KRAFT PULP QUALITIES OF *EUCALYPTUS NITENS*, *E. GLOBULUS*, AND *E. MAIDENII*, AT AGES 8 AND 11 YEARS

R. P. KIBBLEWHITE, B. I. JOHNSON and C. J. A SHELBOURNE

New Zealand Forest Research Institute,
Private Bag 3020, Rotorua, New Zealand.

(Received for publication 23 August 2000; revision 1 February 2001)

ABSTRACT

Kraft fibre and pulp properties were assessed for 10-tree bulked chip samples from 8- and 11-year-old species/provenance trials of *Eucalyptus globulus* Labill., *E. nitens* (Deane et Maiden) Maiden, and *E. maidenii* Labill., grown on two sites south of Kaikohe in Northland, New Zealand. Mean basic density of bulked chip samples ranged from 447 kg/m^3 for both ages of *E. nitens* to 576 kg/m^3 for 11-year-old *E. maidenii*. Pulp yields for all wood types were similar, from 54.5 to 55.6%. The kraft fibres of *E. maidenii* were somewhat longer, with higher wall area (coarseness) than those of *E. globulus*, which were in turn of higher coarseness than those of *E. nitens*. Fibre collapse potential (as indicated by fibre width/ thickness ratio) of both *E. maidenii* pulps and the *E. globulus* 11-year-old material was much less than that for *E. nitens*. For these six wood origins, pulps of premium quality were obtained from *E. globulus* aged 11 and from *E. maidenii* aged 8 years. The pulp from 11-year-old *E. maidenii* was too high in bulk, requiring excessive refining, and the pulps from *E. nitens* (aged 8 and 11 years) were deficient in bulk and unsuitable for many eucalypt market kraft end uses.

Keywords: kraft pulp; fibre; chemistry; *Eucalyptus nitens*; *Eucalyptus maidenii*; *Eucalyptus globulus*.

INTRODUCTION

Eucalyptus globulus is the preferred species, worldwide, for short-fibred pulp because of its rapid growth, high basic wood density, high pulp yield, and good fibre and handsheet properties. New Zealand pulpwood growers have, in the past, been constrained from planting this species by its local reputation for susceptibility to fungal disease and insect attack, and its poor frost tolerance.

Early trials established by the New Zealand Forest Research Institute in the 1970s were mostly on unfavourable sites and indicated poor prospects for *E. globulus*. Species and provenance trials established by Carter Holt Harvey Forests in 1988 and 1991 on warm, low-altitude sites in Northland, New Zealand (latitudes 35° 31′ to 35° 34′S) included *E. globulus*, *E. maidenii, E. nitens* and several other species, and in 1987 a close-spaced, coppice-fuelwood trial established at Clive (Hawke's Bay) included amongst others the same three species. Recent assessment of these trials on four Northland sites and at Clive (Low &

Shelbourne 1999; Shelbourne *et al.* 2000) have shown excellent health of *E. maidenii* and extremely poor health of *E. nitens* from Victoria and of *E. globulus*. By age 11 years, the standing volume of *E. nitens* of both NSW and Victorian origin was still greater than that of *E. maidenii* and *E. globulus*, but the health of Victorian provenances and their prospects for further growth were poor and those of the healthier provenances were deteriorating with age on these warm Northland sites.

There is, however, some renewed interest in growing *E. globulus* for local pulping and for chipwood export plantations on less disease-prone sites in New Zealand. Such plantations are developing rapidly in Victoria, South Australia, and Western Australia with this species. Comprehensive *E. globulus* subspecies and provenance trials (including also *E. maidenii*, *E. bicostata* Labill., and *E. pseudoglobulus* Labill.) were planted in 1999 at a variety of sites in Bay of Plenty, Hawke's Bay, and Northland (S. Concheyro unpubl. data) and these will provide necessary performance information about provenance and siting for this group of species.

