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Colour variation and correlations in *Eucalyptus dunnii* sawnwood

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Abstract

A study of material thinned from a 9-year-old *Eucalyptus dunnii* progeny trial revealed that *E. dunnii* has light yellowish wood that is relatively uniform in colour, and varies little within and between trees. The variation in colour between half-sib families is small, but statistically significant (P=0.008). Most of the colour variation relates to the yellowness (CIE b^*) of the wood, which in heartwood, is moderately heritable (h=0.6). The colour of the endgrain, especially its lightness (CIE L^*) and whiteness index (E313), is correlated with basic density, hardness, and rates of shrinkage. The CIE rectangular opponent scale (L^*, a^*, b^*) appeared to be the most informative about wood colour and properties, and no additional information was gleaned from an analysis of full spectral data in the range 400-700 nm.

Introduction

Eucalyptus dunnii Maiden (Dunn's white gum[1]) is a relatively new, but increasingly important plantation species in eastern Australia. Over 10,000 ha of *E. dunnii* plantation has been established in NSW, and it remains one of the favoured species for planting, with some 40% of current plantings in north-east NSW and south-east Queensland using this species. Although it forms a crucial component of the long-term supply to the sawlog industry, this emerging resource remains relatively untried by industry. This is one of a series of studies[2,3] of wood quality in *E. dunnii*, and explores colour variation and correlations with other wood properties in this emerging plantation resource.

Colour is an important property in sawnwood, but is difficult to quantify[4]. The most widely used system of colour measurement is the rectangular opponent scale (L^*, a^*, b^*) of the International Commission on Illumination[5]. This scale represents colour as psychometric lightness (L^*, which varies from 0=black to 100=white), red-greenness (a^*, which measures red when positive, grey when zero, and green when negative), and yellow-blueness (b^*, which measures yellow when positive, grey when zero, and blue when negative). Other alternatives exist, and two of the more common are the tristimulus (X, Y, Z) scale which records reflectance of each of the three primary colours, and the CIE polar (L^*, C^*, $h°$) scale which represents lightness, chroma and hue. A one-to-one mathematical relationship exists between these scales, so colour measurements can be converted unambiguously from one scale to another. We used the CIE rectangular (L^*, a^*, b^*) scale because the ease of interpretation and calculation of colour differences[5]. This system has been used in several studies of wood colour[6,7,8]. Dominant wavelength has also been used to characterise wood colour[9,10].

The colour recorded by a colorimeter depends on the viewing conditions. We used the 10° standard observer (which represents the human retinal response viewing an object subtending an angle of 10°) under standard daylight (D65 with colour temperature 6500°K), consistent with the work of Nishino[11].

The colour of wood may vary greatly within trees. Rink[12] recorded that heartwood colour in black walnut may depend on the position in the tree (height, radius), and on the growth rate of the tree. Amusant[8] recorded that heartwood colour in *Dicorynia* became redder and darker as distance from the pith increased, and as distance from the stump decreased. Raymond and Bradley[7] also reported that redness (a^*) and yellowness (b^*) decreased with increasing height within *Eucalyptus nitens* trees, but they found that an estimate of yellowness (b^*) from a single core sample could provide a reliable indication of whole-tree colour.

Mononen et al.[13] reported that wood became darker on drying, mainly due to a decrease in lightness (L^*). Sullivan[9] observed that during drying, brightness increased and chroma decreased, while dominant wavelength remained unchanged. These changes were prominent near the fibre saturation point. Sullivan[14] also observed that ultraviolet light tended to darken the surface of timber during the first thirteen days of exposure after which continued exposure tended to cause bleaching.

Beckwith[10] found that radial and tangential sawnwood surfaces were indistinguishable in colour, but that the transverse surface (endgrain) differed significantly in colour from the longitudinal surfaces. Hannrup[15] reported that wood colour in *Picea abies* had low heritability ($h<0.2$).

