Between-site and between-provenance differences in shrinkage properties of 10-year-old *Eucalyptus globulus* Labill.

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Summary

Basic shrinkage properties of three provenances of 10-y-old plantation-grown *Eucalyptus globulus* Labill. from two sites in Mt Gambier region were determined. The properties included shrinkage and collapse in radial and tangential directions, and cross-sectional shrinkage after re-conditioning. Site had a highly significant effect on a number of shrinkage properties. There was no significant difference between provenances in any shrinkage property. Nevertheless, Jeeralang provenance consistently had the highest mean value for every shrinkage property in both radial and tangential directions (except for radial shrinkage), followed by King Island then South-eastern Tasmania provenances. Values for mean radial and tangential shrinkage, and mean radial collapse, in this study were well below the values of corresponding properties for 17–23-y-old *E. globulus* trees in Tasmania as reported by previous researchers. Internal checking was virtually absent in small specimens (20 mm × 20 mm × 90 mm) that were dried from green to 12% moisture content. The effect of growing conditions (stocking, pruning, water availability, soil conditions) on shrinkage properties and drying degrade requires detailed examination in future extensive studies.

Keywords: wood properties; shrinkage; collapse; wood density; provenance; *Eucalyptus globulus*

Introduction

The magnitude of total shrinkage of wood from young, collapse-prone species is an important attribute largely because high levels of total shrinkage are responsible for drying degrade. Total shrinkage has two components: normal shrinkage and collapse. Normal shrinkage results from the reduction of cell wall thickness following moisture loss below fibre saturation point. Collapse refers to the reduction in cross-sections of cell lumens. Internal checking and surface checking severely affect the recovery of high-value sawn timber products and are the most serious forms of drying degrade for the Australian hardwood timber industry. Internal checking is often associated with cell collapse during drying; it is common in many eucalypt species. High levels of normal shrinkage are undesirable as they lead to high levels of drying stresses that are known to cause surface checking. Excessive drying stresses, which are often due to drying conditions and variation in shrinkage levels, can also result in other forms of drying degrade such as case hardening.

Collapse and all forms of checking are affected by wood permeability, extractive content, wood density and its variation, board thickness, drying practices and the presence of tension wood. Generally the severity of collapse checking increases with collapse. The amount of collapse is positively related to low permeability, high extractive content, low density and large variation of density, board thickness in the radial direction, severe drying conditions, and the presence of severe tension wood (Tiemann 1915, 1929, 1941; Wardrop and Dadswell 1948, 1955; Bisset and Ellwood 1951; Dadswell and Wardrop 1955; Kauman 1960, 1964; Pankevicius 1961, 1962; Cuevas 1969; Chafe 1985, 1986a,b, 1987, 1990a,b, 1992, 1993; Ilic and Hillis 1986; Wilkes and Wilkins 1987; Wilkes 1988; Thomson 1989; Chafe and Ilic 1992; Ilic 1993, 1995, 1999; Bekele 1995; Innes 1995; Northway and Blakemore 1996; Yang, 1996; Chafe and Carr 1998; Washusen and Ilic 2001). While there have been numerous studies on shrinkage characteristics of other eucalypts as shown in the references above, systematic information on shrinkage properties of *Eucalyptus globulus* Labill., including collapse and the effect of site and provenance, hardly exists.

This paper deals with several interrelated experiments to evaluate shrinkage and drying characteristics of wood from three provenances of 10-y-old *E. globulus*. Cross-sectional shrinkage, total shrinkage, normal shrinkage and collapse were examined for between-site and between-provenance differences. Properties were studied in both radial and tangential directions. Normal shrinkage is referred to in this paper as shrinkage.

Materials and methods

Fifty-nine trees of 10-y-old *E. globulus* were sampled from three provenances (Jeeralang, King Island, and South-eastern Tasmania) grown at two separate sites (Heath Block and Johnstons Block) in the Mt Gambier region of South Australia. These two sites were established in 1988, before the rapid expansion of blue gum plantations in the Green Triangle from the late 1990s onward. When clear fallen the two sites yielded woodchip at rates corresponding to a mean annual increment (MAI) of 25–30 m^3 ha^{-1}, with Johnstons being less productive than the Heath site. Thus the sites were of medium to high productivity in current industry terms. The study trees are described in detail in Yang *et al*. (2001). The same abbreviations as those used in Yang *et al*. (2001) are used in this paper to designate six groups of trees: HJ, HK and HT respectively refer to Jeeralang, King Island and South-eastern Tasmania (SE Tasmania) provenances at Heath Block; JJ, JK and JT respectively refer to Jeeralang, King Island and SE Tasmania provenances at Johnstons Block.