The kraft pulp properties of *E. nitens* and several other eucalypt species have been assessed in a number of recent studies (Cotterill & Macrae 1997; Cotterill *et al.* 1998; Clarke 2000). All the *E. nitens* pulps were of good yield and easy to refine, with handsheets of good strength and optical properties, in agreement with corresponding assessments of *E. nitens* grown in New Zealand (Kibblewhite *et al.* 1998, 2000; Kibblewhite & Riddell 2000). Unfortunately, neither strength nor optical properties either separately or together, are sufficient to indicate the papermaking quality of a eucalypt kraft pulp (Kibblewhite & Shelbourne 1997; Kibblewhite 1999). In the assessment of eucalypt kraft pulps, strength and optical properties need to be compared to corresponding handsheet bulk values. On this basis, *E. nitens* kraft pulps are deficient in bulk and of inferior quality compared to most *E. globulus* market kraft pulps. Kraft pulp made from 4-year-old *E. maidenii* trees grown in Uruguay was of poor papermaking quality (Backman & De Leon 1998). The fibres of the *E. maidenii* pulp were short (0.47 mm) but of the same coarseness as those of the corresponding 4-year-old *E. dunnii* Maiden pulp (0.6 mm) which was of good quality.

There is no public domain information about New Zealand-grown *E. maidenii* or *E. globulus*. For *E. nitens* there are detailed accounts of the wood and kraft pulp properties of twenty-nine 15-year-old trees of the central Victorian provenance (Kibblewhite *et al.* 1998; Kibblewhite & Riddell 2000; Lausberg *et al.* 1995). Much work on individual-tree kraft pulping has been done in the last 5 years on *E. regnans* F. Mueller, *E. fastigata* Deane et Maiden, and *E. nitens* of central Victoria provenance (Kibblewhite *et al.* 2000), and an earlier bulked tree study compared 15-year-old *E. nitens* of both southern NSW and central Victorian provenances with 8-year-old material of the central Victorian provenance (Kibblewhite unpubl. data). There were minor differences between *E. nitens* of NSW and Victorian provenances for the 15-year-old material, but the chips from 8-year-old trees gave very inferior results.

A recent evaluation of basic wood density of these species in a biomass study (Jansen 1998) has shown that at Clive, at age 11 years, mean whole-tree densities (based on five trees) were 450 kg/m^3 for *E. nitens*, 489 kg/m^3 for *E. globulus*, and 582 kg/m^3 for *E. maidenii*. At Knudsen Road, Kaikohe, at age 7 years these were, respectively, 435 kg/m^3, 490 kg/m^3, and 550 kg/m^3.

This report describes the wood density and chemistry, and kraft fibre and handsheet properties for bulked 10-tree samples of *E. nitens* of southern NSW provenances, *E. globulus,* and *E. maidenii*, each from 8-year-old and 11-year-old trials, located at Knudsen Road and Carnation Road, Kaikohe, respectively.

MATERIALS AND METHODS

Sample Origin and Selection

Eucalypt species and provenance trials were planted at Knudsen Road (latitude 35°31′S; altitude 180 m) and Carnation Road (35°34′S; altitude 195 m), 12 and 20 km south of Kaikohe in Northland, in 1992 and 1988 (Low & Shelbourne 1999; Shelbourne *et al.* 2000). Both sites were ex-pasture, with similar Northland clay soils, with mean annual temperatures of 14.4° and 14.2°C, and mean annual rainfalls of 1770 and 1920 mm, respectively. At Knudsen Road at age 7 years (a year before felling), *E. nitens* from southern NSW had a trial mean breast-height diameter (dbh) of 200 mm and basal area/ha of 40 m^2, *E. globulus* was 170 mm and 21 m^2, and *E. maidenii* was 174 mm and 30 m^2. At Carnation Road at age 11 years, the trial mean dbh and basal area/ha for *E. nitens* were 286 mm and 48 m^2, for *E.globulus* they were 212 mm and 27 m^2, and for *E. maidenii* 236 mm and 42 m^2. Unfortunately, at this site, the *E. maidenii* and *E. globulus* were planted in a separate trial area from the *E. nitens* and other species.

