**WOOD RESEARCH** doi.org/10.37763/wr.1336-4561/71.3.385395
**e-ISSN 2729-8906**
**71(3): 2026 385-395 pp.**

# VARIATION IN BASIC DENSITY AND TRANSVERSE SHRINKAGE AMONG SIX *EUCALYPTUS* CLONES PLANTED IN VIETNAM

DOAN VAN DUONG[1], MASUMI HASEGAWA[2]
[1]THAI NGUYEN UNIVERSITY, VIETNAM
[2]KYUSHU UNIVERSITY, JAPAN

(RECEIVED MAY 2026)

## ABSTRACT

This study examined clonal and radial variation in basic density (BD) and transverse shrinkage among six *Eucalyptus* clones grown under uniform conditions in north-central Vietnam. A total of 30 ramets were sampled, and 196 small clear specimens were prepared from positions near the pith and the bark. Partial and total shrinkage in tangential ($T_n$, T) and radial ($R_n$, R) directions were determined following ISO 13061-13:2017. Basic density (BD) ranged from 0.39 to 0.50 g/cm³ and increased consistently from pith to bark. Tangential shrinkage ($T_n$: 4.45–5.83%; T: 5.64–6.85%) showed greater variation among clones than radial shrinkage ($R_n$: 2.95–3.32%; R: 3.89–4.72%). Clone U1427 showed the highest BD while also presenting the lowest shrinkage values, suggesting excellent dimensional stability and considerable potential for utilization in solid wood and lumber production in northern Vietnam.

KEYWORDS: *Eucalyptus*, basic density, partial shrinkage, total shrinkage, clones.

## INTRODUCTION

Eucalypt species (*Eucalyptus* spp.) are among the most widely planted fast-growing hardwoods in tropical and subtropical regions, owing to their rapid growth, adaptability, and suitability for industrial plantations (Zhang and Wang 2021). These species are increasingly utilized not only for pulp and paper but also for solid wood products such as furniture and construction materials (Nguyen et al. 2026). In Vietnam, *Eucalyptus* was first introduced in the 1980s and has been extensively established in plantation forestry since the early 1990s (Kha et al. 2003). Along with *Acacia*, *Eucalyptus* has become one of the principal species for plantation forestry in Vietnam (Van Duong et al. 2023, 2024). The total area of these two species is approximately 1.7 million hectares, accounting for about 70% of the country's production forest plantations (Vietnamese Ministry of Agriculture and Rural Development 2022). Among *Eucalyptus*, hybrid *Eucalyptus* clones are more widely selected for planting (Vo et al. 2018). They are derived from interspecific hybridisation between *E. urophylla* and other eucalypt species such as *E. pellita* or *E. grandis* through natural or controlled pollination, and exhibit superior plantation performance, including improved stem form and volume, enhanced pest and disease resistance, and better wood quality (Grattapaglia and Kirst 2008, Van Duong et al. 2025a). However, despite their favorable growth characteristics, the utilization of eucalypt wood for high-value applications is often constrained by its dimensional instability, particularly during drying processes.

Dimensional stability, which describes how wood shrinks and swells with moisture changes, is a key trait for structural wood applications (Falade et al. 2025). Wood from short-rotation *Eucalyptus* plantations is commonly associated with high growth stresses and pronounced shrinkage anisotropy. Although these properties arise from different anatomical and physical characteristics of wood, both are known to induce defects such as warping and checking during processing. The combined effects of these factors can lead to a substantial reduction in solid wood recovery and a deterioration in the quality of sawn timber products. Numerous studies have investigated the shrinkage properties of *Eucalyptus* wood (Washusen and Evans 2001, Yang et al. 2003, Nguyen et al. 2026). Shrinkage properties of eucalypt wood are influenced by a combination of physical, anatomical, and chemical factors (Sadoh and Kingston 1966). Basic density is often considered one of the most important variables affecting shrinkage behavior, although the relationship may vary depending on species and growth conditions (Kingston and Risdon 1961, Washusen et al. 2001).

Shrinkage properties of eucalypt wood have been widely reported, showing considerable variation among species, genetic materials, and growing conditions. Tangential shrinkage in *Eucalyptus* species typically ranges from approximately 8% to 16%, while radial shrinkage varies from about 3% to 8%, resulting in relatively high anisotropy ratios (Yang et al. 2003, Wu et al. 2006). In plantation-grown *E. urophylla* × *E. grandis*, total transverse shrinkage has been reported to vary substantially, with pronounced differences observed both within and between trees (Yang et al. 2022). Significant variation in transverse shrinkage has also been documented among clones and provenances, with marked differences in radial and tangential shrinkage reported among hybrid eucalypts (Listyanto et al. 2020). In addition, within-tree variation is evident, as higher transverse shrinkage is often observed in juvenile wood compared to mature wood in species such as *E. globulus* and *E. nitens* (Yang et al. 2003). These findings highlight the high variability of transverse shrinkage in eucalypt wood, which remains a major constraint for its efficient utilization in solid wood applications.

