Within-tree variation of some wood and kraft fibre properties of *Eucalyptus fastigata* and *E. nitens*

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The variation in wood density, wood chemistry and kraft fibre properties with height position are compared for nine-tree samples from 16-year-old stands of E. fastigata and E. nitens. The shapes of the average-tree predicted models for the two species are significantly different (0.10 level) for all properties except fibre wall area (coarseness) and relative number of fibres. Some specific conclusions are:

- Wood density and resistance to fibre collapse change only slightly with increasing height position for E. fastigata, but markedly increase for E. nitens.
- Kraft fibre wall thickness increases for E. nitens and decreases for E. fastigata, with increasing height position, in accordance with their similar wall areas but different perimeters.
- Wood glucose, xylose and lignin model-predicted means are significantly different (0.05 level) for E. fastigata and E. nitens.

KEYWORDS

Fibre dimensions, lignin, carbohydrates, extractives, kraft handsheets

In 1989, cooperative breeding programs were initiated for *Eucalyptus nitens*, *E. fastigata* and *E. regnans*, which were the three eucalypt species considered to be most suitable for growing in New Zealand in commercial plantations for pulp production (*1*). A comprehensive program has been underway to quantify the potential of each species for pulp and paper products. The wood, and kraft fibre and pulp property variation among 29 *E. nitens* and 29 *E. fastigata* trees of age 16 years, and for different height positions (logs) of nine of the *E. nitens* trees, have recently been reported (*2-6*). The properties of cold soda chemimechanical pulps made from nine of the 29 *E. nitens* trees have also been reported (*7*) with comparable information on *E. fastigata* and *E. regnans* forthcoming. Both the 29- and 9-tree sets were selected to cover the range of wood basic density available within provenance/progeny trials at each species' trial sites, located in the central North Island of New Zealand.

Recent research reports detail the wood density, wood chemistry and kraft fibre property variation with height position for nine of the 29 *E. nitens* (*5*), and the radial and vertical variation in wood density and microfibril angle for the same 29 *E. nitens* trees using SilviScan 2 (*6*). Some average-tree critical property distribution trends for the two species are summarised as follows:

- Chip basic density, and xylose and ash contents, increase linearly with increasing height position in the tree, whereas lignin content initially decreases then increases, and glucose content decreases. Kraft fibre properties of length, perimeter and wall area normally decrease with increasing height position. Hence, for toplogs, numbers of fibres and handsheet apparent density values are higher than expected when compared to chip density.
- Wood density increases with increasing height position, but the radial variation is less predictable than in radiata pine (SilviScan 2 measurements (*6*)). Microfibril angle is in the range 20 to 30 degrees near the pith at all heights and decreases towards the bark to about 10 degrees. Less variation is found over most of the height of the tree, but microfibril angle tends to increase at the base and top of the stem.

In this report, the wood density, wood chemistry and kraft fibre property variation with height position are compared for the nine-tree sets of *E. fastigata* and *E. nitens*.

EXPERIMENTAL

Sample origin

For both *E. fastigata* and *E. nitens* the trees used (aged 16 years) in these individual-log studies were nine of 29 selected trees previously assessed for individual-tree wood, and kraft fibre and handsheet properties (*2,3*). Trees were obtained from provenance / progeny trials in Kaingaroa Forest, in the central North Island of New Zealand.

For both species the nine-tree samples were made up of three trees of low, three of high and three of medium density. Logs were numbered from 1 to 5 starting from ground level, with each log being 5.5 m long (except the toplogs which were taken to 100 mm s.e.d. and ranged in length from 4 to 7 m). Only the upper 4.1 m of the butt log was chipped since the lower 1.4 m billet was used for solid wood property assessment (*4*). Each log was chipped separately in a commercial chipper and the accept chips were those that passed through a 40 mm diameter overs screen and were retained on a 10 mm diameter screen. Individual-log chips were collected at the chipper outfall, sampled, and then all the chips of the logs of each tree were bulked and well-mixed before individual-tree chip samples were taken (*2,3*).

Chip basic density

Chip basic density was determined in accordance with AS 1301.P1s-79, except that the fresh chips were not given the specified soaking period (*8*).

Chemical analyses

300 g o.d. chip samples were collected for chemical analyses prior to pulping. Chips were air-dried for three days prior to grinding (20 mesh). Samples were extracted in a Soxtec extractor with dichloromethane – boiling time 30 minutes, rinsing time 60 minutes. Extractives were vacuum dried overnight. Moisture contents were determined on separate samples.

Dichloromethane extracted samples were further ground to 40 mesh for analysis of lignin and carbohydrates. After acid hydrolysis these were analysed following Tappi T222 om-88 for lignin, Tappi um 250 for acid soluble lignin, and the method of Pettersen and Schwandt (*9*) for carbohydrates. Reported klason lignin values could include some non-lignin polyphenolic substances not extracted by dichloromethane (AS 1301. P11s-78, J. A. Lloyd unpublished data).

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Ash, hot water solubles and 1% sodium hydroxide extractives were also determined for the air-dried chip samples as follows:

- Ash was determined according to ASTM D1102 at 580°C to constant weight.
- Hot water solubility was determined following TAPPI T207 om-88.
- One per cent sodium hydroxide solubility was determined following TAPPI T212 om-88.