One billet, 1.2 m long, between points on the stem corresponding to heights of 1.3 and 2.5 m, was removed from each tree stem after felling. From each billet, two end-matched pith-to-bark strips were cut (20 mm × 90 mm, tangential × longitudinal), which were free of visible defects. In addition, twelve of the billets had fewer knots in them than did other billets, enabling a third end-matched strip to be obtained. Results from this set will be reported separately. As many specimens as possible, 20 mm × 20 mm × 90 mm, were cut from each strip, starting from the pith. Their ends were immediately sealed with silicon gel and covered with aluminium foil to prevent moisture loss. The cross-sectional size of our specimens, 20 mm × 20 mm, was close to that used in earlier shrinkage studies by Kingston and Risdon (1961), 25 mm × 25 mm, to enable reliable comparison of shrinkage data. Our earlier work had shown that there was little difference in shrinkage and collapse between samples of 20 mm × 20 mm and 25 mm × 25 mm cross-section. End-matched specimens of 20 mm × 20 mm × 30 mm were also prepared from each billet for determining moisture content (MC).

One set of end-matched specimens was dried in a 17% equilibrium moisture content (EMC) room from green until equilibration. The specimens were cross-cut at the mid-length to give two subsets of specimens, 20 mm × 45 mm. One subset was reconditioned for one hour in saturated steam then dried to equilibration in a 12% EMC room; the density of each specimen in this subset was then determined. The other subset was dried in a 12% EMC room from green until equilibration. Tangential and radial dimensions of all specimens in both subsets at various moisture contents were measured at the last-cut end using a calliper. Shrinkage and collapse for both radial and tangential directions were calculated from these measurements and measured green linear dimension (Equations 1–4). Then, from the last-cut end of each 20 mm × 45 mm specimen in the reconditioned subset, one cross-section 2 mm thick was removed, and its total area and total internal check area were measured using an in-house imaging routine. From these measurements and green cross-sectional area, cross-sectional shrinkage after reconditioning ($CS_{12\%MC}$) was calculated (Equation 5).

The second set of end-matched specimens was dried from green in an oven at 50ºC until the weight stabilized. Each specimen was then cross-cut at the mid-length to yield two subsets of specimens, 20 mm × 45 mm. One subset was not used. For the other subset, tangential and radial dimensions of each specimen were measured at the last-cut end using a calliper. From these measurements and the recorded green dimensions, total shrinkage in both radial and tangential directions was calculated in the same way as for shrinkage from green to 12% MC.

$$S_R = (D_{R,Green} - D_{R,12\%MC}) / D_{R,Green} \times 100 \tag{1}$$

$$S_T = (D_{T,Green} - D_{T,12\%MC}) / D_{T,Green} \times 100 \tag{2}$$

$$C_R = (D_{R,12\%MC} - D'_{R,12\%MC}) / D_{R,Green} \times 100 \tag{3}$$

$$C_T = (D_{T,12\%MC} - D'_{T,12\%MC}) / D_{T,Green} \times 100 \tag{4}$$

$$CS_{12\%MC} = (A_{Green} - A_{12\%MC}) / A_{Green} \times 100 \tag{5}$$

where:

S_R = Radial shrinkage (green to 12% MC, %)

S_T = Tangential shrinkage (green to 12% MC, %)

C_R = Radial collapse (green to 12% MC, %)

C_T = Tangential collapse (green to 12% MC, %)

$CS_{12\%MC}$ = Cross-sectional shrinkage from green to 12% MC after reconditioning (%)

$D_{R,Green}$ = Radial green dimension measured (mm)

$D_{T,Green}$ = Tangential green dimension measured (mm)

$D_{R,12\%MC}$ = Radial dimension after reconditioning at 12% MC (mm)

$D_{T,12\%MC}$ = Tangential dimension after reconditioning at 12% MC (mm)

$D'_{R,12\%MC}$ = Radial dimension before reconditioning at 12% MC (mm)

$D'_{T,12\%MC}$ = Tangential dimension before reconditioning at 12% MC (mm)

A_{Green} = Green cross-sectional area ($= D_{R,Green} \times D_{T,Green}$) (mm^2)

$A_{12\%MC}$ = Cross-sectional area after reconditioning at 12% MC (mm^2).