Despite extensive research on shrinkage properties of eucalypt wood, most studies have focused on species or provenance levels, with limited attention to variation among commercially important clones grown under comparable conditions. This gap is particularly relevant for fast-growing hybrid *Eucalyptus* clones in Vietnam, where wood quality traits such as dimensional stability remain insufficiently characterized. In addition, radial variation within stems has not been adequately addressed. Therefore, the primary objective of this study was to characterize radial and inter-clonal variations in transverse shrinkage and basic density of *Eucalyptus* clones grown under uniform conditions in north-central Vietnam. The relationship between basic density and transverse shrinkage was further investigated. The findings are expected to contribute to the selection of high-quality clones suitable for solid wood production and to support the sustainable development of plantation forestry in the region.

## MATERIAL AND METHODS

### Sampling and measurements

The study material was obtained from a clonal trial of *Eucalyptus* established in December 2014 by the Vietnamese Academy of Forest Sciences in Cam Hieu commune, Cam Lo district, Quang Tri province, Vietnam (16°45′56″N, 107°01′32″E). The trial comprised three hybrid clones (*E. urophylla* × *E. pellita*) and three *E. urophylla* clones, selected to evaluate growth performance and stem quality. A randomized complete block design was employed, with five replicates and 49 ramets per plot (7 rows × 7 ramets per row). The initial planting spacing was 3 × 2 m (1660 ramets/ha), with a central measurement area of 25 ramets per plot (Vo et al. 2018).

A total of 30 ramets (five per clone) were selected in December 2020 from three hybrid clones (UP54, UP95, and UP99) and three *E. urophylla* clones (U892, U1427, and PN14). Sample ramets were chosen based on stem straightness, branching characteristics, and the absence of visible disease or pest damage. Prior to felling, diameter at breast height (1.3 m) was measured, and the north–south orientation of each stem was marked. After felling, total tree height was recorded. The sampled ramets were the same as those used in a previous study on static bending properties (Van Duong and Schimleck 2022). A 1.0 m log was obtained from each sampled stem between 0.5 and 1.5 m above ground, and a 100 mm thick cross-sectional disc was collected at 1.5 m above ground from each ramet for the determination of selected wood properties.

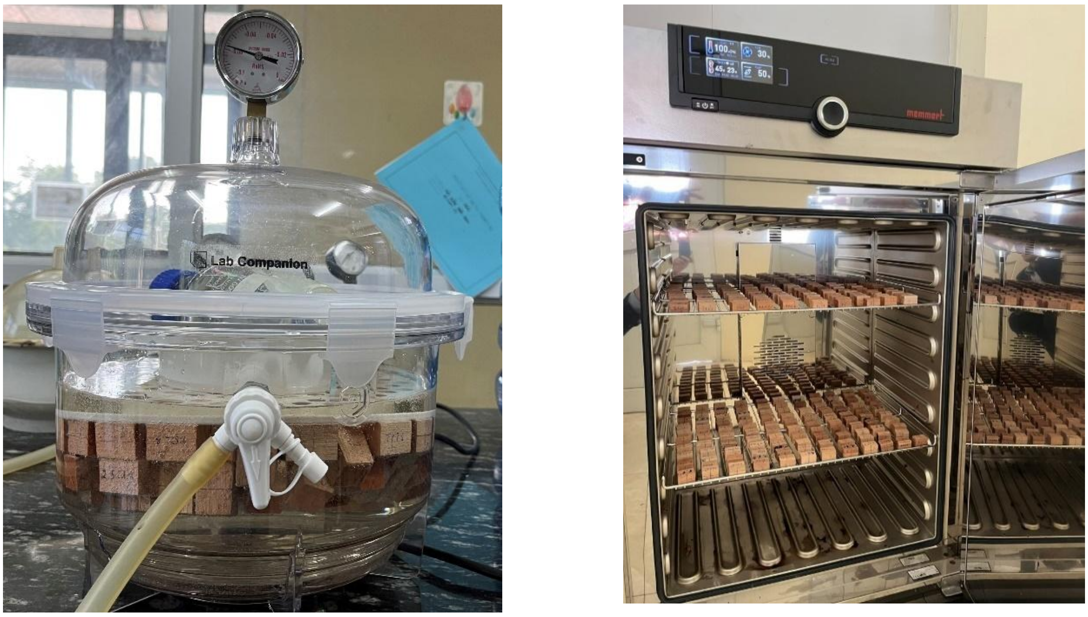
*Tab. 1: Mean values and standard deviations of stem diameter and tree height for each clone (Van Duong and Schimleck 2022).*