Pulping

One kraft pulp of Kappa number 20±2 was prepared from each chip sample by varying the H-factor at constant alkali charge. The pulping conditions were:

12% effective alkali as Na_2O
33% sulfidity
4:1 liquor-to-wood ratio
90 minutes to maximum temperature
170°C maximum temperature

Pulps were prepared in 2.0 L pressurised reactors with 300 g o.d. chip charges. Pulps were disintegrated with a propeller stirrer and screened through a 0.25 mm slotted flat screen. After dewatering and fluffing, Kappa number, % rejects and total yield were determined. Single point pulping was carried out for the individual-log samples wherever possible and, hence, estimates of pulp yield were only semi-quantitative at best. For this reason, individual-log pulp yields at Kappa 20±2 were excluded from the database.

Handsheet preparation and evaluation

Handsheets were prepared and pulp physical evaluations made in accordance with AS/NZS 1301.procedures. The load applied during pulp refining with the PFI mill was 1.77 N/mm. Pulps were refined at 10% stock concentration for 500, 1000, 2000 and 4000 rev.

Table 1
Definitions of fixed and random effect variables.

a	Tree age less average number of log growth rings
s	Species
t	Tree identification
s*a	Species by age less growth rings interaction
t(s)	Tree identification within species

Fibre dimensions and relative number

Cross-sectional kraft-fibre dimensions of thickness, width, wall area and wall thickness were measured using image processing procedures described previously (Fig. 1) (*10*). Measurements were made on dried and rewetted fibres reconstituted from kraft handsheets. The ratio, width/thickness, is an indicator of the level of collapse of the dried and rewetted fibres. The greater the width and the lower the thickness of a fibre cross-section, the greater is the extent of fibre collapse. Relative number of fibres per unit mass of pulp was calculated using the reciprocal of the length x wall area product. Length weighted average fibre lengths were determined with a Kajaani FS 200 instrument using Tappi T271 pm-91.

Statistical analyses

Wood and fibre property models for the *E. fastigata* and *E. nitens* 9-tree data sets were calculated using the SAS Mixed Procedure. The initial models were polynomial models with the fixed effects a, a^2, a^3, a^4, s, s*a, s*a^2, s*a^3, s*a^4 and random effects t(s), t(s)*a, t(s)*a^2, where a, s, and t are defined as in Table 1. The initial estimates of covariance parameters were for an unstructured covariance model. Backward elimination of higher order random and fixed effects was used to drop terms from the initial model until the highest order terms remaining in the final model were significant at the 0.10 level.

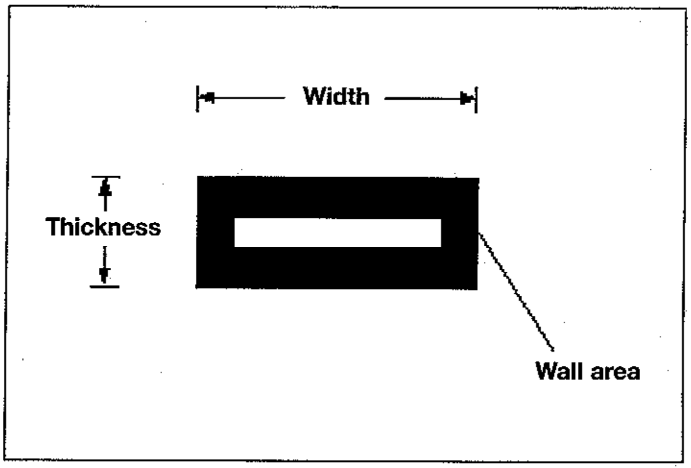

Fig. 1 **Cross section diagram of a fibre dried and rewetted from a handsheet.**

RESULTS AND DISCUSSION

The wood density and chemistry, kraft fibre and handsheet property values (at 500 PFI mill rev) are listed in Table 2 for the *E. fastigata* log-set, and elsewhere for *E. nitens* (*5*). The basis of comparison among logs is tree age less mean number of growth layers per log, simplified to 'age-less-rings' throughout the text, which increases with increasing height position or log number from the ground. Log number from the ground was used in an earlier assessment of the logs from 9 trees of *E. nitens* (*5*). The different numbers of logs in the *E. fastigata* (2 x 3 logs, 7 x 4 logs) and *E. nitens* (6 x 4 logs, 3 x 5 logs) 9 - tree sets required that the age-less-rings of each log be used as the comparative base for the two species.

For most properties *E. fastigata* and *E. nitens* have significantly (0.10 level) different slopes or shapes of the regression relationships between age-less-rings and properties, except for fibre length, wall area, and relative number of fibres which did not have a significant species by age-less-rings interaction (Table 3). The species have significantly different fibre lengths, but the relationships between age-less-rings and length are not significantly different for the two species. For fibre wall area and relative number of fibres the differences between species in location (intercept), slope, or shape are not significant at the 0.10 level. For the other properties the relationship with age-less-rings is different for the two species, and hence the size and statistical significance of differences between species is dependent on the age-less-rings value at which the species are compared.

Table 2
Wood density and chemistry, and kraft fibre and handsheet properties, of the logs of nine trees of *E. fastigata*.

