Kraft pulp qualities of eleven radiata pine clones

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SUMMARY

The kraft pulp and fibre properties of eleven 16-year-old radiata pine clones are assessed. Kraft pulp qualities and chip basic density of individual trees are not correlated one with another in the clone population. Furthermore, handsheet properties of the clones are determined by the interactive influences of fibre length, coarseness and width, rather than by length and/or coarseness alone. The 11 clones contain fibres which are generally wide, large, and of high coarseness (wall area) and wall thickness when compared with seedling trees of radiata pine of the same age.

Recent research suggests that the well defined relation between kraft pulp properties and chip basic density of radiata pine wood types of widely different age may not hold for wood of the same tree age (1,2,3). For example, the papermaking qualities of progeny of radiata pine clone 850-55 are able to be predicted by fibre coarseness and length but not by chip basic density alone (3). Fibres of the progeny of clone 850-55 are long, of high coarseness, extremely wide, thin walled and easily collapsed, when compared with those of the radiata pine population as a whole. Such softwood kraft fibre properties are equivalent or inferior to those currently produced from the New Zealand plantation resource, for many conventional papermaking end uses. Thus the possible selection of clones which give long and relatively slender fibres of low coarseness can be expected to increase the versatility of, and number of market niches available for, New Zealand radiata pine market kraft pulp (4). The kraft fibre and handsheet properties are assessed in this report for two trees each of ten selected radiata pine clones, and two pulps of a bulked four-tree sample of an eleventh clone. Parallel mechanical pulping trials and evaluations have been made using the same raw material (4).

EXPERIMENTAL METHODS

Sample selection and preparation

Eleven 16-year-old radiata pine clones were selected from a total of 120 clones located in Compartment 327, Kaingaroa Forest (4). Clone selection was based on wood basic density and tracheid length determined from cores taken at breast height (1.4 m). Clones were selected to cover the extreme basic density and tracheid length combinations possible: high density and long tracheids; high density and short tracheids; low density and short tracheids; low density and long tracheids and medium density and medium length tracheids. Two clones were selected for each of the five wood property combinations, with each clone represented by two trees. Such an experimental design required a total of ten clones and twenty trees. An eleventh clone with medium density and tracheid length was selected, it consisted of 4 trees which were bulked to give a bulked chip sample used to estimate differences between refiner runs in the mechanical pulping trials (4).

Two trees of each of ten clones, and a bulked four-tree sample from one clone were selected for kraft pulp quality assessment. For the ten clones each tree was chipped and pulped separately. Two replicate kraft pulps were prepared from the four-tree bulk sample.

The whole-tree samples were chipped in a commercial chipper. The chips were passed through a 40 mm overs screen, retained on a 10 mm screen, and well mixed.

Pulping and pulp processing

Kraft pulps of Kappa number 28–30 were prepared by pulping 200 g o.d. of chips using a 15% effective alkali charge at 4:1 liquor to wood ratio for H-factor levels in the range 1500 – 2000. Similar pulping conditions were used to produce the toplog and thinnings pulps (2). Further details of pulping procedures can be made available on request (unpublished data). Handsheets were prepared and pulp physical evaluations made in accordance with Appita standard procedures. The load applied during pulp refining with the PFI mill was 3.4 N/mm. Pulps were refined at 10 % stock concentration. Handsheet physical evaluation data are reported on an o.d. bases.

Fibre dimension measurement

Cross-section fibre dimensions of thickness, width, wall area, and wall thickness were measured using image processing procedures (5). Measurements were made on dried and rewetted fibres from handsheets. The product fibre width x fibre thickness represents the minimum fibre cross section rectangle. The ratio width: thickness is an indicator of the collapse potential 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 wall area x length product. Relative weighted average fibre length and fibre coarseness were determined with a Kajaani FS 200 instrument using TAPPI Method T271 pm-91.