| Clone | Species | *n* | DBH (cm) | Tree Height (m) |
|---|---|---|---|---|
| UP54 | *E. urophylla* × *E. pellita* | 5 | 14.24 ± 0.88 | 18.81 ± 0.54 |
| UP95 | *E. urophylla* × *E. pellita* | 5 | 15.43 ± 0.58 | 20.01 ± 0.38 |
| UP99 | *E. urophylla* × *E. pellita* | 5 | 13.17 ± 0.93 | 18.40 ± 0.60 |
| U892 | *E. urophylla* | 5 | 14.18 ± 1.96 | 18.08 ± 0.63 |
| U1427 | *E. urophylla* | 5 | 14.06 ± 1.09 | 16.48 ± 0.65 |
| PN14 | *E. urophylla* | 5 | 13.83 ± 1.18 | 15.23 ± 0.30 |
| Note: DBH is diameter at breast height (1.3 m above the ground); *n* is number of sampled ramets. | | | | |

From each disc, specimens with dimensions of 20 mm (R) × 20 mm (T) × 30 mm (L) were carefully cut from near the pith (R1) and near the bark (R2) in each cardinal direction (north–south and east– west) to examine the basic density (BD) and transverse shrinkage. The small size of the logs only allowed test specimens to be cut in the north–south direction. In total, 196 small clear wood specimens were prepared.

### Transverse shrinkage and basic density determination

Specimen preparation and transverse shrinkage measurements were conducted in accordance with ISO 13061-13:2017. Prior to measurement, all specimens were saturated by immersion in distilled water under vacuum using a desiccator (AS ONE Co., Ltd., Japan) until full saturation was achieved. Tangential and radial dimensions were measured at the midpoint of each axis, previously marked for re-measurement, using a digital micrometer (CD-S20C, resolution 0.01 mm). The specimens were then conditioned at 20°C and 60% relative humidity for eight weeks to minimize the influence of drying stresses. Subsequently, the specimens were oven-dried at 103 ± 2°C to constant mass, and final tangential and radial dimensions were re-measured (Fig. 1).




(a) (b)

*Fig. 1: The experimental procedures: (a) specimens were immersed in distilled water until full saturation; (b) specimens were oven-dried at 103 ± 2°C to constant mass.*

Basic density (BD) was calculated as the ratio of oven-dry mass to green volume. Dimensional changes between the saturated (green) state and either air-dried (12% moisture content, MC) or oven-dry conditions were used to estimate partial and total shrinkage in the tangential ($T_n$ and T) and radial ($R_n$ and R) directions. The coefficients of anisotropy were calculated as $T_n/R_n$ (partial) and T/R (total). $T_n$, $R_n$, T, and R were calculated as follows:

$$T_n = (D_{T,\ Green} - D_{T,\ 12\%MC}) / D_{T,\ Green} \times 100$$

$$R_n = (D_{R,\ Green} - D_{R,\ 12\%MC}) / D_{R,\ Green} \times 100$$

$$T = (D_{T,\ Green} - D_{T,\ Oven\text{-}dry}) / D_{T,\ Green} \times 100$$

$$R = (D_{R,\ Green} - D_{R,\ Oven\text{-}dry}) / D_{R,\ Green} \times 100$$

where: $T_n$ = Partial shrinkage in tangential direction (%), $R_n$ = Partial shrinkage in radial direction (%), T = Total shrinkage in tangential direction (%), R = Total shrinkage in radial direction (%), $D_{T,\ Green}$ = Tangential green dimension measured (mm), $D_{R,\ Green}$ = Radial green dimension measured (mm), $D_{T,\ 12\%MC}$ = Tangential dimension after reconditioning at 12% MC (mm), $D_{R,\ 12\%MC}$ = Radial dimension after reconditioning at 12% MC (mm), $D_{T,\ Oven\text{-}dry}$ = Tangential oven-dry dimension measured (mm), $D_{R,\ Oven\text{-}dry}$ = Radial oven-dry dimension measured (mm).

**Data analysis**

The mean values of each clone were calculated by averaging the values obtained from near the pith and the bark for each clone. The difference in BD, $T_n$, $R_n$, $T_n/R_n$, T, R, and T/R between the two radial positions was examined using a *t-test*. A one-way analysis of variance test was applied to evaluate the differences among clones in BD and transverse shrinkage properties, followed by Tukey's HSD test with the level of significant differences at $P < 0.05$. All analyses were conducted using R software version 4.0.0. (Version 4.0.0; RStudio, Boston, MA, USA).