Tree, log and pulp numbers	Tree age less mean growth layers per log	Handsheet properties at 500 rev PFI mill				Individual-log chip properties					Individual-log kraft fibre properties								
		Apparent density (kg/m³)	Tensile index (Nm/g)	Stretch (%)	Light scattering coefficient (m²/kg)	Basic density (kg/m³)	Total lignin (g/100g)	Ash g/100g	Glucose g/100g	Xylose g/100g	Length (mm)	Width (µm)	Thickness (µm)	Width + thickness (µm)	Width x thickness (µm²)	Wall area (µm²)	Wall thickness (µm)	Width / thickness	Relative number of fibres
D/1/96939	2.5	641	83	2.53	36.14	486	31.2	0.21	45.1	11.3	0.89	12.9	6.6	19.5	85	55	2.19	2.05	116
D/2/96928	6	663	83	2.71	33.44	488	30.4	0.23	44.9	12.0	0.85	13.5	6.7	20.2	91	61	2.37	2.09	109
D/3/96923	9.5	724	89	2.98	32.81	482	31.2	0.49	41.4	15.7	0.79	14.3	6.2	20.6	89	56	2.01	2.40	128
E/1/96924	2	667	82	2.44	33.45	478	30.8	0.16	43.6	14.2	0.84	13.9	6.3	20.2	88	60	2.39	2.27	113
E/2/96934	4	641	86	2.32	32.86	497	30.5	0.22	43.3	14.9	0.84	13.3	6.8	20.1	90	60	2.35	2.05	113
E/3/96937	6	655	80	2.16	33.42	499	-	-	-	-	0.82	12.7	6.6	19.3	85	57	2.44	1.97	121
E/4/96929	9	660	89	2.67	33.94	482	30.8	0.31	41.0	15.8	0.77	13.6	6.3	19.9	87	58	2.33	2.22	127
F/1/96935	2	673	87	2.47	32.69	465	32.6	0.19	41.4	13.7	0.89	13.7	7.0	20.8	97	64	2.39	2.01	100
F/2/96910	4.5	657	84	2.47	32.45	490	31.3	0.20	43.1	14.0	0.89	13.4	6.7	20.2	91	59	2.19	2.09	108
F/3/96920	7	697	91	2.71	32.47	480	31.8	0.28	41.2	15.2	0.82	13.3	6.8	20.1	90	60	2.35	2.05	115
F/4/96921	9	712	87	2.81	30.56	475	31.8	0.21	43.5	14.0	0.80	13.5	6.7	20.2	91	57	2.19	2.10	121
H/1/96938	2.5	660	84	2.66	32.6	488	31.8	0.20	44.4	11.8	0.92	13.2	6.8	20.1	91	61	2.42	2.02	100
H/2/96925	4.5	649	91	2.71	33.1	501	30.0	0.22	43.0	13.5	0.92	13.8	6.3	20.1	87	5	2.35	2.27	109
H/3/96918	7	666	85	2.61	33.9	508	30.6	0.24	43.0	14.1	0.88	12.8	6.5	19.3	84	55	2.24	2.02	116
H/4/96913	9.5	636	88	2.74	33.9	510	30.7	0.29	42.3	14.7	0.85	12.4	6.4	18.9	80	53	2.20	2.00	125
I/1/96914	1	668	84	2.55	31.8	429	29.3	0.26	45.8	11.9	0.94	13.9	7.0	20.9	98	64	2.39	2.06	94
I/2/96942	4.5	665	93	2.28	31.6	446	28.6	0.23	44.3	14.3	0.92	14.3	6.7	21.0	96	65	2.42	2.25	94
I/3/96911	7.5	687	93	2.37	32.3	464	28.9	0.30	42.7	15.1	0.83	13.8	6.8	20.6	94	63	2.32	2.11	108
I/4/96917	9	712	95	2.72	31.6	478	29.5	0.33	42.2	15.6	0.81	13.5	6.4	19.9	86	55	2.10	2.19	127
A/1/96930	2.5	677	94	2.48	31.11	416	30.4	0.23	45.9	12.0	0.93	13.7	6.4	20.2	88	59	2.34	2.24	103
A/2/96933	5	671	90	2.37	32.20	423	29.1	0.25	44.6	13.9	0.91	13.5	6.9	20.5	94	62	2.37	2.06	100
A/3/96941	7	678	97	2.44	32.44	431	29.4	0.30	44.7	14.3	0.90	13.1	6.4	19.6	85	55	2.23	2.12	114
A/4/96915	8	728	106	2.96	32.39	415	30.2	0.39	43.4	14.5	0.80	13.7	6.6	20.3	90	58	2.17	2.17	122
G/1/96916	2	705	95	2.65	32.0	434	30.1	0.30	43.3	14.1	0.92	13.7	6.5	20.3	91	58	2.18	2.18	106
G/2/96912	5	696	103	2.78	32.9	439	28.3	0.32	43.5	14.7	0.90	13.8	6.4	20.2	89	57	2.15	2.22	110
G/3/96909	8	708	103	2.69	32.7	442	29.4	0.37	41.9	15.7	0.85	13.7	6.3	20.0	88	54	2.00	2.22	123
G/4/96919	10	726	100	2.77	32.9	445	29.4	0.43	41.0	16.8	0.79	13.7	6.6	20.3	91	60	2.30	2.16	119
C/1/96940	2	602	81	2.38	40.40	434	32.3	0.25	41.7	13.8	0.86	13.3	6.5	19.8	86	56	2.19	2.17	117
C/2/96931	5	716	101	2.89	34.17	423	31.4	0.31	42.1	14.2	0.84	13.4	6.3	19.7	85	56	2.20	2.23	120
C/3/96932	8	738	105	2.90	32.82	415	30.9	0.39	40.8	15.6	0.81	13.6	6.1	19.8	84	54	2.06	2.31	129
B/1/96922	2	740	117	2.824	32.1	409	32.2	0.24	43.0	13.1	0.91	14.9	6.2	21.1	93	57	1.96	2.53	109
B/2/96927	3.5	744	117	2.92	32.0	402	31.1	0.23	41.7	13.8	0.91	12.9	6.7	19.6	86	59	2.46	2.00	106
B/3/96926	5.5	764	111	3.04	31.0	410	30.8	0.28	41.7	14.9	0.88	13.9	6.3	20.2	88	57	2.15	2.30	113
B/4/96936	8.5	753	95	2.88	33.5	412	31.2	0.45	39.7	15.9	0.76	13.3	6.0	19.4	81	53	2.07	2.29	140

Table 3
Factors used in models* for selected wood and kraft pulp properties.

