Changes in density and wood-fibre properties with height position in 15/16-year-old *Eucalyptus nitens* and *E. fastigata*

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SUMMARY

Variation among trees in wood density and wood-fibre properties with height position was assessed for 29 trees each of *E. fastigata* and *E. nitens* from 15/16-year-old stands. Seven properties were measured, namely density, vessel-free density, microfibril angle, fibre perimeter, coarseness, wall thickness and the perimeter/wall thickness ratio (P/T_w ratio), all using SilviScan technology. The changes in species wood properties with percentage height were found to be significantly different for the two species. It was concluded that:

- Wood density, vessel-free density and the P/T_w ratio changed only slightly with increasing height position for *E. fastigata*, but markedly increased (decreased for P/T_w) for *E. nitens*.
- Fibre wall thickness increased with increasing height position for *E. nitens* and decreased for *E. fastigata*, in accordance with their different coarseness and perimeter.
- Species trends in chip density and kraft fibre dimensions with height showed similar trends to those of wood-fibre properties, except for coarseness. This difference was explained by the high lignin content of the *E. fastigata* (30.6 %) compared to that of the *E. nitens* (27.6 %) chips.

Keywords

Wood density, wood-fibre dimensions, microfibril angle, SilviScan, kraft fibre dimensions

In 1989, cooperative breeding programs were initiated in New Zealand for *Eucalyptus nitens*, *E. fastigata* and *E. regnans,* which were then considered the three eucalypt species most suitable for growing in commercial plantations for pulp production (*1*). A comprehensive program has been under way to quantify the potential of each species for pulp and paper products. The variation among trees in chemical, wood, and kraft fibre and pulp properties for 29 *E. nitens* (*2-4*) and 29 *E. fastigata* trees (*5*), aged 15/16 years, and 29 *E. regnans* trees (*6*), aged 20/21 years have recently been reported. Furthermore the among- and within-tree variation for different height positions have also been reported for nine of the *E. nitens* and nine of the *E. fastigata* trees (*7,8*). The individual-tree properties of cold soda mechanical pulps, made from the same nine-tree subsets of *E. nitens*, *E. fastigata* and *E. regnans* have also been reported (*9,10*). Both the 29 trees and their 9-tree subsets were selected within provenance/progeny trials, located in the central North Island of New Zealand, to cover the range of wood basic density available at each species' trial site.

In this study, the wood-fibre properties of 29 trees per species, including density, microfibril angle (MFA), and fibre perimeter, coarseness, wall thickness and perimeter/wall thickness (P/T_w) ratio, of *E. fastigata* and *E. nitens* were determined using SilviScan technology. Relationships among corresponding wood fibre and kraft fibre properties (*2,5,7,8*) and the influence of tree-height, were also considered. Both the radial and vertical patterns of within-tree variation will be described (for the 29 *E. nitens* trees) in a subsequent paper (*11*).

EXPERIMENTAL

Sample origin

Twenty-nine trees each of *E. fastigata* and *E. nitens* were obtained from two provenance/progeny trials, planted in 1979, located 4 km apart in Kaingaroa Forest in the central North Island of New Zealand (latitude ~38°27´S). Altitudes of each site were 270 m and 230 m respectively, with mean annual rainfall of both sites of 1300 mm and mean annual temperatures of 11.8°C and 12.2°C, respectively. In each case, a sub-set of 20 trees was processed in the first year (aged 15 years), with the remaining nine trees processed in the following year (aged 16 years) (*2,5*). The trees included in each of the 20- and nine-tree samples were selected to cover the range of densities of trees at each site, excluding suppressed trees.

Pith-to-bark strips were cut at time of felling from 5 cm-thick discs from each tree at nominal heights of 0, 1.4, 5.5, 11, 16.5 and 22 m, one radial strip per disc. Fibre properties were determined from each strip using SilviScan technology. All remaining material was used for assessments of pulping and solid-wood properties (*2,4-10*).

Wood-fibre properties

Transverse fibre dimensions and microfibril angle were determined on SilviScan 2 using image analysis, X-ray densitometry and X-ray diffractometry (*3,11-13*). All SilviScan samples were conditioned to 20°C and 40% RH. A single pith-to-bark radius was cut from each disc, then solvent-exchanged in ethanol and dried, and a thin pith-to-bark strip (2mm wide x 7mm high) was cut from each dried strip. Wood density, and fibre radial and tangential diameters were measured at 50 µm intervals along the strip. Fibre coarseness, outer perimeter (from radial and tangential diameters) and average wall thickness were generated from these primary measures. Estimates of vessel-free density were calculated from the vessel proportions in each strip, also determined using SilviScan-2 (*11*). The sampling point values for each property along the radial strip were weighted by annulus areas to calculate 'disc' values. Whole-tree mean wood and fibre properties were then calculated for each tree by interpolation and volume weighting of the 'disc' values obtained from all sampling heights.