## RESULTS AND DISCUSSION

**Among-clonal and radial variations of basic density and shrinkage properties**

Tab. 2 presents the mean and standard deviation of BD, $T_n$, $R_n$, $T_n/R_n$, T, R, and T/R for each clone and for all clones combined. BD differed significantly among clones, ranging from 0.39 to 0.50 g/cm³, with an overall mean of 0.43 g/cm³ (Tab. 2). Clone U1427 had the highest BD, whereas clone UP54 had the lowest value, the remaining clones formed intermediate groups with statistically significant differences. This finding is consistent with the results of Hoffmann et al. (2026), who reported significant differences in BD among *Eucalyptus* clones (*E. urophylla* × *E. camaldulensis* and *E. urophylla* × *E. grandis*) planted in Brazil. Nguyen et al. (2026) reported a higher BD of 0.51 g/cm³ at eight years of age for the same species, *E. urophylla*, planted in Nghe An Province, Vietnam. The difference between that value and the present result may be partly attributable to tree age, as wood density generally increases with age, particularly in fast-growing species, as reported by Van Duong et al. (2025b).

*Tab. 2: Mean values and standard deviations (in brackets) of basic density and shrinkage properties for each Eucalyptus clone.*

| Properties | Clone | | | | | | |
|---|---|---|---|---|---|---|---|
| | UP54 | UP95 | UP99 | U892 | U1427 | PN14 | Mean |
| BD (g/cm³) | $0.39^{d}$ (0.03) | $0.41^{c}$ (0.03) | $0.47^{b}$ (0.05) | $0.41^{c}$ (0.03) | $0.50^{a}$ (0.02) | $0.43^{c}$ (0.04) | 0.43 (0.05) |
| $T_n$ (%) | $4.63^{b}$ (1.14) | $4.81^{b}$ (0.94) | $4.73^{b}$ (0.73) | $4.96^{b}$ (1.04) | $4.45^{b}$ (0.86) | $5.83^{a}$ (1.25) | 4.87 (1.08) |
| $R_n$ (%) | $3.07^{a}$ (0.64) | $3.05^{a}$ (0.47) | $3.21^{a}$ (0.52) | $3.12^{a}$ (0.50) | $2.95^{a}$ (0.66) | $3.32^{a}$ (0.52) | 3.11 (0.56) |
| $T_n/R_n$ | $1.57^{a}$ (0.50) | $1.61^{a}$ (0.40) | $1.51^{a}$ (0.38) | $1.63^{a}$ (0.43) | $1.59^{a}$ (0.48) | $1.82^{a}$ (0.56) | 1.62 (0.46) |
| T (%) | $5.64^{b}$ (0.93) | $6.21^{ab}$ (0.99) | $6.85^{a}$ (1.13) | $6.68^{a}$ (1.34) | $6.41^{ab}$ (1.34) | $6.19^{ab}$ (1.25) | 6.28 (1.21) |
| R (%) | $3.89^{c}$ (0.64) | $4.11^{bc}$ (0.54) | $4.72^{a}$ (0.65) | $4.29^{abc}$ (0.65) | $4.43^{ab}$ (0.48) | $4.14^{abc}$ (0.56) | 4.24 (0.64) |
| T/R | $1.48^{a}$ (0.32) | $1.53^{a}$ (0.29) | $1.46^{a}$ (0.22) | $1.58^{a}$ (0.32) | $1.46^{a}$ (0.35) | $1.53^{a}$ (0.39) | 1.51 (0.32) |

The same alphabet letters used after mean values indicate no significant differences among provenances based on Tukey's HSD test at 5%.

The ANOVA results for BD and shrinkage properties showed significant effects of clone and radial position (Tab. 3). In the evaluation of dimensional stability, significant differences were observed among the *Eucalyptus* clones for $T_n$, T, and R. On the other hand, there was no significant difference in $R_n$, $T_n/R_n$, and T/R (Tab. 3). $T_n$ ranged from 4.45 to 5.83%, whereas T varied from 5.64 to 6.85%. These values fall within the range typically reported for medium-density woods (approximately 5–10%) (Walker 2006). In a study on *Eucalyptus* clones aged 7 to 10 years, Lago et al. (2022) reported tangential shrinkage values ranging from 4.72% to 6.42%, which are comparable to those observed in the present study. $R_n$ ranged from 2.95 to 3.32%, with no significant differences observed among clones. R varied from 3.89 to 4.72%, with clone UP99 exhibiting the highest value and clone UP54 the lowest, while the remaining clones formed overlapping groups. The mean values of $R_n$ (3.11%) and R (4.24%) are consistent with those reported for plantation-grown *Eucalyptus*. Ferreira et al. (2020) reported the values of radial shrinkage for 7-year-old *E. urophylla* × *E. grandis* clone planted in Brazil ranging from 3.87 to 3.94%. In combination with its high wood density and superior mechanical properties (Van Duong and Schimleck 2022), clone U1427 exhibited the lowest $T_n$ and $R_n$ values among the clones evaluated in the present study. These findings indicate that clone U1427 is a promising genetic material for deployment on comparable sites in this region of Vietnam and may be particularly suitable for *Eucalyptus* breeding programs targeting improved wood quality for solid wood and lumber production.