Unweighted tree averages were calculated for each following shrinkage property:

1 and 2. Radial and tangential shrinkage (green to 12% MC, %);

3 and 4. Radial and tangential collapse (green to 12% MC, %);

5 and 6. Total radial and total tangential shrinkage (green to 12% MC, %);

7 and 8. Total radial and total tangential shrinkage (green to EMC of 50ºC oven, %); and

11. Cross-sectional shrinkage after reconditioning (green to 12% MC, %).

The significance of differences in the means of shrinkage properties between sites and provenances was tested using Model III analysis of variance (ANOVA). Site and provenance were respectively treated as the random and fixed factors. Environmental factors within each site were assumed to be uniform between the stands of each provenance.

Relationships between basic wood properties (e.g. density, microfibril angle and cellulose crystallinity) and shrinkage properties, differences in shrinkage characteristics between drying

Table 1. Mean values and standard deviation (in brackets) of shrinkage properties, moisture content and density

Properties	HJ	HK	HT	JJ	JK	JT
Number of trees	10	9	10	10	10	10
1. Radial shrinkage, S_R	2.39	2.57	2.72	2.57	2.33	2.30
(green to 12% MC, %)	(0.46)	(1.18)	(1.17)	(0.72)	(0.84)	(0.48)
2. Tangential shrinkage, S_T	5.34	5.64	5.31	6.55	5.87	5.67
(green to 12% MC, %)	(0.77)	(1.14)	(0.95)	(0.91)	(1.04)	(0.44)
3. Radial collapse, C_R	0.67	0.42	0.59	2.19	1.15	0.71
(green to 12% MC, %)	(0.53)	(0.19)	(0.45)	(0.68)	(0.74)	(0.42)
4. Tangential collapse, C_T	3.35	2.95	3.01	7.63	6.31	4.71
(green to 12% MC, %)	(0.94)	(1.19)	(0.66)	(2.24)	(2.45)	(1.44)
5. Total radial shrinkage, $S_R + C_R$	3.06	2.99	3.32	4.76	3.48	3.02
(green to 12% MC, %)	(0.90)	(1.23)	(1.43)	(1.10)	(1.32)	(0.49)
6. Total tangential shrinkage, $S_T + C_T$	8.69	8.56	8.31	14.18	12.19	10.38
(green to 12% MC, %)	(1.21)	(1.90)	(1.15)	(2.54)	(2.51)	(1.53)
7. Total radial shrinkage from green	6.65	6.92	7.05	8.28	7.36	6.53
to EMC of 50°C oven (%)	(1.05)	(0.87)	(1.76)	(2.99)	(2.20)	(0.99)
8. Total tangential shrinkage from green	16.19	16.13	15.84	21.03	19.90	18.41
to EMC of 50°C oven (%)	(2.43)	(3.26)	(1.93)	(2.92)	(3.97)	(3.84)
9. Ratio of tangential to radial	2.32	2.50	2.20	2.69	2.67	2.55
shrinkage, S_R / S_T	(0.56)	(0.89)	(0.82)	(0.68)	(0.52)	(0.53)
10. Ratio of total tangential to radial	3.12	3.20	2.83	3.05	3.77	3.50
shrinkage, $(S_T + C_T) / (S_R + C_R)$	(1.12)	(1.13)	(0.97)	(0.61)	(1.08)	(0.64)
11. Cross-sectional shrinkage,	8.13	7.87	7.15	9.89	8.54	8.37
$CS_{12\%MC}$ (green to 12% MC, %)	(2.06)	(3.29)	(3.70)	(2.11)	(1.89)	(2.09)
12. Moisture content (%)	105	126	122	103	118	114
	(9)	(6)	(15)	(10)	(19)	(7)
13. Weighted density at	656	563	577	706	592	650
12% MC (kg m^{-3})	(43)	(37)	(50)	(73)	(87)	(54)

conditions and specimen sizes, and the effect of shrinkage on internal checking will be reported in separate papers.

Results

The mean and standard deviation of shrinkage properties, moisture content and density, for each provenance at each site are given in Table 1.

The ANOVA results on all shrinkage properties, moisture content and density are summarized in Table 2, together with mean values for each site averaged over three provenances, and for each provenance averaged over two sites.