Materials and Methods

Short boards (about 30 cm in length and 20 mm in thickness) were sawn from logs at a standard height of 3 m above ground level. These boards were sawn radially from pith to bark with a bandsaw, in a plane parallel to any end-splitting observed in the log. Sawing was completed within a week of felling, and logs were stored under sprinklers during the few days prior to sawing. Boards were air-dried for two weeks to about 25% moisture content under controlled conditions (in an air-conditioned laboratory), and were neither sanded nor planed. The colorimeter used to assess wood colour was a HunterLab Miniscan XE which sampled a circle of 24mm diameter. The instrument was placed to record a sample representative of the board, midway along its length, wholly within the heartwood, but near the heart-sapwood boundary. The instrument recorded both tristimulus (X, Y, Z and L^*, a^*, b^*) and full spectral data (by 10 nm increments between 400 and 700 nm), as well as the dominant wavelength and whiteness index (E313 of the American Society of Testing and Materials).

Endgrain colour was recorded from discs, 25 mm thick, cut from at a height of about 2.5 m above the ground. The discs were air-dried for two weeks and fine-sanded with a belt sander. The same HunterLab Miniscan XE instrument was used to record the colour attributes of the sapwood and heartwood. Endgrain surfaces tended to darken slightly during the first few hours after sanding, so all samples were left for two days between sanding and colour measurement, to minimise any possible impact of any small difference in the measurement interval. Sanded surfaces were wiped with a dry cloth to remove any loose dust.

Several other issues were also explored with the endgrain samples. Fine-sanding is a time-consuming process, so a colour measurement was taken on an unsanded surface (rough-sawn with a chainsaw) to examine if any useful information could be gleaned from such a surface. This colour measurement was taken on the opposite side (cf. upper versus lower surface) of the disk.

Wetting wood, especially endgrain, with water or oil causes the wood to darken and may highlight patterns in the wood. Thus we took additional colour measurements, from the same locations as the fine-sanded and rough-sawn samples, immediately after immersing the sample briefly in water. A final colour measurement was taken two days later, after the wetted surface had dried.

Results and Discussion

Boards

A study of a small sample of the boards confirmed that the tangential and radial faces were indistinguishable in colour (as previously reported[10]), so the radial-sawn face used for comparison.

Boards exhibited a mean dominant wavelength of 575.5 nm with a standard deviation of ±0.6 and a range from 573-577 nm, implying that all the boards have a yellowish hue. Expressed in CIE polar coordinates, the typical board has lightness L^*=77.2 (±2.5), chroma C^*=15.8 (±1.4), and hue $h°$=76.3 (±1.7). This means that boards are quite light (since L^* has a range 0-100 where 100% is bright white), pale (since C^* has a range 0-100% indicating the proportion of reflected light at the dominant wavelength), and yellowish (since $h°$ varies between 0-360° where 0° is red and 90° is yellow). In CIE rectangular coordinates, L^*= 77.2 (±2.5), a^*=3.8 (±0.6, a trace of red), and b^*=15.3 (±1.4, some yellow). Although the boards are quite pale, they have a low whiteness index of -30 (±12; a perfect reflecting diffuser is +100) on the E313 scale of the American Society of Testing and Materials.

The CIE standard measure of colour difference, ΔE ($=\sqrt{\Delta L^2+\Delta a^2+\Delta b^2}$), was used to assess how each board differed from the "typical" board. This difference averaged 8.4, and correlated most strongly with the yellowness (b^*) of the individual boards (r=0.23). This correlation, plus the observation that single samples of yellowness (b^*) may be characteristic of whole-tree colour[7], indicate that b^* offers a good basis for comparing trees and families of *E. dunnii*. Yellowness (b^*) was not significantly correlated with any easily-observable tree characteristics (height, diameter, etc), but was inversely related to density (P=0.05; denser wood is less yellow) and exhibited a statistically significant relationship with family affinity (P=0.008, after an inverse transformation to stabilise variance). This implies that yellowness

(b^*) is moderately heritable, and that tree-breeding efforts aimed at increasing wood density may also favour paler wood

[Figure 1 near here]

The sap-heartwood boundary was almost indistinguishable on most radially-sawn boards, and was most clearly visible on the sanded endgrain. The colour of the radial surface was rather similar to endgrain heartwood (colour difference ΔE=13±4), and tended to be paler than the endgrain sapwood (colour difference ΔE=21±4). The colour difference between the radial and endgrain surfaces was mainly due to a change in lightness (L^*; Table 1).