*Tab. 3: F-value obtained from the ANOVAs for basic density (BD) and shrinkage properties.*

| Source of variation | *df* | *F*-value | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | BD | $T_n$ | $R_n$ | $T_n/R_n$ | T | R | T/R |
| Clone (C) | 5 | $158.07^{***}$ | $12.42^{***}$ | $1.84^{ns}$ | $2.24^{ns}$ | $16.57^{***}$ | $8.72^{***}$ | $1.15^{ns}$ |
| Radial position (R) | 1 | $180.21^{***}$ | $91.11^{***}$ | $9.25^{**}$ | $90.93^{***}$ | $385.36^{***}$ | $0.29^{ns}$ | $137.37^{***}$ |
| C × R | 5 | $7.09^{***}$ | $1.28^{ns}$ | $1.98^{ns}$ | $1.07^{ns}$ | $4.79^{***}$ | $1.28^{ns}$ | $2.78^{*}$ |

*df* degree of freedom; $^{*}$Significant at the 0.05 probability level; $^{**}$Significant at the 0.01 probability level; $^{***}$Significant at the 0.001 probability level; $^{ns}$No significance.

The $T_n/R_n$ and T/R ratios ranged from 1.51 to 1.82 and 1.46 to 1.58, respectively, with mean values of 1.62 and 1.51, and no significant differences were observed among clones (Tab. 2). The results of this study are consistent with those reported by Hoffmann et al. (2026), where average values of 1.65 for *E. urophylla* × *E. camaldulensis*; however, they are lower than the ratio of tangential to radial shrinkage reported for *E. globulus* by Yang et al. (2002) where average values of 2.48 for *E. globulus* were observed. As the coefficient of anisotropy deviates further from unity, the wood becomes increasingly prone to cracking, splitting, and dimensional deformation as a result of its hygroscopic behavior.

Radial position had a significant effect ($P < 0.001$) on BD and most shrinkage properties across all clones, with the exception of R (Tab. 3). *T-test* results showed that the mean BD value in outer wood was higher than that near the pith in all tested clones, whereas clone U1427 exhibited no significant difference (Tab. 4). This pattern is consistent with previous studies reporting an increase in density from pith to bark (Hein and Brancheriau 2011, Van Duong et al. 2025a).

A similar radial trend was observed for $T_n$ and T, both of which increased markedly from R1 to R2 in all clones. For instance, $T_n$ increased from 3.87–5.01% at R1 to 4.91–6.66% at R2, while T increased from 5.04–6.01% to 6.24–7.72%. In contrast, $R_n$ and R showed relatively minor changes between radial positions, with most differences being statistically non-significant. $R_n$ remained within a narrow range (approximately 2.58–3.45%), while R varied only slightly across positions (Tab. 4).

The shrinkage ratios ($T_n/R_n$ and T/R) increased significantly from R1 to R2 across all clones, reflecting greater anisotropy in outer wood. For example, $T_n/R_n$ increased from approximately 1.24–1.50 at R1 to 1.68–2.15 at R2, while T/R increased from 1.20–1.40 to 1.57–1.83 (Tab. 4). These values are consistent with reported radial increases in shrinkage anisotropy have been documented in earlier studies (Yang et al. 2002).

*Tab. 4: Radial variation of basic density and shrinkage properties for each Eucalyptus clone.*

| Properties | Radial position | Clones | | | | | |
|---|---|---|---|---|---|---|---|
| | | UP54 | UP95 | UP99 | U892 | U1427 | PN14 |
| BD ($g/cm^3$) | R1 | $0.37^b$ | $0.39^b$ | $0.45^b$ | $0.39^a$ | $0.49^a$ | $0.40^b$ |
| | R2 | $0.40^a$ | $0.43^a$ | $0.49^a$ | $0.43^b$ | $0.50^a$ | $0.46^a$ |
| $T_n$ (%) | R1 | $3.87^b$ | $4.26^b$ | $4.26^b$ | $4.36^b$ | $3.98^b$ | $5.01^b$ |
| | R2 | $5.38^a$ | $5.35^a$ | $5.19^a$ | $5.57^a$ | $4.91^a$ | $6.66^a$ |
| $R_n$ (%) | R1 | $3.10^a$ | $3.04^a$ | $3.26^a$ | $3.22^a$ | $3.31^a$ | $3.45^a$ |
| | R2 | $3.00^a$ | $3.06^a$ | $3.16^a$ | $3.02^a$ | $2.58^b$ | $3.19^a$ |
| $T_n/R_n$ | R1 | $1.29^b$ | $1.41^b$ | $1.34^b$ | $1.39^b$ | $1.24^b$ | $1.50^b$ |
| | R2 | $1.85^a$ | $1.81^a$ | $1.68^a$ | $1.88^a$ | $1.94^a$ | $2.15^a$ |
| T (%) | R1 | $5.04^b$ | $5.43^b$ | $5.98^b$ | $6.01^b$ | $5.23^b$ | $5.09^b$ |
| | R2 | $6.24^a$ | $6.99^a$ | $7.72^a$ | $7.35^a$ | $7.58^a$ | $7.30^a$ |
| R (%) | R1 | $3.89^a$ | $4.10^a$ | $4.47^a$ | $4.35^a$ | $4.44^a$ | $4.21^a$ |
| | R2 | $3.90^a$ | $4.13^a$ | $4.78^a$ | $4.23^a$ | $4.43^a$ | $4.06^a$ |
| T/R | R1 | $1.33^b$ | $1.34^b$ | $1.35^b$ | $1.40^b$ | $1.20^b$ | $1.23^b$ |
| | R2 | $1.63^a$ | $1.72^a$ | $1.57^a$ | $1.75^a$ | $1.73^a$ | $1.83^a$ |