Terminology

Chip basic density, kg/m^3 — D_c

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Wood density (air-dry), kg/m^3	D_{ss}
Vessel-free density, kg/m^3	Dv
Microfibril angle, °	MFA
Fibre perimeter, µm	P
Fibre wall thickness, µm	T_w
Fibre coarseness, µg/m	C
Fibre perimeter/wall thickness	P/T_w
Kraft fibre wall area, µm^2	A_w
Kraft fibre width/thickness	W/T

Statistical analyses

The individual-tree 'disc' values for the different properties were examined graphically. Seven of the *E. nitens* trees and nine of the *E. fastigata* trees had discs from various heights with very high density. These outliers had air-dry density values more than 100 kg/m^3 higher than for the adjacent-height discs, below and above. The pith to bark measurements of density for these discs showed that density was very high across multi-ring groups somewhere in the radial profile. These high density values were thought to be unrepresentative of the tree properties at this height and were probably caused by proximity to knots or by tension wood. For several discs these unusually high density regions were accompanied by high MFA. The data from these 16 high density discs were therefore excluded from model fitting, and the data from the zero height disc were also excluded. The problem posed by these anomalies has to be dealt with by selective rejection of data, because only one radial strip per height level was measured.

Linear mixed models for each characteristic were then fitted to the disc values at each height interval (expressed as 'percentage merchantable height') for each tree, across species, using the SAS MIXED procedure. The model fixed effects were 'species', and 'percentage merchantable height', and higher order polynomial and interaction effects. Likelihood ratio tests were used to determine the number of polynomial terms. The models' random effects were 'tree-within-species' (intercept) and 'per cent merchantable height x tree-within-species' (individual tree slope). An unstructured covariance structure for the random effects was used, with uniform variances for both species. The type III tests of fixed effects were used (Table 2) to determine the statistical significance of differences in regression slopes of the different properties on height as the independent variable, for each species (the species x per cent height interaction).

RESULTS AND DISCUSSION

Variation between species, *E. fastigata* and *E. nitens*, and among trees within species

Comparisons of the means of 29-tree samples of the two species, *E. nitens* and *E. fastigata*, are inextricably confounded with the different environmental effects of the two sites in Kaingaroa forest in which they were grown. However the sites were only separated by four km, with the *E. nitens* trial site at altitude 230 m and that of *E. fastigata* at 270 m . Thus any tests of differences between the two sets of trees test the combined effects of species and site.

There were significant differences ($P < 0.01$ level) between the whole-tree species means for MFA, coarseness and perimeter, but not for air-dry density, vessel-free density, the related perimeter/wall thickness (P/T_w) ratio, and fibre wall thickness (Table 1). MFA, coarseness and fibre perimeter all showed significantly higher values for *E. fastigata* than *E. nitens*. For all properties the species variance was not different. It is noteworthy that neither mean density nor mean P/T_w ratio of each tree or species convey the pattern of change with height within trees, or the interactive effects of variation in fibre perimeter and wall thickness or coarseness (which together determine the compound wood property of density (*14,15*)).

Effects of height position on wood and fibre properties of *E. fastigata* and *E. nitens*

Species means (predicted by linear mixed models) of the various wood and wood-fibre properties on per cent of merchantable tree height (based on 29 trees each of *E. fastigata* and *E. nitens*) are shown in Figures 1-4. Predicted property

Table 1
Whole-tree (excluding lower 1.4 m) volume-weighted species mean wood and fibre properties for *E. fastigata* and *E. nitens*.

	Density (D_{ss}) (kg/m^3)	Vessel-free density (D_v) (kg/m^3)	MFA (°)	Coarseness (C) (µg/m)	Perimeter (P) (µm)	Wall thickness (T_w) (µm)	P/T_w
E. fastigata							
Mean	587	618	15.1	114	54.6	1.59	34.7
Std. Dev.	52.6	60.4	1.43	6.6	2.04	0.14	3.9
Range	489-695	507-765	12.6-17.7	101-125	50.6-57.7	1.32-1.93	26.7-43.0
CV%	9.0	9.8	9.5	5.8	3.7	8.8	11.2
E. nitens							
Mean	580	615	13.5	106	52.9	1.53	34.8
Std. Dev.	43.9	46.6	1.26	5.1	1.49	0.11	3.1
Range	495-659	525-700	11.9-17.3	93-114	50.6-55.9	1.33-1.71	29.6-41.5
CV%	7.6	7.6	9.3	4.8	2.8	7.2	8.9
Means comparison (t-tests)	NS	NS	**	**	**	NS	NS
Variance comparison (F-test)	NS	NS	NS	NS	NS	NS	NS

* difference significant at 0.05 level
** difference significant at the 0.01 level

Table 2
Statistical significance of model effects.