[Table 1 near here]

Endgrain

The endgrain of samples tended to be somewhat darker than the radial-sawn face, and tended to accentuate the difference between sap and heartwood (Table 1). The major difference between heart- and sapwood was in lightness, which varied by 8 units, whereas the difference in dominant wavelength was imperceptible.

Heartwood colour, especially its lightness (L^*), was correlated with tree size, with larger trees having darker heartwood, and less difference between sap and heartwood (Table 2). Sapwood, notably its whiteness (E313 index), was significantly (P<0.01) correlated with basic density and hardness (Pilodyn), with denser wood having a more yellow appearance. There is some suggestion that large colour differences between sap- and heartwood may be correlated with high radial shrinkage (Table 2).

[Table 2 near here]

Sanding is time consuming, but appears necessary to obtain reliable measurements of colour. Correlations between sanded and unsanded material are low (Table 3), and unlike sanded material (Table 2), unsanded material does not appear to offer any useful insights into wood properties. Dominant wavelength of unsanded material appeared to be relatively unbiased (Table 1), but this property exhibits a poor correlation with the fine-sanded material (Table 3).

[Table 3 near here]

Texture in wood can often be highlighted by wetting the sample with water or oil, so we remeasured our samples after dipping them briefly in water. Wetting in this way tended to darken the wood (reduce L^*) and increase the chroma (C^*, see Table 1), but did not significantly change the dominant wavelength or hue. Wetting the wood in this way did not reveal any new insights into wood quality; correlations between colour and wood properties were uniformly lower than those reported in Table 2, except for the correlation between heartwood and stem size (-0.33, -0.23 and -0.20 for L^*, b^* and whiteness index respectively, cf. Table 2).

It seems possible that sanding may cross-contaminate end-grain of samples, and that the rinsing of samples may remove dust left behind by sanding. Thus samples were reassessed for colour after rinsing and drying. However, the results were disappointing, and yielded few insights not already offered by the original fresh-sanded samples. The only substantial improvement offered by this treatment was in the correlation between heartwood and stem size (-0.33 and -0.22 for L^* and whiteness index respectively, cf Table 2).

[Figure 2 near here]

Complete spectral responses by 10 nm intervals for the full visible spectrum 400-700 nm were also recorded. Spectra derived from sapwood observations tended to form a series of parallel lines, but the heartwood data exhibited a greater range of trends. Figure 2 illustrates the spectral data from 182 samples of heartwood. Four of the samples have been highlighted with darker and heavier lines to emphasise the highest and lowest average values, and the greatest and least gradients. Many samples show a ‘kink’ at 680 nm, with reflectance at this wavelength greater than the general trend, but there is no obvious explanation for this phenomenon, and the magnitude of the kink was not correlated with observable wood properties. The first derivative of the spectral signatures was also examined, but it appears that the 10 nm resolution of the Miniscan XE is insufficient for informative analyses. These detailed spectral data offered no new insights not already revealed by the lightness (L^*), yellowness (b^*) and whiteness indices reported in Table 2.

Conclusions

E. dunnii has pale yellowish wood that is relatively uniform in colour within trees and between families. The variation in colour between families is small, but statistically significant (P=0.008). Most of the colour variation relates to the yellowness (CIE b^*) of the wood.

The colour of the endgrain, especially its lightness (L^*) and whiteness index (E313), is correlated with basic density, hardness (Pilodyn), and with rates of shrinkage, but does not appear to be informative about other wood properties in *E. dunnii*. Sanding of endgrain material is necessary to obtain reliable insights of wood colour and other properties, but there appeared to be no advantage in wetting samples to highlight colours and texture. Tristimulus data, especially the CIE rectangular (L^*, a^*, b^*) and polar (L^*, C^*, $h°$) opponent scales, appeared to be the most informative about wood colours and properties, and no additional information was gleaned from an analysis of full spectral data in the range 400-700 nm.