The same alphabet letters used after mean values indicate no significant differences between radial positions based on Tukey's HSD test at 5%.

### *Relationship between basic density and shrinkage properties*

Tab. 5 summarizes relationships of BD with shrinkage properties for individual *Eucalyptus* clones and all clones combined. BD showed significantly positive correlations with $T_n$ and T for all clones, except for clone U1427. The correlation (*r*) between BD and $T_n$ ranged from 0.37 to 0.58, whereas that between BD and T varied from 0.45 to 0.71. In contrast, no significant relationships were detected between BD and either $R_n$ or R for most clones. An exception was observed in clone UP99, where significant but weak positive correlations were found, with *r* values of 0.36 for $R_n$ and 0.34 for R (Table 5).

Density is generally regarded as the principal factor controlling the shrinkage behaviour of wood. As moisture content decreases from the green to the oven-dry state, wood of higher density typically exhibits greater dimensional shrinkage compared with lower-density material (Schulgasser and Witztum 2015, Van Duong and Matsumura 2018). The density–shrinkage relationship is frequently interpreted using a simplified view in which only the solid fraction contributes to dimensional change, while void spaces remain unaffected. Under this assumption, wood with higher density, characterized by a greater proportion of cell wall and reduced lumen volume, is expected to undergo more pronounced shrinkage and swelling (Walker 2006, Bowyer et al. 2007, Derome et al. 2011). Similar results are reported for hybrid *Populus* × *euramericana* clones, in which the correlation coefficients between BD and $R_n$ and R were low or statistically insignificant, whereas the correlation coefficients between BD and $T_n$ and T were higher and statistically significant (Koubaa et al. 1998).

No significant correlations were found for clone U1427, suggesting that shrinkage behavior in this clone is largely independent of BD. This lack of association may reflect the influence of other wood structural factors, such as microfibril angle (Barber and Meylan 1964) or lignin content (Boyd 1974) between the tangential and radial walls, which have been reported to modulate shrinkage independently of density. Further studies are needed to clarify the effects of microfibril angle and anatomical characteristics on the shrinkage properties of *Eucalyptus* clones.

*Tab. 5: Correlations of basic density with shrinkage properties for each Eucalyptus clone and all clones combined.*

| Clone | $T_n$ (%) | $R_n$ (%) | $T_n/R_n$ | T (%) | R (%) | T/R |
|---|---|---|---|---|---|---|
| 1 | $0.47^{**}$ | $-0.13^{ns}$ | $0.40^{*}$ | $0.45^{**}$ | $0.17^{ns}$ | $0.23^{ns}$ |
| 2 | $0.58^{***}$ | $0.16^{ns}$ | $0.39^{*}$ | $0.74^{***}$ | $-0.07^{ns}$ | $0.67^{***}$ |
| 3 | $0.37^{*}$ | $0.36^{*}$ | $-0.03^{ns}$ | $0.71^{***}$ | $0.34^{*}$ | $0.19^{ns}$ |
| 4 | $0.57^{**}$ | $-0.04^{ns}$ | $0.43^{*}$ | $0.71^{***}$ | $0.21^{ns}$ | $0.52^{***}$ |
| 5 | $0.32^{ns}$ | $-0.22^{ns}$ | $0.34^{ns}$ | $0.22^{ns}$ | $-0.24^{ns}$ | $0.29^{ns}$ |
| 6 | $0.47^{*}$ | $-0.03^{ns}$ | $0.37^{ns}$ | $0.71^{***}$ | $-0.02^{ns}$ | $0.59^{***}$ |
| **Combined** | $\mathbf{0.21}^{**}$ | $\mathbf{-0.04}^{ns}$ | $\mathbf{0.17}^{*}$ | $\mathbf{0.52}^{***}$ | $\mathbf{0.36}^{***}$ | $\mathbf{0.21}^{**}$ |

$^{*}$Significant at the 0.05 probability level; $^{**}$Significant at the 0.01 probability level; $^{***}$Significant at the 0.001 probability level; $^{ns}$No significance.