Ten-tree samples (Table 1) of *E. nitens* from southern NSW, *E. globulus,* and *E. maidenii* were assembled from Knudsen Road (age 8 years) and Carnation Road (age 11 years) by initially selecting about 30 dominant and codominant trees for each species/age category and measuring their dbh and outerwood basic wood density (using 5-mm increment cores). At Knudsen Road (age 8 years) sampled trees were evenly distributed through two replicates of two provenances of *E. maidenii* (from Black Range, Eden, and Bolaro Mtn, Bateman's Bay, NSW) and *E. globulus* (from Huonville, Tas., and Jeeralang, Vic.), and of three provenances of southern NSW *E. nitens* (from Brown Mtn, Tallaganda, and Badja, NSW). At Carnation Road (age 11 years), each species was represented by only one seedlot and the sample trees were distributed over several plots. The *E. nitens* seedlot was a bulked mixture of three seedlots from Tallaganda, Nimmatabel, and Bondi, NSW; the *E. maidenii* seedlot was from a few trees of unknown provenance growing at Waiohiki, Napier, New Zealand, and the *E. globulus* was from a seedlot collected in California, of similarly unknown provenance. Ten trees of each species were then reselected from 30 candidates from within each trial on the basis of outerwood density. The sample was selected to approximate the 30-tree mean, covering the outerwood basic density range available, with similar dbh in order to contribute similar volumes of chips to the bulked sample. Mean height and dbh-inside-bark of each 10-tree sample are shown in Table 1.

Discs were cut from all stems at 5-m intervals, starting from the butt. One-metre billets were taken from the top of the butt logs of the 11-year-old but not from the 8-year-old trees. These discs and billets were used in the assessment of wood and solid-wood properties (to be reported elsewhere). All remaining roundwood was chipped in a commercial chipper as follows:

- The logs of each bulked 10-tree sample were processed as one lot, with the logs entering the chipper in random order.

TABLE 1–Growth, chip density, chemical composition, and pulp yield data—aged 8 at Knudsen Road and aged 11 at Carnation Road)

Species age, provenance	Mean tree height (m)	Mean dbh i.b. (mm)	Outerwood density* (kg/m^3)	Chip density (kg/m^3)	Pulp yield (%)	Total lignin (g/100 g)	Percentage total carbohydrates	
							Glucose	Xylose
E. globulus, 8 yr Huonville, Tas. & Jeeralang, Vic.	19.3	184	430	490	55.6	31.9	72.3	21.9
E. globulus, 11 yr California	23.4	222	508	543	54.5	27.4	74.6	20.4
E. nitens, 8 yr Brown Mt, Tallaganda & Bondi, Sthn N.S.W.	20.9	216	413	447	54.7	30.4	69.9	24.6
E. nitens, 11 yr Nimmatabel, Tallaganda & Bondi, Sthn. N.S.W.	25.7	259	408	448	55.6	29.0	70.2	23.6
E. maidenii, 8 yr Eden & Batesman's Bay, N.S.W.	21.3	185	532	569	55.3	31.8	73.9	20.4
E. maidenii, 11 yr Napier, N.Z.	22.3	241	572	576	55.5	28.8	73.6	20.3
LSD**				35	1.9	2.4	2.3	1.9
Two-way ANOVA F test for Species and Age $P < 0.05$				Species	ns	ns	ns	Species

* Mean outerwood density, @ 1.4 m, for the trees of each bulked 10-tree sample.

** Least significant difference (0.05 level) for chip pile sampling, based on *E. fastigata* (Riddell & Kibblewhite 1999).

- Shovels of chips were continuously collected throughout the chipping run from each species/age sample, consisting of 30 or more logs.
- About 10 kg (o.d. equivalent) of chips were collected, mixed well, and screened for thickness (<8 mm) and size using a laboratory round-hole Williams Classifier. Accepted chips passed through the 26-mm screen, and were retained on the 9-mm screen.

