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VARIATION IN ANISOTROPIC SHRINKAGE OF FIVE TROPICAL DIFFUSE-POROUS HARDWOOD SPECIES

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ABSTRACT

Wood is a complex biological material and is hygroscopic in nature. Since it is anisotropic in nature, shrinkage properties of the wood changes with respect to its different structural directions, resulting in dimensional instability which is problematic in effective utility and consumption of the wood. Current study was undertaken to determine the relationship between basic density and moisture content of wood as well as the dimensional changes in terms of volume along with its three structural wood direction (longitudinal, radial and tangential) of the five hardwood species viz., *Acacia auriculiformis*, *Ailanthus excelsa*, *Casuarina equisetifolia*, *Eucalyptus tereticornis* and *Melia dubia*. Results revealed that all the species showed different shrinkage along different structural directions. Tangential shrinkage was almost twice the shrinkage observed in radial direction, whereas shrinkage along longitudinal direction was negligible for all the species with less than 1% shrinkage. *Casuarina equisetifolia* showed maximum shrinkage along both tangential (8.37%) and radial direction (5.49 %), whereas *Ailanthus excelsa* exhibited minimum shrinkage (4.17%) in tangential direction and *Acacia auriculiformis* exhibited minimum shrinkage (2.06%) in radial direction. Basic density exhibited significant negative correlation with the moisture content at 1% significant level. Basic density exhibited strong positive correlation with shrinkage in both in radial and tangential directions.

Key words : Anisotropic Shrinkage, *Acacia auriculiformis*, *Ailanthus excelsa*, *Casuarina equisetifolia*, *Eucalyptus tereticornis* and *Melia dubia*.

Introduction

Wood is a complex biological material. It is porous and hygroscopic in nature. As a result, it contains water and air along with wood materials. Wood loses or gains water based on the environmental conditions to which it is exposed (Walker, 2006). It is dimensionally stable when the equilibrium moisture content of a particular place is equal to the fibre saturation point (FSP) of wood. But below the FSP, wood gains or loses moisture, as a result volume of the wood changes. This gain or loss of moisture from the wood leads to swelling and shrinkage resulting in dimensional instability (Glass and Zelinka, 2021). The change in the dimensions due to change in the moisture content of the wood is of great practical importance as it directly affects both seasoning and utility of the wood

such as twisting and cracking, dislodging of joints etc. (Ajuziogu *et al.*, 2020).

Wood is an anisotropic material, means the properties of the wood changes with different structural directions (radial, tangential and longitudinal). As a result, shrinkage of the wood differs among different directions. In normal wood, the longitudinal shrinkage is less than transverse shrinkage (radial and tangential) and is usually negligible. Tangential shrinkage is about 1.5 to 2.5 times that of the radial shrinkage (Walker, 2006). There are several theories regarding the unequal shrinkage between radial and tangential direction. Microfibril angle theory given by Barber and Meylon (1964) denotes that the microfibrils in the radial walls are less uniformly arranged and on average lie at larger angles than those in the tangential

walls resulting in less shrinkage. Ray tissue theory assumes that ray tissue shrinks less in the radial direction than the longitudinal direction leading to less shrinkage in radial direction (Walker, 2006).

As wood dimensional instability can cause so many problems in utility and consumption of wood hence, more investigations are needed into this matter. With this view, the present study was carried out to understand the variation in anisotropic shrinkage along three principal directions of wood and its relationship among basic density, moisture content of the five diffuse-porous hardwood species viz., *Acacia auriculiformis*, *Ailanthus excelsa*, *Casuarina equisetifolia*, *Eucalyptus tereticornis* and *Melia dubia* as these hardwoods are used for various end products in solid wood, composite wood industries and packing cases, where dimensional stability are required.

Materials and Methods

Study location

The present study was carried out on the 4-year-old five different hardwood species such as *Acacia auriculiformis*, *Ailanthus excelsa*, *Casuarina equisetifolia*, *Eucalyptus tereticornis* and *Melia dubia* planted at the multispecies plot, near Arboretum at Navsari Agricultural University, Navsari. The experiment was conducted in Forest Products and Utilization Laboratory, College of Forestry, Navsari Agricultural University, Navsari, Gujarat.

