of wood is probably affected by the habitat. The variations in moisture content could be attributed to environmental factors (variation in climate, site quality, competition among individual trees), genetic factors and the interaction between both. They also observed that the wood is hygroscopic in nature, hence it tends to absorb water from the surrounding environment. The hygroscopicity of wood depends upon the cellular composition of wood *i.e*., different types of cells, their cell wall thickness and lumen size. The moisture content may change with season and climate and found variations among populations for density, specific gravity as well as moisture content which may be influenced by the site factors (Suzuki, 1999). The present results are supported by the findings of Lekha (1999) [10] in *Acacia catechu* and Kumar (1996) in *Eucalyptus teriticornis*. Enayati *et al.* (2010) while studying the equilibrium moisture content of wood in the neighboring countries of Iran have also reported similar results.

3.3 Specific gravity

Specific gravity and basic density are the oldest and most widely used criterion for depicting the strength of wood and is said to be influenced by moisture, structure, extractives, and chemical composition (Tsoumis, 1991) [21]. Specific gravity of wood is a measure of the amount of structural material a tree species allocates to provide support and strength. It is a most important wood characteristic because its knowledge allows the prediction of greater number of properties than any other trait (Zobel and Talbert, 1984; Bowyer and Smith, 1998). Some wood properties that are closely related to wood's specific gravity are strength, dimensional stability, ability to retain paint, fiber yield per unit volume, suitability for making particleboard and related wood composite materials and suitability as a raw material for making paper (Bowyer and Smith, 1998).

Table 6: Variation in green specific gravity of *Artocarpus heterophyllus* Lam. wood from three different zones

Girth classes	Zones		
	Lowland	Midland	Highland
30cm-60cm	0.51 (0.04)	0.60 (0.08)	0.53 (0.06)
60cm-90cm	0.47 (0.06)	0.56 (0.06)	0.53 (0.04)
90cm-120cm	0.57 (0.06)	0.58 (0.04)	0.54 (0.07)
Zone mean	0.52 [a]	0.58 [a]	0.53 [a]
F value	3.33 [ns] (Zones)	0.83 [ns] (Girth classes within zones)	

Value in parenthesis is standard deviation; (*) significant at 0.05 level; (ns) non significant at 0.05 level

Specific gravity and density is one of the important characteristics for wood quality evaluation. It has a tremendous effect on different wood physiological, ecological as well as morphological characteristics of the wood (Jerome *et al*., 2006). It can be taken as a crucial property and has a great effect on both solid and fibrous wood products (Bhat, 1985). Wanneng *et al.* (2014) also observed similar results in 10, 15, 20 and, 25 years old teak of different diameter classes. However, Bhat (1998) showed that mean specific gravity varied significantly between juvenile wood and mature wood of 65 years old teak trees grown in three locations in Kerala which is contrary to our findings.

Table 7: Variation in oven dry specific gravity of *Artocarpus heterophyllus* Lam. wood from three different zones

Girth classes	Zones		
	Lowland	Midland	Highland
30cm-60cm	0.54 (0.03)	0.57 (0.01)	0.57 (0.02)
60cm-90cm	0.57 (0.01)	0.55 (0.01)	0.54 (0.03)
90cm-120cm	0.57 (0.02)	0.58 (0.03)	0.55 (0.03)
Zone mean	0.56 [a]	0.57 [a]	0.56 [a]
F value	0.00 [ns] (Zones)	1.94 [ns] (Girth classes within zones)	

Value in parenthesis is standard deviation value; (*) significant at 0.05 level; (ns) non significant at 0.05 level

The different results obtained in the present study attributed to indistinct climatic variation and age effect of the sampled trees across three zones of Thrissur district, Kerala. As density is one of the most heritable characters. As density is one of the most heritable characters in wood, genotypic effect may be one of the reasons. From the table 6, the highest green specific gravity 0.60 was found for the midland which belongs to 30 cm -60 cm girth class and the lowest value for 60 cm -90 cm girth class which belongs to lowland *i.e.* 0.47. The highest zonal mean value for green specific gravity was observed for 0.58 and lowest zonal mean value for lowland *i.e.* 0.52. Analysis of data revealed that there was no significant variation present across three zones as well as between girth classes within zones of Thrissur district of Kerala.

Wood specific gravity is considered as one of the most informative property about the physico-mechanical behavior of wood used for timber, pulp and paper production (Lima *et al*., 2000; Raymond and Muneri, 2001) [10]. The average values for heartwood specific gravity was 10-15 per cent greater than those for sapwood and greater values for heartwood are due to accumulations of polyphenols and other extractives, which are not normally found in sapwood (Hiller *et al.* 1972). Significant variation in specific gravity of wood species from different market locations may be due to various factors, including the geographic location of trees and moisture content which varies by species, d.b.h., age, and stem position (Miles and Smith, 2009). Purkayastha *et al.* (1980); Grzeskowiak *et al.* (2000) and Rao *et al.* (2002, 2003) have reported that the different species and sites have a significant impact on wood specific gravity. Variation in wood traits, *viz*., specific gravity, moisture content and tracheid length has been reported at individual tree level, within individuals of a population and amongst sites or populations of a species.