Property	Significant fixed effects	Significant random effects
Chip basic density	a s s*a	t(s) t(s)*a
Glucose content	a a≤ s s*a	t(s)
Total lignin content	a a≤ a≥ a4 s s*a s*a≤ s*a≥ s*a4	t(s)
Xylose content	a s s*a	t(s)
Fibre length	a a≤ a≥ s	t(s)
Fibre perimeter	a s s*a	t(s)
Fibre wall area	A	t(s)
Fibre wall thickness	a s s*a	t(s)
Mean fibre width/thickness	a a≤ s s*a	t(s)
Relative number of fibres	a a≤	t(s)
Apparent sheet density at 500 PFI revolutions	a a≤ a≥ s s*a	t(s)

* These models only include effects which are significant at the 0.10 level, and lower order effects which are part of significant higher order effects.

Table 4
Square root of residual variance for final models (including fixed and random effects).

Property	Square-root of residual variance
Chip basic density (kg/m^3)	7.49
Glucose content (%)	0.782
Total lignin content (%)	0.437
Xylose content(%)	0.516
Mean fibre length (mm)	0.0195
Mean fibre perimeter (μm)	0.401
Mean fibre wall area (μm^2)	2.74
Mean fibre wall thickness (μm)	0.125
Mean fibre width/thickness	0.100
Relative number of fibres	6.10
Apparent sheet density at 500 PFI revolutions (kg/m^3)	19.7

Table 5
Estimated differences between *E. fastigata* and *E. nitens* at age-less-rings of 2 and 8.

Property	Estimated difference between species (*E. fastigata* minus *E. nitens*) Age-less-rings 2	Age-less-rings 8
Chip basic density (kg/m^3)	-7.0	-39.9
Glucose (%)	0.42	1.92 *
Total lignin (%)	4.06 *	2.50 *
Xylose (%)	-1.76 *	-1.17 *
Fibre length (mm)	-0.051 *	-0.051 *
Fibre perimeter (μm)	0.11	0.57 *
Fibre wall area (μm^2)	0.0	0.0
Fibre wall thickness (μm)	0.06	-0.15 *
Mean fibre width/thickness	-0.01	0.17 *
Relative number of fibres	0.0	0.0
Apparent sheet density at 500 PFI revolutions (kg/m^3)	1	28

* Difference between species is significant at the 0.05 level.

Root mean square errors for each mixed model are listed in Table 4.

The models are also used to estimate the magnitude and statistical significance of property differences between the two species at age-less-rings of 2 (a bottom log value) and age-less-rings of 8 (a top log value) (Table 5). With these bases of comparison, the differences between species in chip basic density and apparent sheet density are not significant (0.05 level) because of the large variation in these properties between trees within species. The variation in chip basic density between trees within species is probably larger than in the population of interest since the 9-tree sets for each species are not random samples but chosen to cover the available range of tree densities (*2,3*). The deliberate choosing of trees with low and high density at 1.4 m may also contribute to more between-tree variation in chip density versus age-less-rings slopes.

Wood density and chemical composition

Magnitudes of variation among logs and trees, and between species (*E. nitens* and *E. fastigata*) can be very different depending on the wood or fibre property involved (Fig. 2-6).

Within-tree chip density distributions are very different for *E. fastigata* and *E. nitens* (Fig. 2). *E. nitens* chip density increases markedly with increasing age-less-rings (458 to 505 kg/m^3) whereas corresponding increases for *E. fastigata* are minimal (452 to 459 kg/m^3). Similar vertical wood density distribution patterns for *E. nitens* have been obtained using SilviScan 2 for the same nine trees of *E. nitens* (*6*). Chip density variation among trees is lower for the *E. fastigata* than for the *E. nitens* 9-tree data set (Fig. 3, Tables 1, 2).

Glucose contents decrease, xylose contents increase, and lignin contents decrease and then increase, with increasing age-less-rings for both species (Fig. 2, 4). Furthermore, lignin, glucose and xylose distribution relationships are generally similar for *E. fastigata* and *E. nitens* although actual content values and slopes are significantly different. For example, lignin contents are significantly higher and xylose contents significantly lower for *E. fastigata* (Fig. 4, 5, 6, Table 3). For glucose (cellulose) contents, that of *E. fastigata* is significantly higher than *E. nitens* at age-less-rings of 8 but not at age-less-rings of 2 (Table 5) (Fig. 4, 7). Lignin, glucose and xylose contents for the two species are also shown to be significantly different in a comparison of mean whole-tree values for 29-tree data sets (Table 6) (2, 3). Included in the two 29-tree data sets are the whole-tree data for the 9-tree log sets of Table 2 and reference 5. Glucose content estimates for the 29 whole-tree samples are marginally but significantly higher for *E. nitens* than for *E. fastigata*, in contrast to the trends shown in Figures 4, 7. In summary, whole-