Preparation of wood specimen

Total five trees from each hardwood species were felled in 2022 and converted into 3 m logs from the ground. Two wooden discs from each tree species were collected at the breast height and diameter at the breast height (DBH), bark thickness, wood and bark percentage were measured (Table 1). Blocks of 2 × 2 cm in cross-section and 2.5 cm in length were prepared for determination of moisture content, while blocks of 2 × 2 cm in cross-section and 6 cm in length were prepared for estimation of wood density and volumetric shrinkage. One wooden block per tree was prepared for each type of test. Thus, total twenty-five wooden blocks from five hardwood species were selected for each type of test.

Data collection

Wooden blocks were soaked in the tap water for 72 hrs. to get the green weight and the green volume of the block. The soaked blocks were then oven dried at 103 ± 2°C to obtain oven dried weight and oven dried volume. Volume of the blocks were measured by water displacement method and weight of the blocks were

recorded with the help of weighing balance for further analysis

Determination of moisture content

Moisture content of the wooden blocks was determined by oven-dry method using the following formula

$$\text{Moisture content (\%)} = \frac{\text{Green weight (g)} - \text{Ovendry weight (g)}}{\text{Ovendry weight (g)}} \times 100$$

Determination of basic density

Basic density of the wooden blocks was determined by the following formula

$$\text{Basic density (gcm}^{-3}\text{)} = \frac{\text{Ovendry weight (g)}}{\text{Green volume (cm}^3\text{)}}$$

Determination of volumetric shrinkage

Volumetric shrinkage was determined using the formula

$$\text{Volumetric shrinkage (\%)} = \frac{\text{Green volume (cm}^3\text{)} - \text{Ovendry volume (cm}^3\text{)}}{\text{Green volume (cm}^3\text{)}} \times 100$$

Determination of radial, tangential and longitudinal shrinkage

Radial, tangential and longitudinal lengths of water soaked wooden blocks and oven dried wooden blocks were measured using Vernier calliper. The change in the dimension along the three directions were determined by subtracting water-soaked wooden block length from oven dried length. Radial, tangential and longitudinal shrinkage were determined using the formula

$$\text{Shrinkage (\%)} = \frac{\text{Dimensional change after water soaking (mm)}}{\text{Length after water soaking (mm)}} \times 100$$

Statistical analysis

The data collected from the study was analysed using a computer software OPSTAT developed by CCU-HAU Hisar. Data was analysed using analysis of variance (ANOVA) at a 99% significance level ($p \leq 0.01$). Statistical comparisons among the groups were made using Duncan New Multiple Range Test (DNMRT). Pearson correlation was used for correlation determination.

Results and Discussion

Variation in growth parameters of tree species

Variation in growth parameters of the five selected diffuse-porous hardwood species were investigated and

Table 1 : Variation in growth parameters of five hardwood tree species.

Tree species	DBH (cm)	Tree height (m)	Bark thickness (mm)	Bark percentage	Wood percentage
<i>Acacia auriculiformis</i>	10.14 ± 1.19	12.86 ± 1.61	4.0 ± 0.32	16.32 ± 3.02	83.68 ± 3.02
<i>Ailanthus excelsa</i>	8.40 ± 1.98	6.90 ± 0.89	4.2 ± 0.37	24.90 ± 7.40	75.10 ± 7.40
<i>Casaurina equisetifolia</i>	10.47 ± 1.57	12.76 ± 1.61	3.6 ± 0.25	14.57 ± 2.46	85.43 ± 2.46
<i>Eucalyptus tereticornis</i>	9.77 ± .66	11.56 ± 1.88	3.2 ± 0.26	14.06 ± 2.23	85.94 ± 2.23
<i>Melia dubia</i>	9.29 ± 1.15	8.42 ± 0.50	3.9 ± 0.46	16.99 ± 2.58	83.01 ± 2.58
S.Em (±)	1.54	1.40	0.34	4.04	4.04
CD	NS	4.16	NS	NS	NS

the results were presented in Table 1. It was revealed that the tree height of five selected tree species varied significantly, while DBH, bark thickness, bark percentage and wood percentage showed non-significant variation. The tree height ranged from 6.9 to 12.86 m. The minimum tree height was recorded in *A. excelsa* and maximum was recorded in *A. auriculiformis*.