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Table 1. Mean colour data for boards and endgrain samples.

Sample	Dominant wavelength	Lightness L^*	Red a^*	Yellow b^*	Chroma C^*	Hue $h°$	Whiteness index
Sawn boards	576	77	4	15	16	76	-30
Rough-sawn sapwood	578	53	7	22	23	70	-128
Sanded sapwood	578	57	6	15	16	70	-77
Wetted sapwood	579	47	9	22	24	68	-151
Dried sapwood	578	56	6	16	17	70	-87
Rough-sawn heartwood	578	52	8	23	24	71	-141
Sanded heartwood	578	65	6	15	17	70	-61
Wetted heartwood	580	53	11	26	28	67	-155
Dried heartwood	578	63	6	18	19	71	-76

Table 2. Correlations between colour of dry fine-sanded endgrain and stem and wood properties.

	Sapwood			Heartwood			Sap:Heartwood
Property	L^*	b^*	WI[1]	L^*	b^*	WI[1]	ΔE
Tree size (Dbh)	0.01	0.03	-0.02	**-0.29**	-0.14	-0.10	**-0.24**
Basic density	-0.20	**0.27**	**-0.35**	-0.16	0.18	**-0.27**	0.02
Pilodyn hardness	**0.25**	**-0.25**	**0.37**	0.10	-0.18	0.23	-0.08
Tangential shrinkage	-0.19	0.14	**-0.25**	**-0.26**	0.07	**-0.27**	-0.07
Radial shrinkage	**-0.27**	0.00	-0.20	0.10	0.12	-0.03	**0.28**
Heritability	0.40	0.42	**0.47**	0.35	**0.64**	0.12	

1. WI is the Whiteness Index (E313). **Bold** font indicates significant correlations ($P<0.05$).
ΔE ($=\sqrt{\Delta L^2+\Delta a^2+\Delta b^2}$) measures the overall colour difference between sap- and heart-wood.

Table 3. The importance of sample preparation affects: correlations with dry fine-sanded end-grain samples.

	Sapwood					Heartwood				
Sample (endgrain)	*L**	*a**	*b**	DW[1]	WI[2]	*L**	*a**	*b**	DW[1]	WI[2]
Rough sawn	0.16	-0.02	0.14	0.15	-0.00	**0.61**	-0.01	**0.33**	-0.19	-0.04
Wetted rough sawn	**0.25**	0.12	0.14	0.22	-0.10	**0.64**	**0.30**	**0.46**	**-0.30**	-0.07
Wetted fine-sanded	**0.70**	**0.48**	**0.58**	**0.57**	0.24	**0.84**	**0.71**	**0.68**	**0.50**	**0.40**
Sanded, rinsed & dried	**0.85**	**0.81**	**0.78**	**0.80**	**0.76**	**0.91**	**0.92**	**0.75**	**0.90**	**0.73**