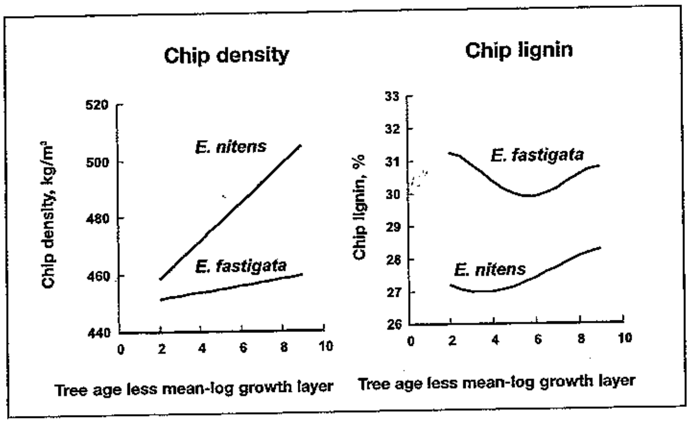

Fig. 2 Chip density and lignin content model-predicted means for *E. fastigata* and *E. nitens* trees.

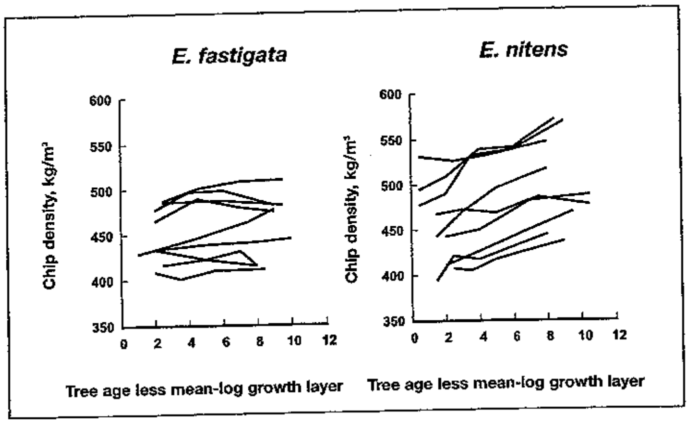

Fig. 3 Within-tree chip density variation among trees for *E. fastigata* and *E. nitens*.

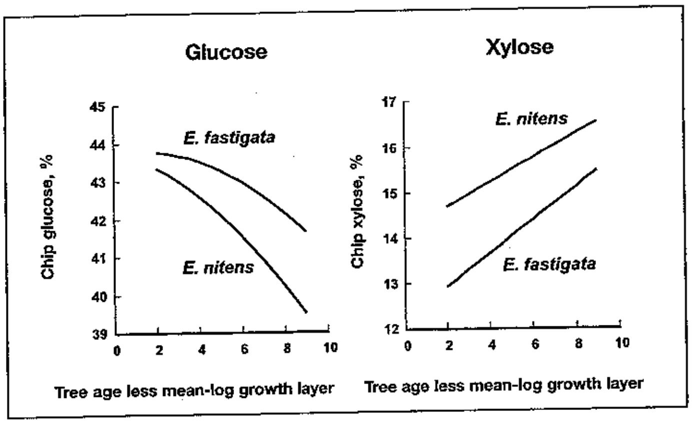

Fig. 4 Glucose (cellulose) and xylose model-predicted means for *E. fastigata* and *E. nitens* trees.

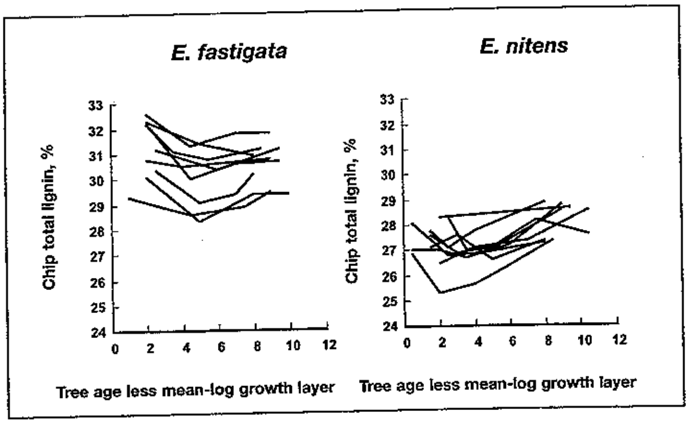

Fig. 5 Within-tree total lignin content variation among trees for *E. fastigata* and *E. nitens*.

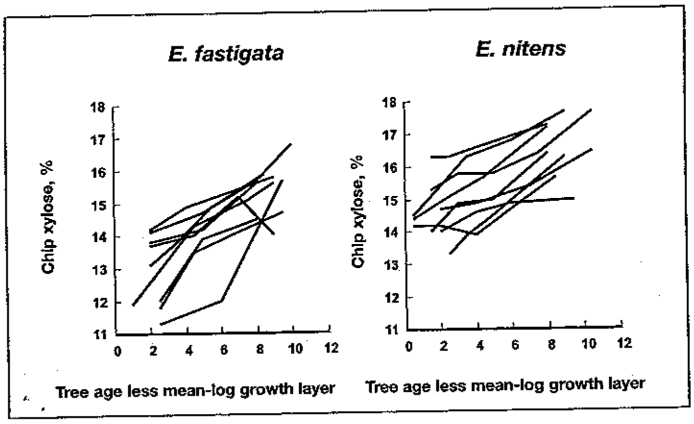

Fig. 6 Within-tree xylose content variation among trees for *E. fastigata* and *E. nitens*.