Variation in basic density of the hardwood species

Basic density was found to be highly different among the different hardwood species (Table 2). The highest basic density was found in *Casuarina equisetifolia* (0.726 g/cc) followed by *Eucalyptus tereticornis* (0.528 g/cc), *Acacia auriculiformis* (0.508 g/cc), *Melia dubia* (0.453 g/cc) and the lowest was found to be in *Ailanthus excelsa* (0.321 g/cc). Sarkar *et al.* (2021) and Hounlonon *et al.* (2021) reported higher densities for *C. equisetifolia* (0.947 g/cm³) grown in Bangladesh and 8–10-year-old individuals of *A. auriculiformis* (0.617–0.825 g/cm³) grown in Benin, respectively, whereas Saravanan *et al.* (2014) reported similar density for 4-year-old *M. dubia* (485.60 kg/m³) grown in Karnataka, India. Low basic density was recorded by Patel *et al.* (2022) for 5 years old *A. excelsa* tree grown in Navsari, Gujarat which was similar to the present study.

Variation in anisotropic shrinkage of the hardwood species

The basic density and anisotropic shrinkage are related to each other. The shrinkage of wood in the three principle directions is different. Tangential shrinkage is generally 1.5 to 2.5 times that of radial shrinkage, while longitudinal shrinkage is negligible (Walker, 2006). The basic density and anisotropic shrinkage of five hardwood tree species were presented in Table 2.

Radial shrinkage

Shrinkage in the radial direction was found to be maximum in *C. equisetifolia* (5.49%), whereas the minimum value for shrinkage was found in *A.*

auriculiformis (2.06%). *E. tereticornis* showed the second highest radial shrinkage (4.28%), followed by *M. dubia* (3.17%) and *A. excelsa* (2.26%). Chowdhary *et al.* (2007) reported similar radial shrinkage for 25-year-old *C. equisetifolia* (6%) at butt end, whereas Sahri *et al.* (1998) and Shukla (2023) reported lower value for 6-year-old *A. auriculiformis* (1.91%) and *M. dubia* (2.82%), respectively. Poonia and Tripathi (2016) reported higher value for 15-year-old *E. tereticornis* (5.31%) which was similar to the present study.

Tangential shrinkage

Similar to radial shrinkage, *C. equisetifolia* had the highest shrinkage (8.37%) in tangential direction. However, the minimum tangential shrinkage (4.17%) was found in *A. excelsa*. *E. tereticornis* had the second highest tangential shrinkage (6.29%) followed by *A. auriculiformis* (5.09%) and *M. dubia* (4.73%). Chowdhary *et al.* (2007) and Poonia and Tripathi (2016) reported higher tangential shrinkages for 25-year-old *C. equisetifolia* (10%) at butt end and 15-year-old *E. tereticornis* (8.12%). However, Sahri *et al.* (1998) and Shukla (2023) reported lower values for 6-year-old *A. auriculiformis* (3.26%) and *M. dubia* (3.03%). The lowest tangential shrinkage (4.17%) was recorded in *Ailanthus excelsa*.

Longitudinal shrinkage

Shrinkage in longitudinal direction was negligible compared to radial and tangential direction. All five hardwoods exhibited less than 1% of shrinkage which were non significantly different (Table 2).

Volumetric shrinkage

Volumetric shrinkage is usually sum of the radial shrinkage and tangential shrinkage. Volumetric shrinkage (14.24%), in terms of volume of the block was found to be maximum in *C. equisetifolia* followed by *E. tereticornis* (11.98%), *A. excelsa* (8.74 %), *M. dubia* (8.60%). *A. auriculiformis* exhibited the lowest shrinkage

Table 2 : Variation in basic density and anisotropic shrinkage of the hardwood species.