Chip Basic Density

Chip basic density was determined in accordance with Appita method P1s-79 except that the fresh chips were not given the specified soaking period (Cown 1980). Breast-height outerwood increment-core basic density was determined by the maximum moisture content method (Smith 1954) for 30 candidate trees of each species/age class and used to select the sample trees for chipping.

Chip Chemical Composition

Air-dried chip samples (300 g o.d.) were ground prior to chemical analysis. Dichloromethane (DCM) extractives were obtained using a Soxtec extractor, boiling time 30 minutes, rinsing time 1 hour. Extracted material was acid hydrolysed following a method based on TAPPI 222 om-88 for Klason (acid-insoluble) lignin, and acid-soluble lignin by TAPPI um-250. Carbohydrates were analysed by a method based on that of Pettersen & Schwandt (1991).

Pulping

One kraft pulp of kappa number 20±2 was prepared from each chip sample by varying the H-factor at constant alkali charge. Pulping conditions were: 12% effective alkali as Na_2O, 30% sulphidity, 4:1 liquor-to-wood ratio, 90 minutes to maximum temperature of 170°C .

Pulps were prepared in 2-litre 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, percentage rejects, and total yield were determined.

Handsheet Preparation and Evaluation

Handsheets were prepared and pulp physical and optical properties were evaluated in accordance with Appita standard procedures. The load applied during pulp refining with the PFI mill was 1.8 N/mm. Pulps were refined at 10% stock concentration for 500, 1000, 2000, and 4000 rev. Handsheet data are reported on an o.d. basis.

Fibre Dimensions and Relative Number

Cross-sectional fibre dimensions of thickness, width, wall area, and wall thickness were measured using image-processing procedures (as given by Kibblewhite & Bailey 1988). The parameters of width, thickness, and wall area indicated in Fig. 1 are for dried fibres, rewetted from handsheets. The product of fibre width × fibre thickness represents the minimum fibre cross-sectional rectangle. The ratio width/thickness is an indicator of the collapse potential

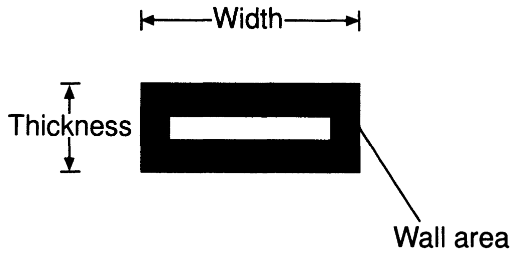

FIG. 1–Schematic diagram of the cross-section dimensions of fibres rewetted from handsheets.

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 numbers of fibres per unit mass of pulp were calculated using the reciprocal of the product "fibre length × fibre wall area". Length weighted average fibre length was determined with a Kajaani FS 200 instrument, using Tappi T271 pm-91.

Statistical Analysis

Least significant difference calculation

The sampling error from repeated sampling of piles of chips resulting from the chipping and aggregation of logs and trees of the six different species/age populations was not directly estimated in this study, but was derived from a study of *E. fastigata* (Kibblewhite & McKenzie 1999; Riddell & Kibblewhite 1999). Here, nine 16-year-old trees grown at the same site were felled, and the logs of each tree were chipped into an individual-tree chip pile. The chip pile for each tree was mixed and then two samples were taken for evaluation of wood, kraft fibre, and handsheet properties. From this study, variance components were calculated for the "between-tree variance" and the "chip pile sampling and analytical error variance". In the present study, 10 trees from each of the six populations were made into bulked 10-tree chip piles from which one chip sample was collected for evaluation. The "population error variance" for each of the six samples was estimated as the sum of $^1/10$ of the "between-tree variance" plus the "chip sampling and analytical variance" from the *E. fastigata* study. This estimate of "population error variance" should be acceptable if the "between-tree variance" is similar for the *E. fastigata* study and for each of the six populations sampled here. The least significant difference (0.05 level) for comparing the six populations sampled was calculated as the product of t-value (8 df) and the square root of twice the estimated "population error variance".