Property	Fixed effect	df numerator	df denominator	F value	Probability*
D_{ss}	Species	1	56	3.75	0.0580
	%height	1	56	31.75	<0.0001
	Species x %height	1	56	41.13	<0.0001
D_v	Species	1	56	3.44	0.0690
	%height	1	56	33.28	<0.0001
	Species x %height	1	56	50.95	<0.0001
P	Species	1	56	3.09	0.0843
	%height	1	56	428.37	<0.0001
	Species x %height	1	56	20.52	<0.0001
T_w	Species	1	56	9.41	0.0033
	%height	1	56	5.31	0.0249
	Species x %height	1	56	37.37	<0.0001
C	Species	1	56	34.68	<0.0001
	%height	1	56	200.60	<0.0001
	Species x %height	1	56	19.40	<0.0001
P/T_w	Species	1	56	3.13	0.0823
	%height	1	56	34.20	<0.0001
	Species x %height	1	56	51.43	<0.0001
MFA	Species	1	56	0.11	0.7460
	%height	1	56	203.28	<0.0001
	Species x %height	1	56	16.56	0.0001
	$(\%height)^2$	1	56	317.35	<0.0001
	Species x $(\%height)^2$t	1	56	16.05	0.0002

* Probability that an F statistic this large or larger occurred by chance if the parameter value for the effect is zero. Type III tests are adjusted for the other effects in the model.

values at each 'per cent merchantable height' are those for 'discs', as indicated above. Per cent merchantable heights range from 4 to 100 based on the lower-most disc being at 1.4 m from ground, and the uppermost disc being of diameter 100 mm.

The slopes of the seven species mean property/per cent merchantable height relationships of *E. fastigata* and *E. nitens* are significantly (0.05 level), and often dramatically different (Fig. 1-4, Table 2). Hence, differences between the two species depend on the percentage height at which comparisons are made (Table 3). A fundamental difference between the two species is that density (and wall thickness) increases with height for *E. nitens*, while density decreases slightly and wall thickness, rapidly, for *E. fastigata*. Density, vessel-free density and the P/T_w ratio are similar for the two species in the lower and central stem but are different for the upper stem. In contrast, fibre perimeter for *E. nitens* is less than *E. fastigata* in the lower stem and diverges even more with increasing height. *E. nitens* has much lower coarseness (wall area) than *E. fastigata* in the lower stem but values converge in the upper stem. MFA values are higher only in the central stem of *E. fastigata* versus *E. nitens* (Table 3). These regressions of properties on height illustrate how differences between species can be non-significant for whole-tree mean density and wall thickness but highly significant (0.01 level) for whole-tree mean perimeter and coarseness (Table 1).

Further observations concerning the relationships of different properties with height position (Fig. 1-4) are as follows:

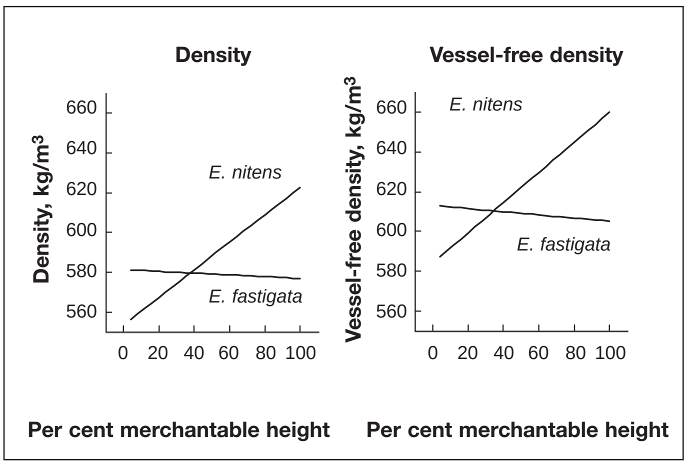

Fig. 1 **Model predicted species means of disc values of density and vessel-free density on per cent merchantable height for 29 trees each of *E. fastigata* and *E. nitens*.**

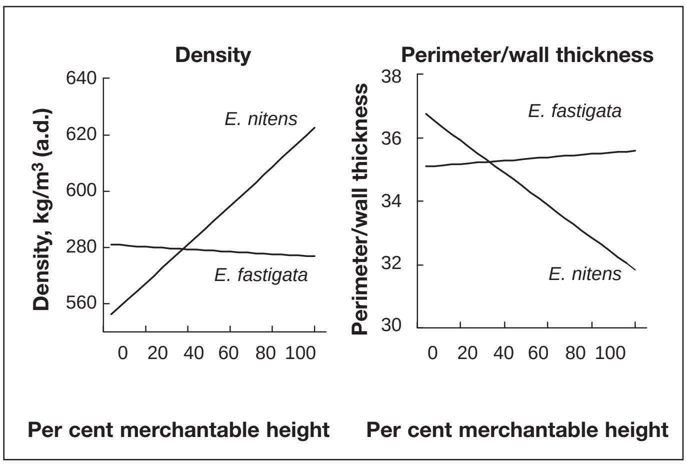

Fig. 2 **Model predicted species means of disc values of density and P/T_w ratio on per cent merchantable height for 29 trees each of *E. fastigata* and *E. nitens*.**