Table 7 shows the data for oven dry specific gravity, the maximum value of 0.58 was observed for 90 cm -120 cm girth class which belongs to midland. The minimum value for 30 cm -60 cm girth class wood which belongs to lowland and 60 cm -90 cm girth class of highland *i.e.* 0.54. The zone mean value shows the maximum for midland *i.e.* 0.57 and the minimum for both lowland and highland. The data shows no significant variation across three zones as well as between girth classes within zones of Thrissur district of Kerala.

Morales (1987) have found highly significant differences in specific gravity between the 220 species from Mexican forests. By analyzing above table of sapwood and heartwood density, it has been observed that provenances with low elevations have more specific gravity as compared to higher elevation. The most probable reason for this is stressed conditions and variable site factors. Similar findings have been reported by Kennedy and Smith (1959) in *Populus trichocarpa*, as the site changed from good to poor, the specific gravity has shown increase from 0.331 to 0.383. Awang and Taylor (1993) have reported that values obtained for specific gravity at drier sites (0.6) were substantially higher than those at wetter sites (0.4) in *Acacia mangium.* Zobel and Buijtenen (1989) have also compared specific gravity in Sitka spruce of North and south provenances and found that faster growing more southerly Sitka spruce provenances produced denser timber compared to slow growing more northerly provenances. Cox *et al.* (2001) have reported that specific gravity is heritable and the differences between wood are due to the genetic makeup and have found significant variations in the specific gravity of *Shorea acuminata, S. ovalis, S. leprosula* and *Dryobalanops aromatica.*

Similarly Martinez *et al.* (2009) have recorded that wood density was more significantly correlated with precipitation and aridity than temperature. As high wood density is achieved through reductions in cell size and increase in the proportion of wall relative to lumen and density is independent of vessel traits. Nageeb *et al*. (2010) have shown significant variations in wood density of core samples collected from *Dipterocarpus indicus* of different populations. Igartual *et al.* (2003) have studied basic density at breast height of 35-year-old *Eucalyptus globulus* for parameter prediction of the whole tree and Wahlgren and Fassnacht (1959) have suggested that increment cores extracted at breast height could be safely used to estimate whole-tree density. Dhillon and Sidhu (2007) have measured specific gravity (at d.b.h) and noticed significant differences with respect to locations.

3.4 Shrinkage (%)

The wood cell wall is mainly composed of polymers with hydroxyl and other oxygen-containing groups that attract moisture through hydrogen bonding. Swelling increases until the cell wall is saturated with water. This point is called the fiber saturation point, and ranges from 20 to 50 per cent in weight gain (Feist and Tarkow, 1967). Water, beyond this point is free water in the void structure and does not contribute to further swelling. This process is reversible, and wood shrinks as it loses moisture below the fiber saturation point. Sorption is combined term for swelling and shrinkage. Many thermodynamic models have been used to describe moisture sorption in wood below fiber saturation point. Although these models differ in their parameters and physical interpretation, they all divide water into two types, tightly bound water and less tightly bound water (Simpson, 1980). The wood starts shrinking when it is dried below fibre saturation point. In the present work the maximum shrinkage (4.48%) has been observed in tangential plane. The significant variation has been recorded among the species w.r.t. shrinkage. Among three species, the maximum shrinkage in all planes has been found in *Pinus roxburghii* Sargent. The minimum shrinkage in longitudinal, radial and tangential planes has been observed in *Bombax ceiba i.e.*, 0.9%, 3.64% and 3.22% respectively. Among treatments lowest shrinkage was observed at 1.50% concentration of *Acorus calamus* L. rhizome extract. The shrinkage in longitudinal plane is negligible as compared to the radial and tangential planes. Tangential shrinkage is always higher and average of radial shrinkage values range from about 2 to 8 per cent (Hoadley, 1998). Wood high in water soluble extractives were found to be shrink less due to the bulking effect of extractive which left in the cell walls. (Stamm *et al.*, 1946).