Two-way analysis of variance

A two-way analysis of variance (ANOVA) was carried out on the chip density, chemistry, pulp yield, fibre dimensions, and handsheet bulk of each of the six species/age samples, using classification variables, species, and age. The effects of age and site were thus confounded, as the sampled trees were from trials at different sites and of different age. Since there is no replication of species and age combinations, an interaction term could not be separately estimated, and is included in the error term (which only has 2 degrees of freedom). F tests of species and age effects are thus very imprecise but are included in the appropriate tables of means.

RESULTS AND DISCUSSION

Chip Density and Chemistry, and Pulp Yield

There were large and significant differences between species in chip density (Table 1), but non-significant differences between sample ages, with *E. maidenii* the highest (569 kg/m^3 at age 8 and 576 kg/m^3 at age 11), *E. globulus* intermediate (490 and 549 kg/m^3), and *E. nitens* much lower (447 and 448 kg/m^3). The large (but non-significant) difference in chip density between the 8- and 11-year-old *E. globulus* may have resulted from the provenance of the 11-year-old seedlot (from California) being different from that of the 8-year-old material.

Pulp yields were similar for all species and ages despite the higher lignin contents of the chips from 8-year-old trees, and the high xylose and low glucose contents of the *E. nitens* samples. The high lignin content of the wood of young 8-year-old trees of *E. nitens* is confirmed by results from another *E. nitens* trial (Richardson unpubl. data). Similarly, the wood of *E. nitens* has previously been shown to have higher xylose and lower glucose contents than the wood of *E. fastigata* and *E. regnans* (Kibblewhite *et al.* 2000).

Fibre Dimensions

There were substantial and often significant differences in various fibre dimensions between species and between the 8-year-old and 11-year-old material (Table 2). *Eucalyptus maidenii* had longer fibres than *E. nitens* and *E. globulus* of the same age, and the fibre length

TABLE 2–Kraft fibre dimensions

	Length (mm)	Perimeter (μm)	Wall area (μm^2)	Wall thickness (μm)	Width/ thickness	Relative number	Handsheet bulk (@500 rev)
E. globulus 8 yr	0.85	40.6	57	2.16	2.07	114	1.42
E. globulus 11 yr	0.85	40.4	62	2.48	1.81	105	1.59
E. nitens 8 yr	0.82	38.8	50	2.10	2.18	135	1.33
E. nitens 11 yr	0.88	40.4	56	2.16	2.14	112	1.36
E. maidenii 8 yr	0.88	40.7	64	2.59	1.81	98	1.65
E. maidenii 11 yr	0.94	42.9	73	2.80	1.83	81	1.77
LSD**	0.04	1.7	6.6	0.29	0.20	20	0.08
Two-way ANOVA F test for species and age $p<0.05$	ns	ns	Species Age	Species	ns	Species	Species

** Least significant difference (0.05 level) for chip pile sampling, based on *E. fastigata* (Riddell & Kibblewhite 1999).

of its 11-year-old samples was longer than the 8-year-old. The 11-year-old *E. maidenii* also had fibres of larger perimeter, much greater wall thickness, and correspondingly larger wall area than *E. globulus*, which itself was higher in these dimensions than *E. nitens*. The width/thickness ratio, indicating fibre collapse potential, was highest for both *E. nitens* samples and equally low for 11-year-old *E. globulus* and both ages of *E. maidenii* samples. The 11-year-old *E. maidenii* sample stood alone because it had the longest fibres of largest perimeter, wall thickness, and wall area of the six species/age pulps. Chip density (Table 1) and the width/thickness ratio of these pulps from different species and ages of material showed the same inverse relationship as individual-tree pulps of a species, i.e., high wood density is associated with kraft fibres that resist collapse (Kibblewhite & Shelbourne 1997; Kibblewhite 1999).