The mean values of six shrinkage properties calculated from the combined data are given in Table 3. Values for the equivalent properties reported by Kingston and Risdon (1961) for 17–23-y-old *E. globulus* trees grown in Tasmania are also given in Table 3 for comparison. In Kingston and Risdon (1961), there are three sets of shrinkage measurements for *E. globulus*. Apparently, their test material was of different ages and/or from different areas. Since their data for the 17–23-y-old group were complete and were based on a much larger sample than those for the other two groups, we chose it for our comparisons (Table 3). In addition, Kingston and Risdon (1961) did not list collapse nor the ratio of tangential to radial shrinkage. We have calculated collapse values by subtracting their normal shrinkage from total shrinkage and present them in Table 3.

Discussion

Differences between provenances and sites

Whereas there is little difference among moisture contents, the density at Johnstons Block is about 50 kg m^{-3} greater than at Heath Block (Table 2). With data averaged over two sites, Jeeralang provenance clearly showed the highest density and lowest moisture content although the differences between provenances were non-significant (Table 2).

Radial shrinkage (green to 12% MC) showed no significant differences between sites and between provenances, and the site × provenance interaction was also non-significant (Table 2).

Radial collapse (green to 12% MC) was significantly higher at Johnstons Block than at Heath Block; the difference was approximately 136% (Table 2). This large difference was primarily due to the much greater collapse in the Jeeralang provenance at Johnstons Block (Table 1). In fact, the mean of this tree group (JJ) was considerably higher than that from any other tree group (Table 1). There were no significant between-provenance differences in radial collapse. Nevertheless, the Jeeralang

Table 2. Summary of ANOVA results and mean values of wood properties for each site and provenance

Properties	Significance of differences			Mean values for each site		Mean values for each provenance		
	Between sites	Between provenances	Interaction	Heath Block	Johnstons Block	Jeeralang	King Island	SE Tasmania
Number of trees				29	30	20	19	20
1. Radial shrinkage, S_R (green to 12% MC, %)	n.s.	n.s.	n.s.	2.56	2.40	2.48	2.44	2.51
2. Tangential shrinkage, S_T (green to 12% MC, %)	*	n.s.	n.s.	5.42	6.03	5.95	5.76	5.49
3. Radial collapse, C_R (green to 12% MC, %)	***	n.s.	***	0.57	1.35	1.43	0.80	0.65
4. Tangential collapse, C_T (green to 12% MC, %)	***	n.s.	*	3.10	6.22	5.49	4.70	3.86
5. Total radial shrinkage, $S_R + C_R$ (green to 12% MC, %)	*	n.s.	*	3.13	3.75	3.91	3.25	3.17
6. Total tangential shrinkage, $S_T + C_T$ (green to 12% MC, %)	***	n.s.	*	8.52	12.25	11.44	10.47	9.35
7. Total radial shrinkage from green to EMC of 50°C oven (%)	n.s.	n.s.	n.s.	6.87	7.39	7.46	7.15	6.79
8. Total tangential shrinkage from green to EMC of 50°C oven (%)	***	n.s.	n.s.	16.05	19.78	18.61	18.02	17.12
11. Cross-sectional shrinkage, $CS_{12\%MC}$ (green to 12% MC, %)	n.s.	n.s.	n.s.	7.59	8.89	8.95	8.23	7.58
12. Moisture content (%)	n.s.	*	n.s.	118	112	104	122	118
13. Weighted density at 12% MC (kg m^{-3})	**	n.s.	n.s.	600	649	681	578	613

Notes: n.s. for $P > 0.05$; * for $P < 0.05$; ** for $P < 0.01$; *** for $P < 0.001$

Table 3. Mean values of shrinkage properties in this study, together with values of the equivalent properties reported by Kingston and Risdon (1961). Values in brackets are standard errors.