## CONCLUSIONS

*(1)* Significant among-clonal and radial variations were observed in basic density and most shrinkage properties of *Eucalyptus* wood. Basic density and tangential shrinkage increased from pith to bark, whereas radial shrinkage showed relatively minor radial variation. *(2)* Clone U1427 exhibited the highest basic density together with the lowest shrinkage values, indicating superior dimensional stability and strong potential for solid wood and lumber production in northern Vietnam. *(3)* Basic density was positively correlated with tangential shrinkage in most clones, while relationships with radial shrinkage were generally weak or non-significant. Further studies are needed to clarify the effects of microfibril angle and anatomical characteristics on the shrinkage properties of *Eucalyptus* clones.

## REFERENCES

1. Barber, N.F., & Meylan, B.A. (1964). The anisotropic shrinkage of wood. A theoretical model. Holzforschung, 18: 146–156.
2. Bowyer, J.L., Shmulsky, R., & Haygreen, J.G. (2007). Forest products and wood science. 5th ed. Wiley-Blackwell, Hoboken.
3. Boyd, J.D. (1974). Anisotropic shrinkage of wood: identification of the dominant determinants. Mokuzai Gakkaishi, 20: 473–482.
4. Derome, D., Griffa, M., Koebel, M., & Carmelier, J. (2011). Hysteretic swelling of wood at cellular scale probed by phase-contrast X-ray tomography. Journal of Structural Biology, 173: 180–190.

5. Falade, O.E., Belleville, B., Spokevicius, A., Ozarska, B., Bossinger, G., Dewi, L.M., Ibrahim, U., & Thumma, B. (2025). SNP-based genetic analysis of dimensional stability and wood density in *Eucalyptus pellita* F. Muell. and hybrids. Forests, 16: 1301.
6. Ferreira, M.D., de Melo, R.R., Tonini, H., Pimenta, A.S., Gatto, D.A., Beltrame, R., & Stangerlin, D.M. (2020). Physical–mechanical properties of wood from a *Eucalyptus* clone planted in an integrated crop-livestock-forest system. International Wood Products Journal, 11(1): 12–19.
7. Grattapaglia, D., & Kirst, M. (2008). *Eucalyptus* applied genomics: from gene sequences to breeding tools. New Phytologist, 179(4): 911–929.
8. Hein, P.R.G., & Brancheriau, L. (2011). Radial variation of microfibril angle and wood density and their relationships in 14-year-old *Eucalyptus urophylla* S.T. Blake wood. BioResources, 6(3): 3352–3362.
9. Hoffmann, W.R., Campos, C.M., Pereira, B.L.C., & Oliveira, A.C. (2026). Properties of *Eucalyptus* clonal wood from a tropical region for application in civil construction. Discover Civil Engineering, 3: 77.
10. Kingston, R.S.T., & Risdon, C.J.E. (1961). Shrinkage and density of Australian and other South-west Pacific woods. CSIRO Division of Forest Products Technological Paper, 13.
11. Koubaa, A., Hernández, R.E., & Beaudoin, M. (1998). Shrinkage of fast-growing hybrid poplar clones. Forest Products Journal, 48(8): 82–87.
12. Kha, L.D., Thinh, H.H., & Cuong, N.V. (2003). Improvement of eucalypts for reforestation in Vietnam. In: Turnbull, J.W. (Ed.), *Eucalyptus in Asia*. Proceedings of an International Conference Held in Zhanjiang, Guangdong, China, 7–11 April 2003. Australian Centre for International Agricultural Research, Canberra, Australia.
13. Lago, M., Lobo, M. V. F., Costa, L. L., César, S. F., & Cunha, R. D. A. (2022). Physical properties of young *Eucalyptus* clone 1404 timber. The Journal of Engineering and Exact Sciences, 8(4): 1-6.
14. Listyanto, T., Nichols, J.D., Glencross, K., & Schoer, L. (2020). Variation in density and shrinkage of six *eucalyptus* species and interspecific hybrid combinations at three sites in Northern New South Wales. IOP Conference Series: Materials Science and Engineering, 935: 012035.
15. Nguyen, K.D., Le, S., Nguyen Huu, S., Brawner, J., Phan Thi Thanh, H., Nguyen Thanh, S., & Nguyen Thi Bich, N. (2026). Genetic control of traits influencing sawn timber properties of plantation-grown *Eucalyptus urophylla*. New Zealand Journal of Forestry Science, 56: 4.
16. Sadoh, T., & Kingston, R.S.T. (1966). Relation between longitudinal shrinkage and structure. Wood Science and Technology, 1: 81–98.
17. Schulgasser, K., & Witztum, A. (2015). How the relationship between density and shrinkage of wood depends on its microstructure. Wood Science and Technology, 49(4): 653–671.
18. Van Duong, D., & Matsumura, J. (2018). Transverse shrinkage variations within tree stems of *Melia azedarach* planted in northern Vietnam. Journal of Wood Science, 64(6): 720–729.