Kraft Pulp Quality Relationships

Handsheet bulk (the reciprocal of handsheet apparent density) is a good indicator of eucalypt kraft pulp quality, particularly when contrasted with corresponding handsheet tensile index values (Kibblewhite & Shelbourne 1997; Kibblewhite 1999). Handsheet apparent density increases (bulk decreases) with refining, and tensile index shows a corresponding increase (Table 3). For example, handsheet apparent density for 11-year-old *E. maidenii* pulp increased from 566 kg/m^3 (after 500 revs of refining) to 677 kg/m^3 after 4000 revs of refining. By contrast, the 11-year-old *E. nitens* increased from 735 to 824 kg/m^3.

TABLE 3–Handsheet physical evaluation data for pulps at four refining levels

Sample	PFI mill rev	Apparent density (kg/m^3)	Bulk (cm^3/g)	Tensile index (N.m/g)
E. globulus 8 yr	500	704	1.42	104
00058D	1000	727	1.38	119
	2000	760	1.32	134
	4000	793	1.26	126
E. globulus 11 yr	500	629	1.59	85
00057A	1000	651	1.54	94
	2000	688	1.45	106
	4000	735	1.36	119
E. nitens 8 yr	500	751	1.33	121
00054B	1000	779	1.28	120
	2000	813	1.23	130
	4000	839	1.19	131
E. nitens 11 yr	500	735	1.36	115
00056C	1000	754	1.33	125
	2000	783	1.28	134
	4000	824	1.21	135
E. maidenii 8 yr	500	607	1.65	81
00059C	1000	625	1.60	91
	2000	662	1.51	104
	4000	713	1.40	125
E. maidenii 11 yr	500	566	1.77	72
00055B	1000	598	1.67	82
	2000	634	1.58	93
	4000	677	1.48	110

The relationship of apparent density and tensile index with increasing refining is shown in Fig. 2 for each species/age. The regressions refer to pulps refined for 500 to 4000 PFI mill revolutions, with the lowest level of refining being the left-hand end of each regression line. The 500 rev treatment reflects pulp properties close to those of unrefined pulps.

On the basis of the pulp tensile index *vs*. bulk regressions and the fibre dimension data (Table 2), the six species/age samples can be classified into three groups:

- *E. maidenii* @ 8 years, *E. globulus* @ 11 years
- *E. globulus* @ 8 years, *E. nitens* @ 8 and 11 years
- *E. maidenii* @ 11 years.

Features of note are the very low apparent sheet density (high bulk) of the *E. maidenii* pulp from 11-year-old trees, and the high apparent density of both the *E. nitens* pulps and the *E. globulus* pulp from 8-year-old trees (Fig. 2). From a eucalypt pulp quality point of view, those most suitable for papermaking have handsheet densities @500 PFI mill rev (left-hand end of each regression) within the range 600–650 kg/m^3 (Kibblewhite & McKenzie 1999; Kibblewhite & Shelbourne 1997). These values are for pulps produced in the laboratory and equate roughly to 560–610 kg/m^3 for market eucalypt kraft pulps. Hence, the *E. globulus* pulp made from 11-year-old trees, and the *E. maidenii* pulp made from 8-year-old trees, have fibre properties most suitable for a market kraft end-use.

The excellent papermaking properties obtained with the *E. maidenii* pulp from 8-year-old trees is noteworthy in view of the apparent poor quality obtained with 4-year-old trees of *E. maidenii* grown in Uruguay (Backman & De Leon 1998). The pulp made with the chips from Uruguay contained very short fibres which accounted for its inferior quality. The