Properties	This study	Kingston and Risdon (1961)
Number of trees	59	18
Age of trees	10	17–23
1. Radial shrinkage (%)	2.48 (0.11)	4.60 (0.19)
2. Tangential shrinkage (%)	5.73 (0.12)	9.40 (0.31)
3. Radial collapse (%)	0.97 (0.10)	2.30*
4. Tangential collapse (%)	4.69 (0.31)	5.00*
5. Total radial shrinkage (%)	3.45 (0.16)	6.90 (0.38)
6. Total tangential shrinkage (%)	10.42 (0.37)	14.40 (0.56)
9. Ratio of tangential to radial shrinkage	2.48 (0.09)	2.04*

*Calculated from data in Kingston and Risdon (1961)

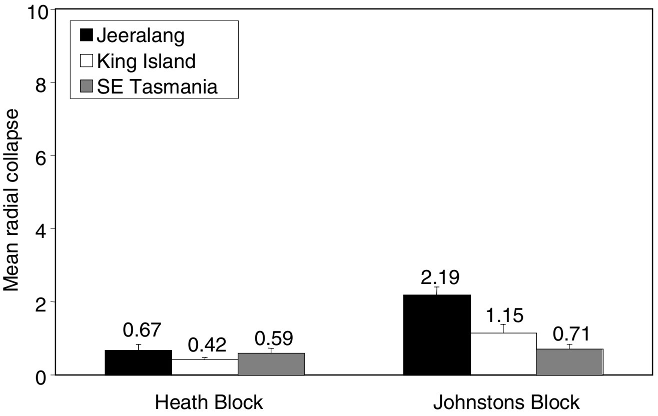

Figure 1. Mean values of radial collapse (green to 12% MC) for each provenance at each block

provenance had the highest mean, followed by King Island then SE Tasmania provenances (Table 2). The significant site × provenance interaction (Fig. 1) may have been due to less uniform environmental factors at Johnstons Block.

Total radial shrinkage (green to 12% MC) was significantly higher at Johnstons Block than at Heath Block; the difference was about 20% (Table 2). This is due to the significant between-site differences in radial collapse, which is a component of total radial shrinkage. There were no significant differences between provenances, but Jeeralang provenance had the highest mean, followed by King Island then SE Tasmania provenances (Table 2).

Total radial shrinkage from drying green specimens in the 50ºC oven showed no significant between-site and between-provenance

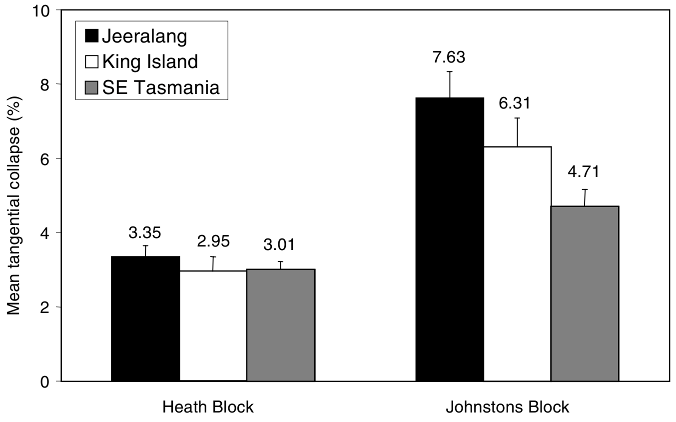

Figure 2. Mean values of tangential collapse (green to 12% MC) for each provenance at each block

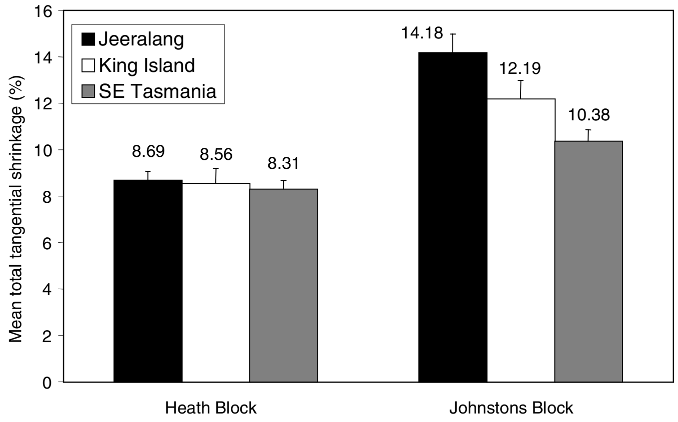

Figure 3. Mean values of total tangential shrinkage (green to 12% MC) for each provenance at each block

differences, and the site-provenance interaction was non-significant (Table 2).

Tangential shrinkage (green to 12% MC) was significantly higher at Johnstons Block than at Heath Block; the difference was about 100% (Table 2). There were no significant differences between provenances, and site × provenance interaction was non-significant (Table 2).