19. Van Duong, D., & Schimleck, L. (2022). Prediction of static bending properties of *Eucalyptus* clones using stress wave measurements on standing trees, logs and small clear specimens. Forests, 13(10): 1728.
20. Van Duong, D., Hasegawa, M., Vu, M.T., & Hoang, V.H. (2024). Radial and among-clonal variations of transverse shrinkage and basic density in 5-year-old *Acacia auriculiformis* clones planted in Vietnam. Wood Research, 69(4): 573–584.
21. Van Duong, D., Hasegawa, M., Yamauchi, S., & Do, C.H. (2025a). Within-tree variation regarding ultrasonic velocity, wood density and compressive strength of the eucalypt hybrid (*Eucalyptus urophylla* × *E. pellita*). Wood Material Science & Engineering, 20(2): 420–426.
22. Van Duong, D., Hoang, V.H., Hasegawa, M., & Sharapov, S. (2025b). The influence of tree age and radial position on the stress-wave velocity and timber properties of *Pinus massoniana* Lamb. planted in Vietnam. Wood Research, 70(1): 117–126.
23. Van Duong, D., Schimleck, L., & Tran, D.L. (2023). Variation in wood density and mechanical properties of *Acacia mangium* provenances planted in Vietnam. Journal of Sustainable Forestry, 42: 518–532.
24. Vietnamese Ministry of Agriculture and Rural Development. (2022). Report: Solutions for developing large-timber plantations to support the wood processing industry. Forum on solutions for developing raw material regions for processing and export industries. Vietnam Administration of Forestry, Quang Tri, Vietnam.
25. Vo, D.H., Tran, L.D., Nguyen, V.B., Hoang, V.T., Tran, A.H., & Duong, Q.T. (2018). Site and productivity management of multi-rotation plantations of *Acacia mangium*, *Acacia auriculiformis* and *Eucalyptus* hybrids for saw-log production in Vietnam. Technical Report. Vietnamese Academy of Forest Sciences, Ha Noi, Vietnam. (In Vietnamese).
26. Walker, J.C.F. (2006). Primary wood processing. 2nd ed. Springer, Dordrecht.
27. Washusen, R., & Evans, R. (2001). Prediction of wood tangential shrinkage from cellulose crystallite width and density in one 11-year-old *Eucalyptus globulus* Labill. Australian Forestry, 64(2): 123–126.
28. Washusen, R., Ades, P., Evans, R., Ilic, J., & Vinden, P. (2001). Relationships between density, shrinkage, extractives content and microfibril angle in tension wood from three provenances of 10-year-old *Eucalyptus globulus* Labill. Holzforschung, 55(2): 176–182.
29. Wu, Y. Q., Hayashi, K., Liu, Y., Cai, Y., & Sugimori, M. (2006). Relationships of anatomical characteristics versus shrinkage and collapse properties in plantation-grown eucalypt wood from China. Journal of Wood Science, 52(3): 187–194.
30. Yang, J.L., Fife, D., Ilic, J., & Blackwell, P. (2002). Between-site and between-provenance differences in shrinkage properties of 10-year-old *Eucalyptus globulus* Labill. Australian Forestry, 65(4): 220–227.
31. Yang, J.L., Ilic, J., Evans, R., & Fife, D. (2003). Interrelationships between shrinkage properties, microfibril angle, and cellulose crystallite width in 10-year-old *Eucalyptus globulus*. New Zealand Journal of Forestry Science, 33(1): 47–61.
32. Yang, L., Zheng, J., & Huang, N. (2022). The characteristics of moisture and shrinkage of *Eucalyptus urophylla* × *E. grandis* wood during conventional drying. Materials, 15(9): 3386.

33. Zhang, Y., & Wang, X. (2021). Geographical spatial distribution and productivity dynamic change of eucalyptus plantations in China. Scientific Reports, 11: 19764.

DOAN VAN DUONG*
THAI NGUYEN UNIVERSITY
INSTITUTE FOR EXCELLENCE IN EDUCATION AND RESEARCH
THAI NGUYEN, VIETNAM
*Corresponding author: duongvandoan@tuaf.edu.vn

MASUMI HASEGAWA
KYUSHU UNIVERSITY
FACULTY OF AGRICULTURE
DEPARTMENT OF AGRO-ENVIRONMENTAL SCIENCES
FUKUOKA, JAPAN