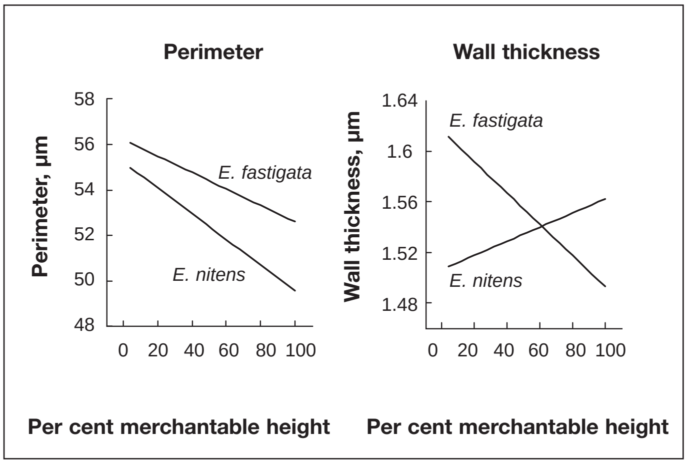

Fig. 3 Model predicted species means of disc values of perimeter and wall thickness on per cent merchantable height for 29 trees each of *E. fastigata* and *E. nitens.*

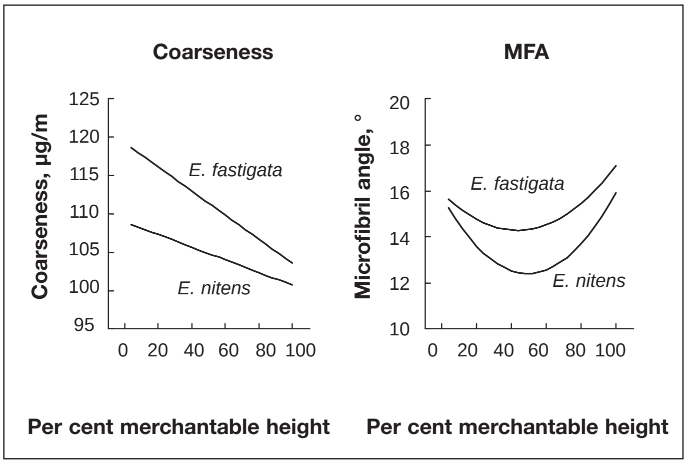

Fig. 4 Model predicted species means of disc values of coarseness and MFA on per cent merchantable height for 29 trees each of *E. fastigata* and *E. nitens*.

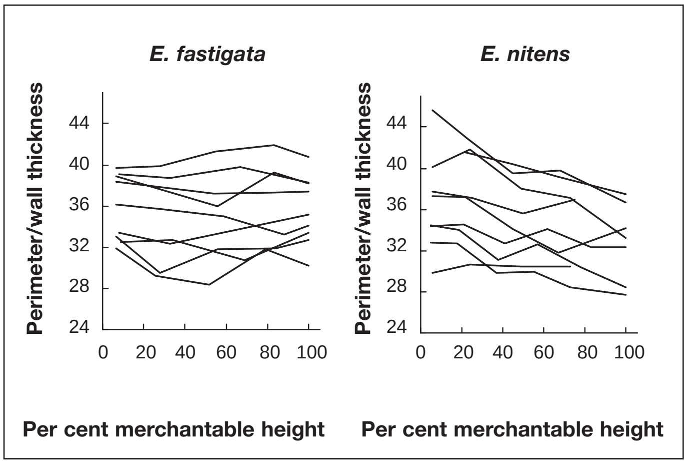

Fig. 5 Line plots of disc values of perimeter/wall thickness ratio on % height of 9 individual trees each of *E. fastigata* and *E. nitens*.

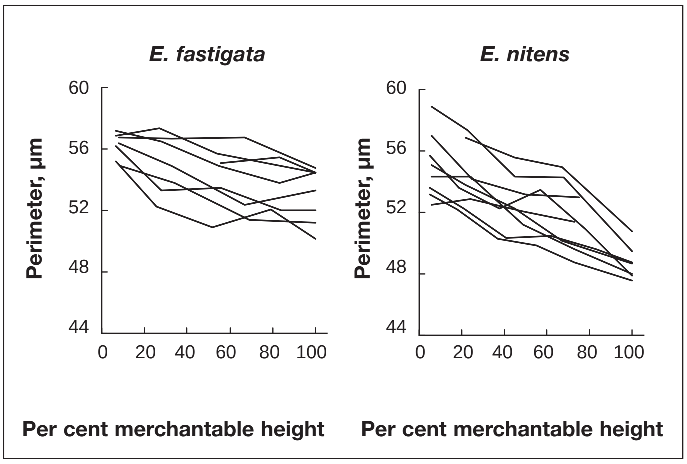

Fig. 6 Line plots of disc values of fibre perimeter on % height of 9 individual trees each of *E. fastigata* and *E. nitens*.