Tangential collapse (green to 12% MC) was significantly higher at Johnstons Block than at Heath Block; the difference was about 100% (Table 2). There were no significant differences between provenances. Nevertheless, the Jeeralang provenance had the highest mean, followed by King Island then SE Tasmania provenances (Table 2). There is a significant site × provenance interaction (Fig. 2) that may have been due to less uniform environmental factors at Johnstons Block.

Total tangential shrinkage (green to 12% MC) was significantly higher at Johnstons Block than at Heath Block; the difference was about 44% (Table 2). There were no significant differences between provenances. Again, however, the Jeeralang provenance had the highest mean, followed by King Island then SE Tasmania provenances (Table 2). The pattern of total tangential shrinkage (Fig. 3) was very similar to that of tangential collapse (Fig. 2), which indicates that variation in total tangential shrinkage is primarily influenced by variation in tangential collapse since tangential shrinkage, the other component of total tangential shrinkage, varied very little. The significant site × provenance interaction (Fig. 3) may have been due to less uniform environmental factors at Johnstons Block.

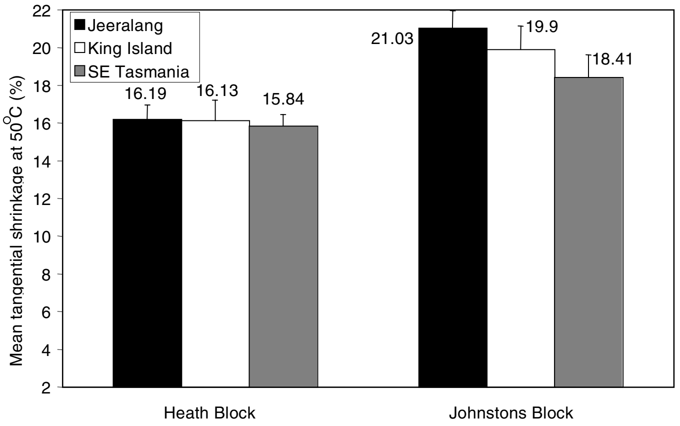

Figure 4. Mean values of total tangential shrinkage from green to oven-dry at 50ºC for each provenance at each block.

While the normal tangential and cross-sectional shrinkage results are consistent with the higher average density of Johnstons Block (Table 2) and of Jeeralang provenance (Table 2), the correspondingly high collapse values are at odds with previously established negative relationships with density (Chafe 1985; Ilic 1999). In this instance, it is likely that the high levels of collapse observed for relatively high density material may have resulted from the presence of tension wood, which is known to exhibit excessive shrinkage (Wardrop and Dadswell 1948, 1955; Dadswell and Wardrop 1955). Despite that, these trees overall were relatively straight.

Total tangential shrinkage from drying green specimens at 50ºC was significantly higher at Johnstons Block than at Heath Block; the difference was about 20% (Table 2). There were neither significant differences between provenances, nor significant site × provenance interaction (Table 2). The pattern for the mean values (Fig. 4) was similar to that for total tangential shrinkage from green to 12% MC (Fig. 3).

The test at 50ºC produced ANOVA results equivalent to those of the green-to-12% MC test for detecting the effect of site and provenance on radial and tangential shrinkage. Its application for purposes of prediction, however, is limited because its ANOVA results did not agree with those of the green-to-12% MC test for other shrinkage properties (Table 2).

Drying green specimens directly at 50ºC resulted in considerable increases in total shrinkage (Table 1). Total radial and tangential shrinkages under this condition were nearly twice those obtained under standard laboratory conditions. This increase was almost entirely due to the increased level of collapse under the harsher drying condition.

There were no significant between-site and between-provenance differences in cross-sectional shrinkage (green to 12% MC), and the site-provenance interaction was non-significant (Table 2).

Total shrinkage can be used to test for between-site and between-provenance differences in collapse, in both radial and tangential

Table 4. Growth characteristics of trees within the measurement plot of each provenance at each site (Yang *et al.* 2001)

Tree properties	Heath Block			Johnstons Block		
	Jeeralang	King Island	SE Tasmania	Jeeralang	King Island	SE Tasmania
Stocking (stems ha^{-1})	833	1042	917	958	875	458
Mean DBHOB (mm)	175	217	182	232	216	257
SD of DBHOB (mm)	86	50	81	52	70	67
Basal area (m^2 ha^{-1})	24.6	40.6	28.3	42.3	35.2	25.2
MAI (m^3 ha^{-1})	21	41	23	37	27	21

directions. This is because differences in normal shrinkage were generally non-significant between sites and provenances, so variation in total shrinkage could be attributed essentially only to variation in collapse. This is of considerable practical advantage as total shrinkage takes much less effort to obtain and requires minimal laboratory facilities.