Table 8: Variation in volumetric shrinkage (%) of *Artocarpus heterophyllus* Lam. wood from three different zones

Girth classes	Zones		
	Lowland	Midland	Highland
30cm-60cm	3.93 (1.97)	4.78 (2.17)	3.91 (1.98)
60cm-90cm	3.63 (1.90)	5.38 (2.32)	3.82 (1.94)
90cm-120cm	4.26 (2.06)	4.79 (2.18)	3.47 (1.84)
Zone mean	3.94^{a}	4.98^{b}	3.73^{a}
F value	13.22* (Zones)	0.29^{ns} (Girth classes within zones)	

Value in parenthesis is square root transformed value; (*) significant at 0.05 level; (ns) non significant at 0.05 level

The data in the table 8 shows the observations for volumetric shrinkage of the respective girth classes within the three zones. The highest value was observed for the wood which belongs to 60 cm -90 cm girth class of midland *i.e.* 5.38% and the lowest value 3.47% was observed for 90 cm -120 cm girth class of highland. The maximum value of zonal mean of 4.98% was observed for midland and the lowest zonal mean value for highland *i.e.* 3.73%. Analysis of the data revealed significant variation between zones and not between girth classes within zone. Wu *et al.*, (2012) also reported that the eucalyptus wood impregnated with chemicals has significant decrease in shrinkage in volume as compared to untreated wood. Similar findings have been observed by Gupta (2012) and Devi (2013). Bowyer *et al*., (2003); Pang (2002) and Walker (2006) have studied that in the transverse direction, shrinkage or swelling is more in the tangential than in the radial direction by a factor of 1.5-3. This is mainly due to the anatomical features of wood such as the presence of ray tissues, frequent pitting on radial walls, microfibril arrangements and earlywood - latewood interaction.

Table 9: Variation in tangential shrinkage (%) of *Artocarpus heterophyllus* Lam. wood from three different zones

Girth classes	Zones		
	Lowland	Midland	Highland
30cm-60cm	3.90 (1.97)	6.45 (2.53)	3.48 (1.84)
60cm-90cm	3.18 (1.77)	4.73 (2.14)	4.31 (2.02)
90cm-120cm	3.16 (1.76)	4.77 (2.16)	3.31 (1.80)
Zone mean	3.41 [a]	5.32 [b]	3.70 [a]
F value	7.00* (Zones)	0.58 [ns] (Girth classes within zones)	

Value in parenthesis is square root transformed value; (*) significant at 0.05 level; (ns) non significant at 0.05 level

The coefficient (ratio of tangential and radial shrinkage or swelling) becomes smaller with increase in density (Kollmann and Cote, 1984). The negligible longitudinal wood swelling is accounted for the almost parallel orientation of the fibre in the longitudinal direction of wood. Boiciuc and Petrician (1970) also found that removal of extractives greatly increased shrinkage and swelling of wood. They suggested that the reduction in shrinkage and swelling was proportional to the space occupied by the extractives in the cell walls. Longitudinal wood swelling is very negligible. The greater swelling in the tangential direction than in the radial is due to the greater amount of total wood substance in the tangential direction and also due to the fact that ray cells, which extend radially in the tree tend to restrain dimension changes (Stamm, 1964).

Table 10: Variation in radial shrinkage (%) of *Artocarpus heterophyllus* Lam. wood from three different zones

Girth classes	Zones		
	Lowland	Midland	Highland
30cm-60cm	2.45 (1.56)	3.95 (1.98)	2.18 (1.46)
60cm-90cm	2.06 (1.43)	3.42 (1.81)	2.07 (1.43)
90cm-120cm	1.98 (1.39)	2.96 (1.71)	2.15 (1.45)
Zone mean	2.17 [a]	3.44 [b]	2.13 [a]
F value	16.19* (Zones)	0.38 [ns] (Girth classes within zones)	

Value in parenthesis is square root transformed value; (*) significant at 0.05 level; (ns) non significant at 0.05 level

Table 9 shows the observations for tangential shrinkage for the three zones in which the maximum value of 6.45% was recorded for the wood samples of 30 cm -60 cm girth class from midland and the minimum value for 90 cm -120 cm *i.e.* 3.16% from lowland. The highest zonal mean value was observed for midland *i.e.* 5.32% and the lowest zonal mean value 3.41% for lowland. The highest radial shrinkage was observed for the wood samples procured from midland *i.e.* 3.95% which belongs to 30 cm -60 cm girth class and the lowest value for the wood collected from lowland which belongs to 90 cm -120 cm girth class *i.e.* 1.98% (Table 10). The highest zonal mean value of 3.44% was recorded for midland and the lowest zonal mean value for highland *i.e.* 2.13%. For both tangential and radial shrinkage, significant variation was observed for the zones and no variation for girth classes within the zones.

4. Conclusion

The study on these wood physical parameters revealed that the strength and durability of wood is closely depend on these properties. The variation of these wood parameters in the different zones of Thrissur helps the concern person to select and use the timber from the respective species and utilize for desired purposes. Except for shrinkage (volumetric, tangential, radial) which showed significant variation between zones, no significant variation was observed for rest of wood physical properties *i.e.* colour, specific gravity, moisture content and texture between zones or between girth classes within zones.

5. References

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