- Density and vessel-free density behave similarly, although the vessel-free values are higher by 20 to 25 kg/m^3 (Fig. 2) (*11*). The similar density and vessel-free-density relationships reflect similar vessel proportions in *E. fastigata* (4.9 %) and *E. nitens* (5.7 %).
- The perimeter/wall thickness ratio (an indicator of fibre collapse potential (*14*)) and density curves show similar but reversed trends (Fig. 2). The model-predicted means at different height positions for the two species (Table 3) are very different, with those for density of *E. nitens* increasing and those for P/T$_w$ decreasing with increasing tree-height. For *E. fastigata*, on the other hand, density and the P/T$_w$ ratio change only slightly with height.
- Fibre perimeters of *E. fastigata* are larger, and their rate of decrease with increasing tree-height is slower, than those of *E. nitens* (Fig. 3). Very different wall thickness trends are obtained for the two species, with values respectively decreasing (*E. fastigata*) and increasing (*E. nitens*) with increasing tree-height. These perimeter and wall thickness trends for the two species reflect the increase in density and decrease in the perimeter/wall thickness ratio of *E. nitens* at increasing height. They also reflect the flat density and P/T$_w$ profiles of *E. fastigata* (Fig. 2).

Variation among trees of *E. fastigata* and *E. nitens* in the relationships of different fibre properties with height

The variation among trees in whole-tree wood/fibre properties for both species is indicated by their ranges and by coefficients of variation and standard deviations (Table 1). There is also tree-to-tree variation in trends with height, if disc values of P/T$_w$, perimeter, wall thickness and MFA are plotted against per cent merchantable height, as shown for the 9-tree sub-sets of each species (Fig. 5-8). Also, similar levels of among-tree variation were obtained for density and fibre coarseness (unreported). The sometimes-erratic nature of the line plot trends with height is probably due to only one radial sample being measured at each height position.

The P/T$_w$ ratio is generally unchanged with increasing height for the *E. fastigata* individual-tree line-plots, and decreases for *E. nitens* with increasing height (Fig. 5). These trends are in agreement with the model-predicted mean curves (Fig. 2). Two of the nine *E. fastigata* individual-tree line-plots show minimum values at intermediate tree-heights, examples of the high-density disc outliers, excluded from the model fitting. Similar high among-tree variation is shown for perimeter and wall thickness (Fig. 6,7). It is noteworthy that fibre perimeter is significantly different for the two species in species-mean and sampling-height comparisons (Tables 1,2,3). Wall thickness, the second component in the P/T_w ratio, shows high among-tree variation together with high levels of overlap among the line plots of *E. fastigata* and *E. nitens* individual trees (Fig. 7). While the differences between species in wall thickness with tree-height are significant as a result of their reversed slopes (Table 3), the whole-tree means for each species do not differ significantly (Table 1), neither do predicted mean values at intermediate heights (Table 3).

The variation among trees, and the resulting overlap between tree-sets (Fig. 5,6,7), makes it difficult to identify wood property differences between species from the individual-tree line plots. The best guide is curve shape and slope of the average-tree model-predicted regressions (Fig. 1-4, Table 2).

The among-tree variation in line plots of MFA for *E. fastigata* appears higher than for *E. nitens* (Fig. 8), although the difference in whole-tree variance between species is not significant (Table 1). The high *E. fastigata* MFA value at 100% merchantable height lies within the range for the species since similar high MFAs are obtained for four of the remaining 20 trees. Similarly, two of the remaining 20 *E. fastigata* trees have MFA values of about 18 degrees at the ≈6 % height level (1.4 m from ground). Hence the trends of Figure 8 are in agreement with the model-predicted mean MFA regressions of Figure 4.

Wood fibre versus kraft fibre property relationships

The shapes and slopes of the wood property/tree-height relationships of Figures 1-4 are generally similar to those obtained for corresponding trends in log-height for kraft pulp fibres and chip density (*8*). The kraft fibre data are based on the 9-tree sub-sets (of each species), whereas those used for Figures 1-4 are based on data for all 29 trees of each species. While the P/T_w ratio is an indicator of wood fibre collapse potential, the kraft fibre width/thickness ratio is a direct measure of the level of collapse of unrefined fibres in handsheets. The trends of variation with tree height for density, wood fibre perimeter, wall thickness and the P/T_w ratio (Fig. 5-7), are similar to those for chip density and kraft fibre perimeter, wall thickness and the width/thickness ratio (*8*).

Wood fibre coarseness is derived from vessel-free density and wood fibre dimensions, and can be compared with corresponding kraft fibre wall area values. Separate wood-fibre coarseness curves (Fig. 4), and a single kraft wall area curve (8), were obtained for *E. fastigata* and for *E. nitens*. Wood-fibre coarseness is greatest for *E. fastigata* with the differences between species decreasing with increas-

Table 3
Comparison of model-predicted species means at various percentage heights.