The two sites differed in their stocking (Table 4) and rainfall (680 mm for Heath Block and 860 mm for Johnstons Block). We are not certain of the magnitude of actual differences in soil nutrients and water-holding capacity between the two sites and their impact on tree growth and wood properties. Site factors resulted in differences in many shrinkage properties between Heath and Johnstons blocks. The small between-provenance differences at Heath Block and relative large differences at Johnstons Block cannot be readily explained by stocking and DBH (Table 4). Although Johnstons Block is suspected to be less uniform, we again do not have enough information to identify the critical site factors.

Despite non-significant differences between provenances, Jeeralang provenance consistently had the highest mean value for every shrinkage property in both radial and tangential directions (except for radial shrinkage), followed by King Island then SE Tasmania provenances (Table 2).

Comparison with other studies

Interestingly, all the shrinkage properties of 10-y-old plantation material in this study were lower than those reported by Kingston and Risdon (1961). Mean radial and tangential shrinkage of all the data were 2.48% and 5.73% respectively, and the mean radial collapse was 0.96%, well below the equivalent mean values reported for the 17–23-y-old *E. globulus* trees grown in Tasmania (Table 3). However, mean tangential collapse was very similar in the two studies (Table 3).

It is interesting that the total-shrinkage anisotropy in this study (3.25) is considerably higher than that reported by Kingston and Risdon (1961) while the collapse levels are about the same (Table 3). (Anisotropy is the difference in shrinkage properties between radial and tangential directions. It is often expressed as the ratio of tangential to radial shrinkage.) Firstly, the normal-shrinkage anisotropy in this study (2.48) is higher than the previously reported result (2.04) although the overall normal shrinkage in this study is lower (Table 3). Secondly, greater lignification of radial walls (Boyd 1974) and an expected higher portion of ray tissue in young developing trees may offer greater radial restraint during drying. Further detailed work is clearly needed to provide a definite explanation.

Internal checking

Internal checking was observed in only one of the 555 *E. globulus* specimens (20 mm × 20 mm × 90 mm) that were dried from green to 12% MC (in the 12% EMC room). About 40 of these specimens had very high density (>750 kg m^{-3} at 12% MC) and showed large amounts of collapse, but no internal checking developed in them. Ilic (1999) showed that mature wood of *E. regnans* with earlywood density >450 kg m^{-3} was free of internal checking. *E. globulus* normally has higher average density than *E. regnans* and has smaller within-ring density variation; hence its earlywood density is moderately high and more resistant to internal checking.

Conclusions

(1) Site had a highly significant effect on shrinkage properties including radial and tangential collapse. At Johnstons Block, all shrinkage properties (except for radial and cross-sectional shrinkage) had significantly higher mean values than at Heath Block.

(2) There were no significant between-provenance differences in any shrinkage property.

(3) Quantitatively, Jeeralang provenance consistently had the highest mean value for every shrinkage property in both radial and tangential directions (except for radial shrinkage), followed by King Island then SE Tasmania provenances.

(4) Total shrinkage can be used as a quick and reliable means to test between-site and between-provenance differences in collapse.

(5) In this study mean values of radial and tangential shrinkage, and mean radial collapse, were well below values of the equivalent properties found in earlier studies for *E. globulus* trees of 17–23 y of age grown in Tasmania, but the shrinkage anisotropy was greater.

(6) Internal checking was almost entirely absent in small specimens (20 mm × 20 mm × 90 mm) of *E. globulus* that were dried from green to 12% MC.

(7) The effect of growth conditions (site quality and silviculture) on shrinkage properties and drying degrade in *E. globulus* requires detailed examination in future studies.

This study has provided comprehensive base information on shrinkage properties of young *E. globulus* and demonstrated the effect of site and provenance on these properties. This information on wood behaviour is crucial to the development of high-value wood products from plantation-grown *E. globulus* as it allows us to understand the potential behaviour of wood in drying and in service. The sites were of medium to high productivity in current industry terms. The range of provenances selected in this study was restricted to that available in the early-established stands but the same, or closely related provenances, have been extensively planted in the Green Triangle over recent years.

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