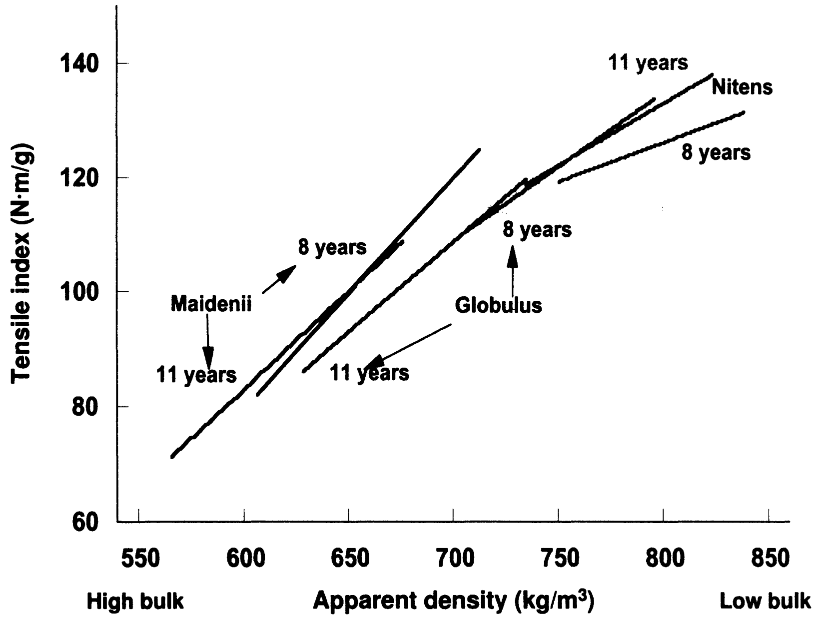

FIG. 2–Handsheet tensile index *versus* apparent density regressions based on four PFI mill refining levels (500, 1000, 2000, and 4000 rev) for each pulp.

converse occurred with the 8-year-old trees of *E. maidenii* grown in New Zealand where fibres were long and pulp quality was high (Table 2, Fig. 2).

The two *E. nitens* pulps and, to a lesser extent, the *E. globulus* pulp made from 8-year-old trees were deficient in handsheet bulk because of their more-readily collapsed, thinner-walled fibres (Table 2). Tensile index for the two *E. nitens* pulps increased more slowly with increasing apparent density or refining (Fig. 2) than for the other four pulps. This slow increase in tensile index development with refining is indicative of highly bonded sheets, collapsed fibres, and tensile index values that are close to the maximum possible for a particular pulp. The majority of individual-tree kraft pulps made from 15-year-old *E. nitens* in New Zealand have been shown to be deficient in handsheet bulk (Kibblewhite & McKenzie 1999).

The *E. maidenii* pulp made from 11-year-old trees contained somewhat longer fibres with larger perimeters and much thicker walls than the fibres of *E. nitens* and *E. globulus* of 8- and 11-year-old trees (Table 2). These fibres are more resistant to collapse, are present in relatively low numbers, and give handsheets of higher bulk (Fig. 2). This pulp had higher refining requirements and could be expected to have poor formation properties (Kibblewhite & Shelbourne 1997).

CONCLUSIONS

For the six bulked 10-tree samples from 8- and 11-year-old stands of *Eucalyptus globulus, E. nitens,* and *E. maidenii,* located near Kaikohe in Northland:

- Pulp yields were similar and independent of chip density and lignin content, for which among-species and between-age differences may be high.
- The six pulps may be classified into the following three categories either by fibre cross-section dimensions (perimeter, wall area, wall thickness) or by handsheet bulk:
  - *E. maidenii* @ 8 years, *E. globulus* @ 11 years
  - *E. globulus* @ 8 years, *E. nitens* @ 8 and 11 years
  - *E. maidenii* @ 11 years.
- Pulps of premium quality can be made from trees of *E. globulus*, aged 11 years and over, and from *E. maidenii,* aged around 8 years.
- Pulps made from *E. nitens* (aged 8 and 11 years) are deficient in bulk and unsuitable for many eucalypt market kraft end uses.

ACKNOWLEDGMENT

Carter Holt Harvey Forests (CHH) planted the field trials and supplied trees for the study and their co-operation is gratefully acknowledged. The land at Knudsen Road was originally part of a joint venture with CHH, and we are grateful for the enthusiastic collaboration of the owner, John Gallilee. Trevor Jones arranged log processing and sampling of the bulked 10-tree chip lots, and Mark Riddell did the statistical analyses. This study was funded by the Foundation for Research and Technology and by the New Zealand Eucalypt Breeding Co-operative and we thank the latter for permission to publish it.

REFERENCES

BACKMAN, M.; DE LEON, J.P.G. 1998: Pulp and paper properties of four-year old *Eucalyptus* trees for early species selection. Proceedings of the 52nd Appita Annual General Conference, Brisbane.