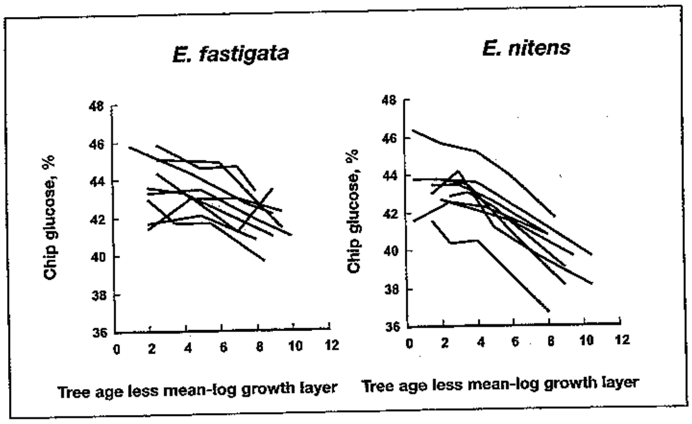

Fig. 7 Within-tree glucose content variation among trees for *E. fastigata* and *E. nitens*.

tree chip glucose (cellulose) contents for the two species can be considered as being roughly similar, with chip lignin contents lower, xylose contents and kraft pulp yields higher, for *E. nitens* than for *E. fastigata* (Table 6). This suggests that *E. nitens* pulps can be richer in xylose by some 2 to 3 %.

Kraft fibre property relationships

Fibre collapse (indicated by width/thickness) decreases markedly with increasing age-less-rings for *E. nitens* but remains, on average, unchanged for *E. fastigata* (Fig. 8). Such behaviour patterns are to be expected since fibre collapse decreases as chip density decreases (*2,3,5*). The flattened and matching *E. fastigata* chip density and kraft pulp fibre collapse profiles are particularly noteworthy (Fig. 2, 8).

Fibre length decreases with increasing age-less-rings for both species, but fibres are significantly longer for *E. nitens* than for *E. fastigata* (Fig. 8, Tables 3, 5). Variation among the trees of *E. nitens* is greater than those of *E. fastigata* (Fig. 9). Differences between species are, however, significant (0.05 level). A noteworthy feature of *E. nitens* is the longer fibres of the second logs of 6 of the 9 trees (Fig. 9). Such a trend is absent for all 9 *E. fastigata* trees.

Interrelationships among fibre collapse and the fibre cross-section dimension properties of perimeter (width + thickness), wall area (coarseness) and wall thickness

Table 6

Mean wood and kraft fibre properties for 29 individual trees of *E. fastigata* and *E. nitens* (2,3).

	Chip	Chip chemistry			Pulp	Kraft fibre properties at Kappa 30								Handsheet at 500	
									PFI rev						
	Density (kg/m³)	Lignin (%)	Glucose (%)	Xylose (%)	Yield at Kappa 30 (%)	Length (mm)	Width (µm)	Thickness (µm)	Width + thickness (µm)	Width x thickness (µm²)	Wall area (µm²)	Wall thickness (µm)	Width/ thickness	Apparent density (kg/m³)	Tensile index (N.m/g)
E. fastigata	458	30.6	41.4	13.2	52.9	0.85	13.3	6.7	20.0	90	59	2.30	2.07	705	103
E. nitens	474	27.6	42.8	15.3	56.3	0.86	13.2	6.9	20.1	92	61	2.42	1.97	677	102
LSD*	19	0.46	0.90	0.44	0.91	0.023	0.28	0.13	0.30	1.9	0.085	0.059	18	5.2	8.0

*Least significant difference between means at the 5% level of significance.

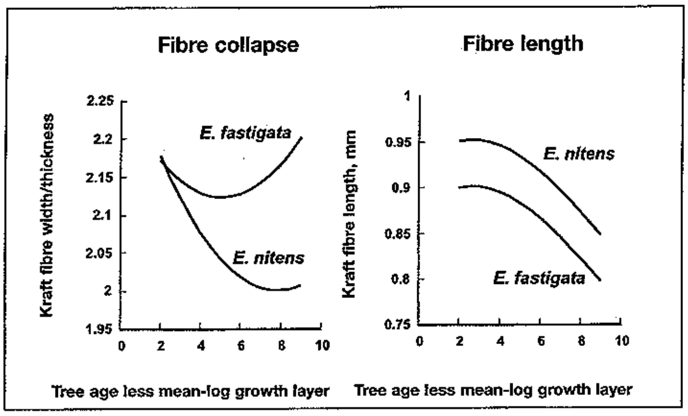

Fig. 8 Kraft fibre width/thickness ratio, and length, model-predicted means for *E. fastigata* and *E. nitens* trees.

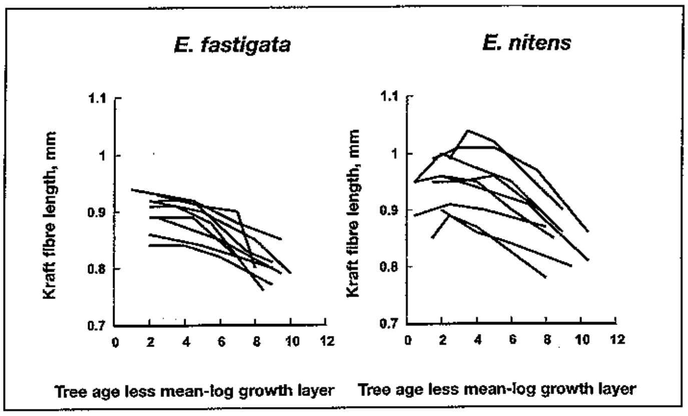

Fig. 9 Within-tree kraft fibre length variation among trees for *E. fastigata* and *E. nitens*.