Property	Percentage height	*E. nitens* predicted mean	*E. fastigata* predicted mean	Difference in means	t-test at 0.05 level
D_{ss}	5	557	581	-24	NS
	25	557	580	-9	NS
	50	588	579	9	NS
	75	605	578	27	S
	100	622	577	45	S
D_v	5	587	613	-25	NS
	25	603	611	-8	NS
	50	622	609	13	NS
	75	641	607	34	S
	100	660	605	55	S
P	5	54.9	56.0	-1.1	S
	25	53.8	55.3	-1.5	S
	50	52.4	54.4	-2.0	S
	75	51.0	53.5	-2.5	S
	100	49.6	52.6	-3.0	S
T_w	5	1.51	1.61	-0.10	S
	25	1.52	1.59	-0.07	S
	50	1.53	1.55	-0.02	NS
	75	1.55	1.52	0.02	NS
	100	1.56	1.49	0.07	S
C	5	108.6	118.5	-9.9	S
	25	106.9	115.4	-8.4	S
	50	104.9	111.4	-6.5	S
	75	102.8	107.5	-4.7	S
	100	100.7	103.6	-2.9	NS
MFA	5	15.13	15.58	-0.44	NS
	25	13.24	14.59	-1.35	S
	50	12.42	14.33	-1.91	S
	75	13.31	15.16	-1.84	S
	100	15.93	17.07	-1.14	S
P/T_w	5	36.70	35.11	1.59	NS
	25	35.68	35.21	0.46	NS
	50	34.40	35.34	-0.94	NS
	75	33.12	35.47	-2.35	S
	100	31.84	35.60	-3.76	S

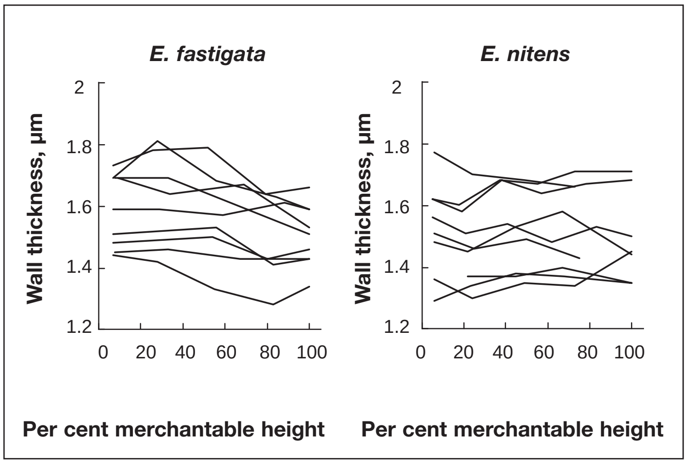

Fig. 7 Line plots of disc values of fibre wall thickness on % height of 9 individual trees each of *E. fastigata* and *E. nitens*.

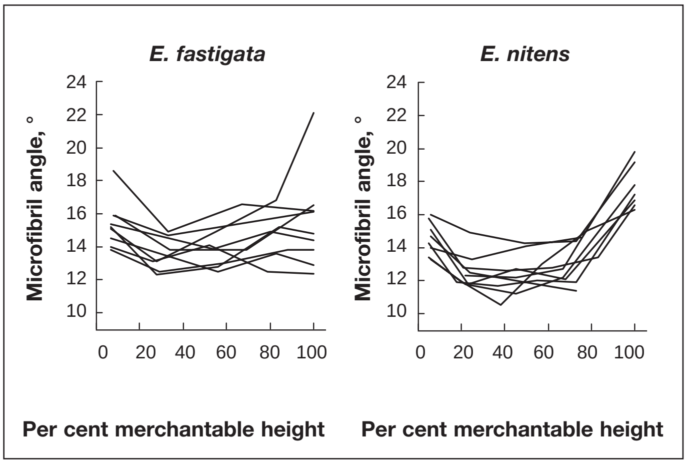

Fig. 8 Line plots of disc values of MFA on % height of 9 individual trees each of *E. fastigata* and *E. nitens*.

ing tree-height (Fig. 4). This difference between the two species is at variance with the similar kraft fibre coarseness of both species (*8*). It is suggested that the wood fibre coarseness (wall area) values of the two species become similar as lignin contents are brought to the same value by kraft pulping. Mean lignin contents for the 29 *E. fastigata* (30.6 %) and *E. nitens* (27.6 %) tree-sets differed by 3 % (*8*).

Correlations among whole-tree wood and wood-fibre property means for each species set of 29-trees (Table 1), as well as between the wood-fibre (Table 1) and corresponding kraft-fibre (*8*) properties were calculated (Tables 4,5). Some points of note are as follows:

- Strong and significant (0.01 level) correlations exist between chip density (D_c), wood density (D_{ss}) and vessel-

Table 4
Correlation matrix ® based on mean whole-tree property values for 29 *E. fastigata* trees.