CLARKE, C.R.E. 2000: Wood and pulp properties of four New South Wales provenances of *Eucalyptus nitens* grown on a warm and a cold site in South Africa. *Appita Journal 53(3)*: 231–236.

COTTERILL, P.; MACRAE, S. 1997: Improving *Eucalyptus* pulp and paper quality using genetic selection and good organization. *Tappi Journal 80(6)*: 82–89.

COTTERILL, P.; MACRAE, S.; BROLIN, A. 1998: Growing *Eucalyptus* for high quality paper-making fibers. Proceedings of 52nd Appita Annual General Conference, Brisbane.

COWN, D.J. 1980: A note on the estimation of basic density of fresh wood chips. *New Zealand Journal of Forestry Science 10(3)*: 502.

JANSEN, G.R. 1998: Wood density and biomass evaluation of *Eucalyptus nitens, E. globulus* and *E. maidenii* on two sites. BSc (Technology) Industry Report, University of Waikato, Hamilton, New Zealand.

KIBBLEWHITE, R.P. 1999: Designer fibres for improved papers through exploiting genetic variation in wood microstructure. *Appita 52(6)*: 429–435.

KIBBLEWHITE, R.P.; BAILEY, D.G. 1988: Measurement of fibre cross section dimensions using image processing. *Appita 41(4)*: 297.

KIBBLEWHITE, R.P.; McKENZIE, C.J. 1999: Kraft fibre property variation among 29 trees of 15 year old *Eucalyptus fastigata*, and comparison with *Eucalyptus nitens. Appita 52(3)*: 218–225.

KIBBLEWHITE, R.P.; RIDDELL, J.C. 2000: Wood and kraft fibre property variation among the logs of nine trees of *Eucalyptus nitens. Appita 53(3)*: 237–244.

KIBBLEWHITE, R.P.; SHELBOURNE, C.J.A. 1997: Genetic selection of trees with designer fibres for different paper and pulp grades. Transactions of the 11th Fundamental Research Symposium "Fundamentals of Papermaking Materials", Cambridge, September 1997.

KIBBLEWHITE, R.P.; RIDDELL, M.J.C.; SHELBOURNE, C.J.A. 1998: Kraft fibre and pulp qualities of 29 trees of 15-year-old New Zealand-grown *Eucalyptus nitens. Appita 51(2)*: 114–121.

———2000: Variation in wood, kraft fibre, and handsheet properties among 29 trees of *Eucalyptus regnans*, and comparison with *E. nitens* and *E. fastigata. New Zealand Journal of Forestry Science 30(3)*: 458–474.

LAUSBERG, M.J.F.; GILCHRIST, K.F.; SKIPWITH, J.H. 1995: Wood properties of *Eucalyptus nitens* grown in New Zealand. *New Zealand Journal of Forestry Science 25(2)*: 147–163.

LOW, C.B.; SHELBOURNE, C.J.A. 1999: Performance of *E. globulus, E. maidenii, E. nitens,* and other eucalypts in Northland and Hawke's Bay at ages 7 and 11 years. *New Zealand Journal of Forestry Science 29(2)*: 274–288.

PETTERSEN, R.; SCHWANDT, V. 1991: Wood sugar analysis by anion chromatography. *Journal of Wood Chemistry and Technology 11(4)*: 495–501.

RIDDELL, M.J.C.; KIBBLEWHITE, R.P. 1999: Variation in test results for kraft pulp wood chip evaluations. *Appita 52(6)*: 454–459.

SHELBOURNE, C.J.A.; LOW, C.B.; SMALE, P.J. 2000: Eucalypts for Northland: 7- to 11-year results from trials of nine species at four sites. *New Zealand Journal of Forestry Science 30(3)*: 366–383.

SMITH, D.H. 1954: Maximum moisture content method for determining specific gravity of small wood samples. *Report of U.S. Forest Products Laboratory, Madison, No. 22014*. 8 p.