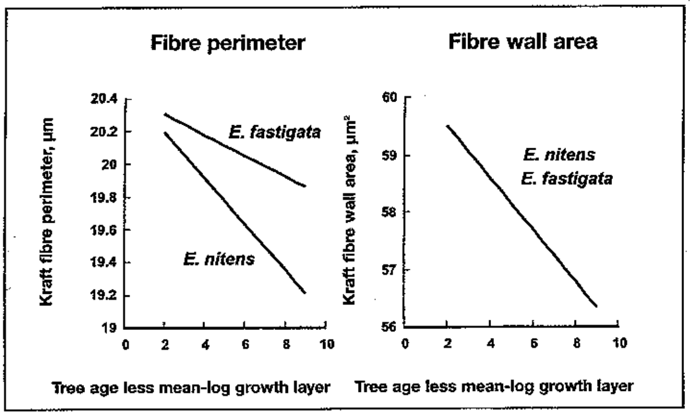

Fig. 10 Kraft fibre half perimeter (width + thickness), and wall area, model-predicted means for *E. fastigata* and *E. nitens* trees.

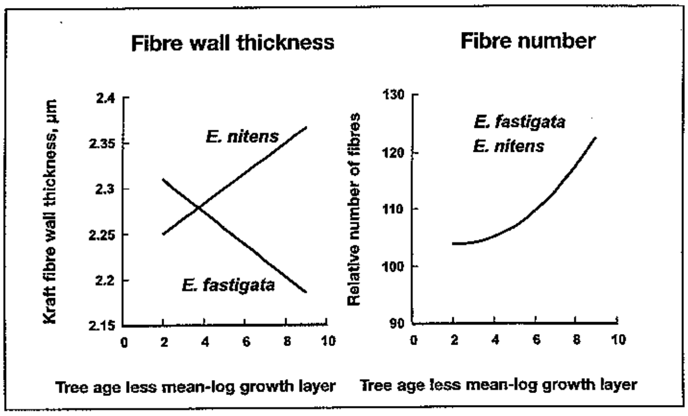

Fig. 11 Kraft fibre wall thickness, and relative number, model-predicted means for *E. fastigata* and *E. nitens* trees.

are of interest (Fig. 8, 10, 11). There are no significant (0.10 level) differences between species for fibre wall area, which decreases with increasing age-less-rings (Fig. 10, Table 3).

Fibre perimeter decreases markedly more with increasing age-less-rings for *E. nitens* than for the *E. fastigata*. Fibre collapse and wall thickness differences for the two eucalypt species are, therefore, determined by the different rate of change in fibre perimeters with increasing age-less-rings. Hence for *E. nitens*, fibre perimeter decreases at a faster rate than wall area decreases with increasing age-less-rings and, therefore, fibre wall thickness increases and fibre collapse decreases in consequence (Fig. 8, 10, 11). For *E. fastigata*, on the other hand, fibre wall thickness and perimeter both decrease with increasing age-less-rings, and changes in perimeter/wall thickness ratios and collapse are small.

Fibre lengths and wall areas decrease with increasing age-less-rings (Fig. 8, 9, 10). The fibres of *E. fastigata* are significantly shorter (0.05 level) than those of *E. nitens* whereas wall areas are not significantly different one from another (Tables 3, 5). Relative numbers of fibres (reciprocal of fibre length x wall area product) increases with increasing age-less-rings and could be expected to be greater for *E. fastigata* than *E. nitens* (Fig. 12). However, the variation between trees within species is too large (for this derived measure) for the difference between species to be significant (0.10 level) (Table 3, Fig. 11, 12).

The widely different changes in chip density and fibre collapse with age-less-rings for *E. fastigata* and *E. nitens* are noteworthy (Fig. 2, 8). The wood property of chip density is roughly inversely proportional to the kraft fibre property of collapse. Different wood density profiles with position in a tree are to be expected among different eucalypt species (*11,12*). The surprising features are the small differences between mean whole-tree wood density and fibre collapse for the 29-tree *E. fastigata* and *E. nitens* data sets (Table 6) (*3*), compared to corresponding within-tree variation shown by the 9 trees of each species (Fig. 2, 8) (*3*). This is probably because the largest differences between species occur in upper logs which contribute less material to whole-tree chip samples.

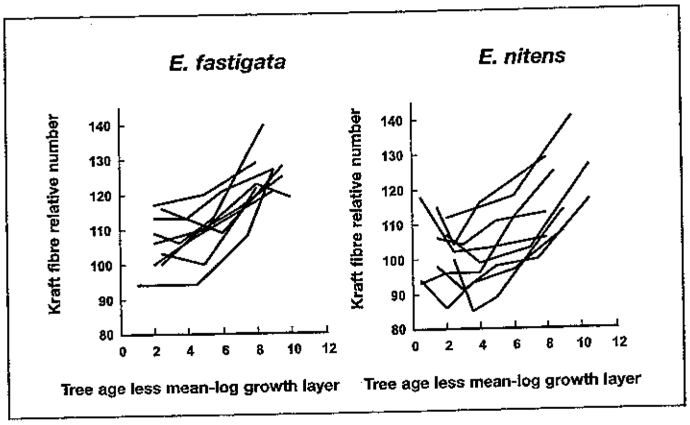

Fig. 12 Within-tree relative number of fibres variation among trees for *E. fastigata* and *E. nitens*.