	D_c	D_{ss}	D_v	C	P	T_w	P/T_w	MFA	P (kraft)	A_w (kraft)	T_w (kraft)	W/T (kraft)	P/T_w (kraft)
D_c	1												
D_{ss}	0.91	1											
D_v	0.93	0.99	1										
C	0.51	0.61	0.62	1									
P	-0.79	-0.81	-0.8	-0.04	1								
T_w	0.88	0.95	0.96	0.81	-0.62	1							
P/T_w	-0.91	-0.99	-0.99	-0.64	0.79	-0.96	1						
MFA	-0.53	-0.56	-0.58	-0.47	0.39	-0.59	0.58	1					
P (kraft)	-0.56	-0.54	-0.53	0.06	0.72	-0.38	0.52	0.2	1				
A_w (kraft)	0.02	-0.07	-0.03	0.26	0.24	0.06	0.02	-0.08	0.72	1			
T_w (kraft)	0.61	0.46	0.49	0.24	-0.44	0.45	-0.5	-0.26	-0.07	0.63	1		
W/T (kraft)	-0.88	-0.84	-0.85	-0.45	0.74	-0.8	0.85	0.63	0.53	-0.06	-0.62	1	
P/T_w (kraft)	-0.78	-0.65	-0.67	-0.22	0.68	-0.58	0.67	0.31	0.47	-0.26	-0.91	0.77	1

Table 5
Correlation matrix ® based on mean whole-tree property values for 29 *E. nitens* trees.

	D_c	D_{ss}	D_v	C	P	T_w	P/T_w	MFA	P (kraft)	A_w (kraft)	T_w (kraft)	W/T (kraft)	P/T_w (kraft)
D_c	1												
D_{ss}	0.93	1											
D_v	0.91	0.99	1										
C	0.72	0.74	0.71	1									
P	-0.64	-0.74	-0.78	-0.11	1								
T_w	0.91	0.98	0.97	0.86	-0.6	1							
P/T_w	-0.91	-0.99	-0.9		-0.7	0.78	-0.97	1					
MFA	-0.02	-0.11	-0.14	-0.09	0.12	-0.14	0.15	1					
P (kraft)	-0.21	-0.31	-0.35	0.02	0.52	-0.25	0.34	0.08	1				
A_w (kraft)	0.12	0.01	-0.01	0.13	0.14	0.04	0	-0.07	0.85	1			
T_w (kraft)	0.38	0.33	0.34	0.17	-0.31	0.31	-0.34	-0.23	0.38	0.77	1		
W/T (kraft)	-0.74	-0.83	-0.85	-0.6	0.66	-0.82	0.84	0.32	0.27	-0.07	-0.4	1	
P/T_w (kraft)	-0.55	-0.55	-0.57	-0.16	0.64	-0.47	0.57	0.25	0.0	-0.47	-0.88	0.56	1

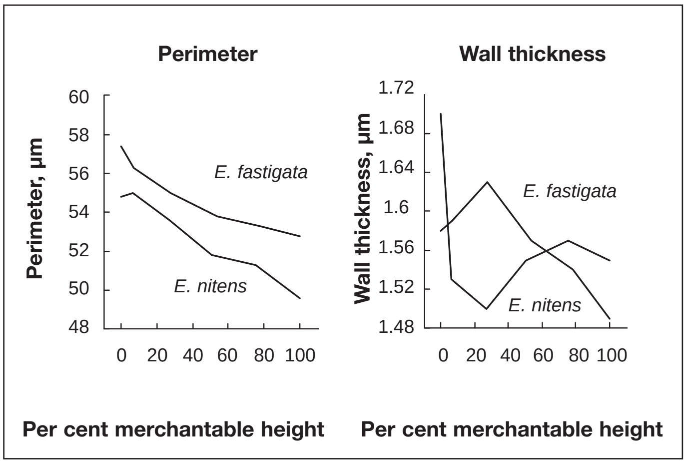

Fig. 9 Line plots of species-mean disc fibre perimeter and wall thickness on percentage-height for 29 trees each of *E. fastigata* and *E. nitens*, with zero-height values included (for *E. nitens*, the zero percentage height values are an average for 9 trees only).

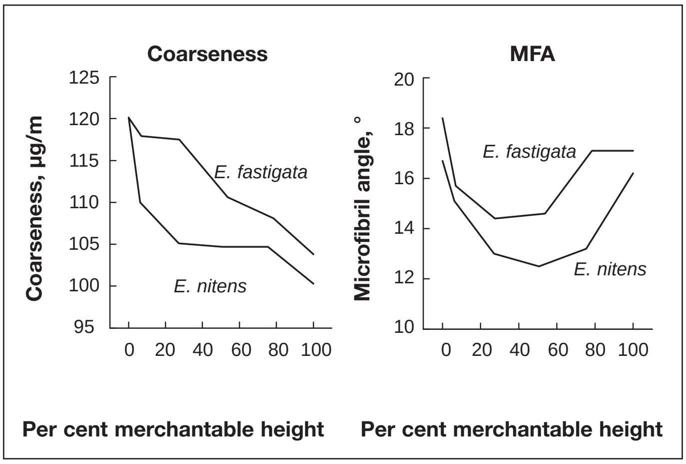

Fig. 10 Line plots of species-mean disc fibre coarseness and MFA on percentage-height for 29 trees each for *E. fastigata* and *E. nitens*, with zero-height values included (for *E. nitens*, the zero percentage height values are an average for 9 trees only).

free density (D_v), as well as between these estimates of whole-tree density and the wood-fibre P/T_w ratio, as expected (*2,5*).