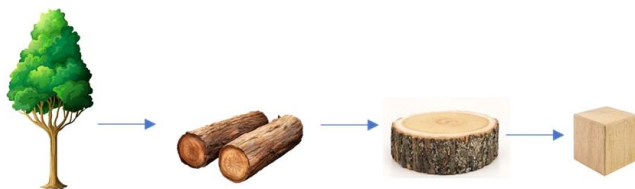
Species name	Basic Density (g/cc)	Shrinkage (%)			
		Radial	Tangential	Longitudinal	Volumetric
<i>Acacia auriculiformis</i>	0.508 ^{bc}	2.06±0.37 ^c	5.09±0.31 ^{bc}	0.80±0.30 ^a	6.97±0.36 ^c
<i>Ailanthus excelsa</i>	0.321 ^d	2.26±0.48 ^c	4.17±0.23 ^c	0.66±0.23 ^a	8.74±1.69 ^{bc}
<i>Casaurina equisetifolia</i>	0.726 ^a	5.49±0.65 ^a	8.37±0.77 ^a	0.76±0.74 ^a	14.24±0.49 ^a
<i>Eucalyptus tereticornis</i>	0.528 ^b	4.28±0.74 ^{ab}	6.29±0.53 ^b	0.42±0.39 ^a	11.98±0.33 ^{ab}
<i>Melia dubia</i>	0.453 ^c	3.17±0.19 ^{bc}	4.73±0.90 ^{bc}	0.58±0.25 ^a	8.60±1.91 ^{bc}

Note: The means with different letters as superscripts within each column are significant ($P < 0.05$). The means with same letters or having common letter (s) within each column are not significantly different.

Table 3 : Correlation between basic density and Shrinkage.

Shrinkage				
	Basic Density (g/cc)	Radial (%)	Tangential (%)	Longitudinal (%)
Basic Density (g/cc)	1.000**	0.689**	0.772**	0.067 ^{NS}
Radial (%)	0.689**	1.000**	0.727**	-0.174 ^{NS}
Tangential (%)	0.772**	0.727**	1.000**	-0.055 ^{NS}
Longitudinal (%)	0.067 ^{NS}	-0.174 ^{NS}	-0.055 ^{NS}	1.000**

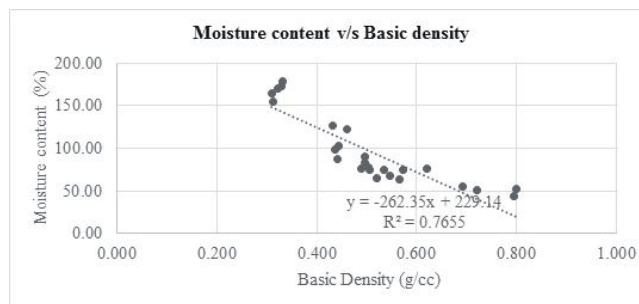
Note: ** - Correlation is significant at the 1% level of significance.

**Fig. 1 :** Diagrammatic representation of preparation of the wood specimen.

(6.97%). Sangeetha *et al.* (2018) recorded higher volumetric shrinkage for *C. equisetifolia* (17.02%) and similar value for *E. tereticornis* (11.90%). In contrast, Poonia and Tripathi (2016) reported lower values for 15-year-old *E. tereticornis* (9.18%). Shukla (2023) reported lower value in *M. dubia* (6.44%). Shukla *et al.* (2007) observed higher volumetric shrinkage for 8-year-old *A. auriculiformis* (7.84%). The changes in volumetric shrinkage is due to change in the basic density of the wood of different ages. Dense wood has high shrinkage value than less dense wood (Walker, 2006).

Relationship between basic density and moisture content

The relationship between basic density and moisture content of the wood was studied using Pearson correlation (Fig. 1). Basic density exhibited significant negative correlation with the moisture content at 1% significant level with r value of -0.875 and R^2 value of 0.766. Walker (2006) reported that there is usually a negative correlation between basic density and moisture content.

**Fig. 1 :** Relationship between basic density and moisture content.

Relationship between basic density and anisotropic shrinkage

Basic density exhibited strong positive correlation with shrinkage in both radial and tangential directions. Radial and tangential shrinkage were significantly correlated with basic density with r values of 0.689 and 0.772 respectively at 1% significant level. Longitudinal shrinkage showed no significant correlation with basic density with very weak positive correlation of 0.067.

Conclusion

It is concluded that wood with high basic density has high anisotropic shrinkage. *Casaurina equisetifolia*, *Eucalyptus tereticornis* and *Acacia auriculiformis* exhibits higher shrinkage due to high basic density. *Melia dubia* shows moderate shrinkage due to moderate basic density. However, *Ailanthus excelsa* shows lower shrinkage due to low basic density.

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