Handsheet and fibre property relationships

For many end uses, handsheet apparent density or bulk are considered to be the most important eucalypt kraft pulp quality determinants (*13*). For this reason the between-species handsheet apparent density differences indicated in Figures 13, 14 require explanation. Handsheet apparent density increases with increasing age-less-rings for *E. fastigata* and on average is unchanged for *E. nitens*. This is related to:

- *E. fastigata* – unchanging levels of fibre collapse and decreasing fibre length with increasing age-less-rings give increased handsheet apparent density.
- *E. nitens* – decreasing levels of fibre collapse and fibre length with increasing age-less-rings, give little change in apparent sheet density. The lower apparent density for some second logs occurs because these second logs have longer fibres.

Such large between-species differences in handsheet apparent density (Fig. 13, 14) are fibre property induced (fibre collapse, perimeter, wall thickness and length (Fig. 8 - 12)) which can be expected to influence both papermaking and product qualities (*13,14*). Furthermore, these large within-tree differences between species are unable to be identified in comparisons of mean whole-tree property differences (Table 6) (*2,3*).

CONCLUSIONS

Model-predicted means for the average tree of each nine-tree sample show that wood and kraft fibre property changes with tree height can be the same or very different for *E. nitens* and *E. fastigata*. The magnitudes of the differences are indicated by the model-predicted mean property curves.

E. fastigata and *E. nitens* within-tree mean predicted model curves are significantly different (0.10 level) for wood lignin, glucose and xylose contents and basic density, and kraft fibre collapse (indicated by width/thickness ratio), wall thickness, perimeter and length. Kraft fibre wall area (coarseness) and relative number of fibres are not significantly different for the two species. Some specific conclusions are:

- Wood density and resistance to fibre collapse are on average unchanged with increasing height position for *E. fastigata*, but markedly increased for *E. nitens*.
- Kraft fibre-wall thickness increases for *E. nitens* and decreases for *E. fastigata*, with increasing height position, in accordance with their similar wall areas and different perimeters.
- Wood and kraft fibre model-predicted means for *E. fastigata* and *E. nitens* are significantly different (0.05 level) for wood glucose, xylose and lignin contents, and kraft fibre collapse, length, wall thickness and perimeter. Model shapes are generally similar but still statistically different (0.10 level) for wood glucose, xylose and lignin contents, and kraft fibre length.

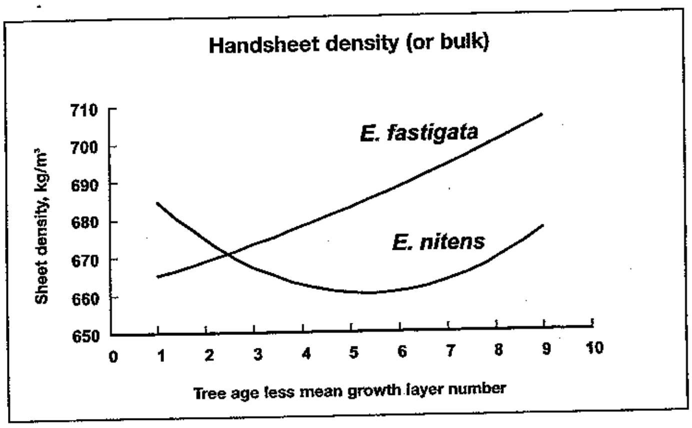

Fig. 13 Handsheet apparent density, and bulk, model-predicted means for *E. fastigata* and *E. nitens* trees.

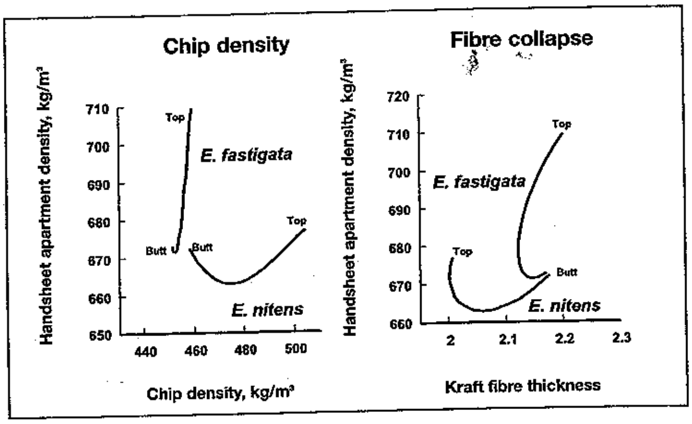

Fig. 14 Handsheet apparent density versus chip density, and fibre width/thickness ratio relationships, within *E. fastigata* and *E. nitens* trees.

Handsheet apparent density, with increasing height position, increases for *E. fastigata* because of unchanging fibre collapse and decreasing fibre length, and on average is unchanged for *E. nitens* because of decreasing fibre collapse and fibre length. These between-species differences in handsheet apparent density are large and fibre-property induced (fibre collapse, perimeter, wall thickness and length), and can be expected to influence both papermaking and product qualities. Furthermore, these large within-tree differences between species are unable to be identified in comparisons of mean whole-tree property differences.

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