1. DW is the Dominant Wavelength. 2. WI is the Whiteness Index (E313).

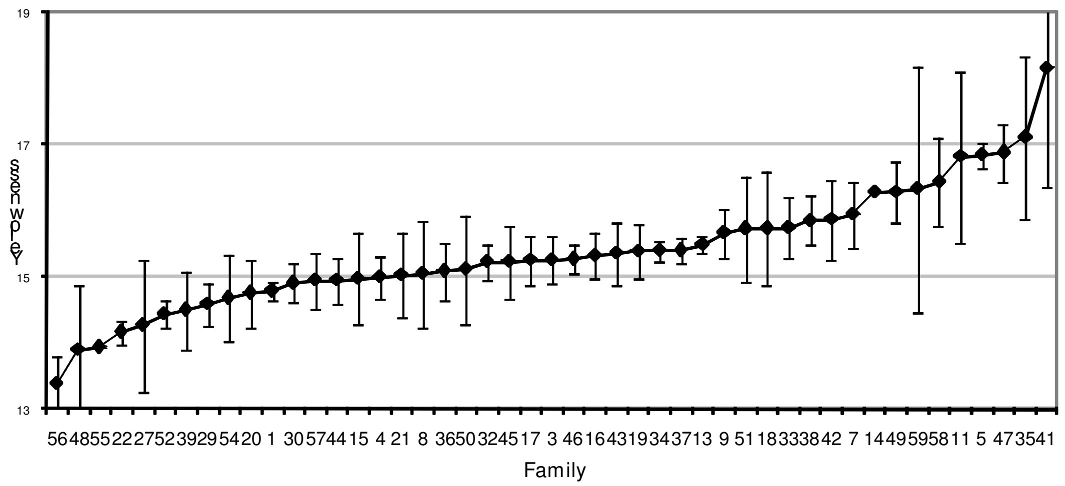

Figure 1. Average yellowness (CIE b^*) of radial-sawn *E. dunnii* boards, ranked by family, with error bars showing one standard error.

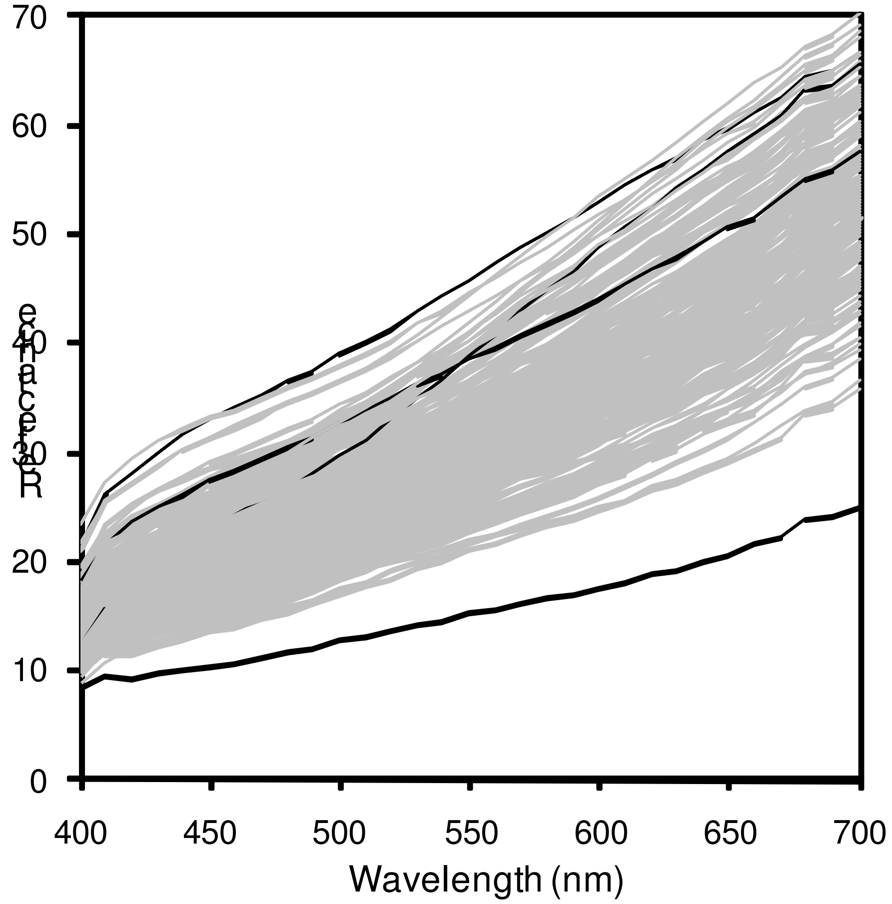

Figure 2. Spectral signatures of 182 heartwood samples by 10 nm intervals between 400 (blue) and 700 nm (red). The diversity in trends is indicated by the four dark lines illustrating families 30, 13, 36 and 52 (top to bottom).