- The kraft-fibre width/thickness (W/T) ratio, which is a direct measure of fibre collapse, is also strongly correlated with the three estimates of density, as well as with the wood-fibre P/T_w ratio, as expected (*2,5*). In contrast, the kraft-fibre P/T_w ratio is only moderately correlated (r = 0.6 to 0.8 for *E. fastigata*) and weakly (r= 0.5 to 0.6 for *E. nitens*) with wood density and wood-fibre P/T_w ratio, again as expected. These correlations are significant at the 0.01 level.
- Correlations between wood-fibre and kraft-fibre perimeter (P) are weak to moderate (but significant at 0.01 level), depending on the species. However the correlation of wood-fibre coarseness and kraft-fibre coarseness, or wall area (A_w), was weak and not significant (0.01 level). The correlation between wood- and kraft-fibre wall thickness was similarly weak. These weak correlations between wood- and kraft-fibre properties concur with those obtained with radiata pine (*16*). It has been suggested for radiata pine that the poor correlations for wall area and wall thickness could be related to a non-uniform response of latewood fibre populations to kraft pulping (*16*).

Wood-fibre properties at the base of the tree in *E. fastigata* and *E. nitens*

Wood-fibre perimeter, wall thickness and coarseness, as well as the P/T_w ratio, density and MFA at the base of a tree can be very different from those elsewhere in the stem (Fig. 9-11). The data used to generate Tables 1-5 and Figures 1-8 omitted the zero height disc and extended from the breast height (1.4 m) disc, up the tree to a 100 mm-diameter top disc. The effect of the basal disc is particularly marked for *E. nitens*, where disc values for fibre wall thickness and coarseness, and density increase markedly at zero height compared to those at 1.4 m. For *E. fastigata*, on the other hand, the effect is smaller and possibly in line with the generally flat profiles of the P/T_w and density regressions (Fig. 1,2) and line plots (Fig. 5,11).

It is recognised that wood-fibre property trends can change in the lower part of the tree for *E. nitens* and for some other but not all eucalypts (*7,8,17,18*). The change is however, generally gentle and continuous. There are indications (to be confirmed) that the abrupt changes at zero-height in *E. nitens* wood-fibre properties (Fig. 9-11) are confined to the lowermost 30 to 50 mm of a stem.

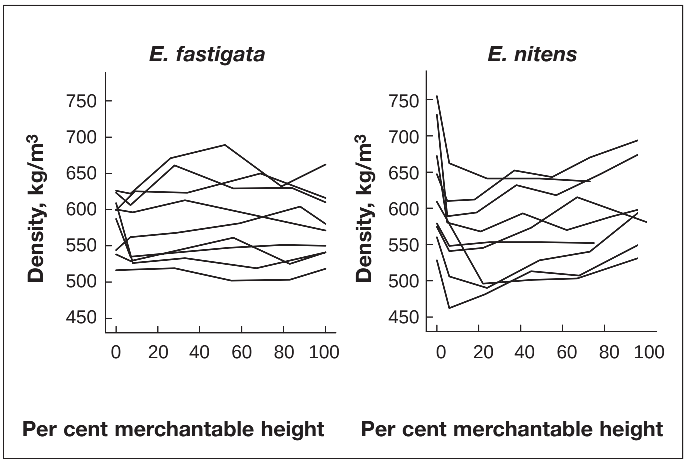

Fig. 11 Line plots of mean disc density on percentage-height for 9 E. fastigata and 9 *E. nitens* trees, with zero-height values included.

CONCLUSIONS

There was substantial variation among trees of *E. nitens* and *E. fastigata* in wood and wood-fibre properties of density, vessel-free density, microfibril angle, and fibre perimeter, coarseness, wall thickness and the perimeter/wall thickness ratio. There were also well-defined patterns of variation within trees in most properties with increasing height up the tree.

Species-mean whole-tree density, vessel-free density, fibre wall thickness and perimeter/wall thickness ratio values were not significantly different for the 29-

tree sets of *E. fastigata* and *E. nitens* (which were grown on different but not distant sites). Their mean fibre perimeter and coarseness, and MFA values, were, on the other hand, very different. Hence, neither mean density nor mean P/T_w ratio of each tree or species convey the pattern of change with height within trees, or the interactive effects of variation in fibre perimeter and wall thickness or coarseness (which together determine wood density).

The relationships of the different wood and fibre properties to height up the tree stem, characterised by the shape and/or slope of the species model predicted means, were significantly different (0.01 level) for *E. fastigata* and *E. nitens* for each of the seven property/% height relationships. Also, each of the seven wood-fibre properties was different for the two species at some part of the stem.

The shapes and trends of wood-fibre and kraft-fibre species means with height were very similar for perimeter and wall thickness but not for coarseness. Average-tree lignin contents were significantly different for *E. fastigata* (30.6 %) and *E. nitens* (27.6 %). While wood-fibre coarseness species-mean/height relationships were different for each species, the kraft-fibre coarseness species-mean/height relationship was not significantly different for the two species, when pulped to the same Kappa number (lignin content).

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