RESULTS

Fibre property – clone relation

Fibre coarseness and length are both uncorrelated with chip basic density (Fig. 1, Table 1). There is therefore no correlation between these traits at the individual tree and at the clone mean levels. Fibre length and coarseness values of the 22 pulps from individual trees are correlated one with another ($r^2 = 0.64$) (Fig. 2), but to a lesser extent than those made from bulked whole-tree samples taken from radiata pine seedling populations of widely different age ($r^2 = 0.95$) (1).

Individual-tree fibre coarseness and wall area values show remarkably little variation between the two trees of each clone with high and low coarseness values corresponding to high and low

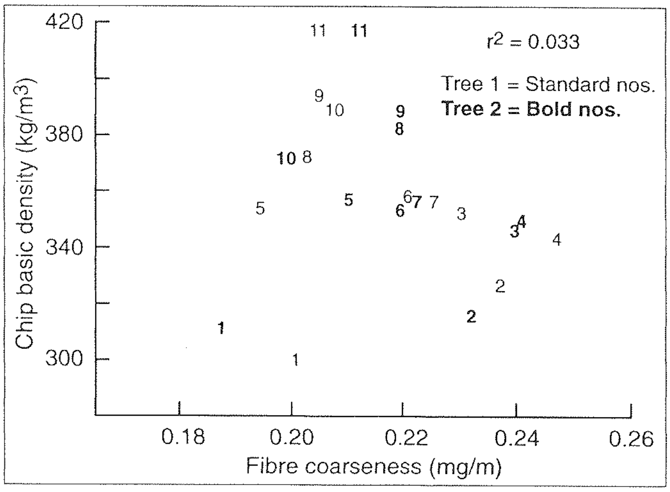

Fig. 1 Chip basic density and fibre coarseness.

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wall area values respectively (Table 1). Overall there is a strong correlation between fibre coarseness and fibre wall area for the 22 samples (Fig. 3). Other important fibre parameters are size (width and the width x thickness product), fibre collapse potential (width: thickness ratio) and relative number of fibres (1,5).

One-way analysis of variance for the traits of chip basic density, fibre length, fibre coarseness, and fibre size (width x thickness) show highly significant differences between clones, with very small error for between-tree differences (Table 2).

Fibre property interrelationships

Fibre coarseness, length and size, and chip basic density, for each of the 22 pulps are classified into broad categories in Table 3 in accordance with mean property values and their least significant differences (Table 1). On these bases, the paired pulps of only three of the clones are different one from another: the fibres from the two trees of clone 8 differ in wall area (coarseness), length and collapse potential, those from clone 9 differ in wall area (coarseness); and those from clone 10 differ in length. Some general chip and kraft fibre property relations are indicated in Table 3:

- Low chip basic density with high fibre coarseness is indicative of

Table 1
Fibre dimensions and coarseness

Clone	Tree	Chip basic density kg/m³	Kraft fibre dimensions basic density kg/m3: Coarseness† mg/m	Length* mm	Width µm	Thickness µm	Width x thickness µm²	Wall area µm²	Wall thickness µm	Width: thickness	Relative number of fibres
1	1	298	.201	2.32	34.8	11.2	390	209	2.95	3.33	100
1	2	310	.187	2.29	35.2	10.6	372	202	2.82	3.57	105
2	1	326	.237	2.66	35.5	12.1	432	233	3.16	3.20	78
2	2	315	.232	2.53	37.8	12.0	457	246	3.13	3.40	86
3	1	351	.231	2.54	35.8	13.3	477	244	3.17	2.93	80
3	2	344	.239	2.52	35.6	12.1	436	236	3.22	3.11	82
4	1	342	.247	2.60	36.0	12.4	451	243	3.28	3.14	77
4	2	348	.241	2.65	35.7	12.3	443	246	3.43	3.06	74
5	1	353	.194	2.25	31.9	11.2	361	196	3.02	3.06	110
5	2	356	.211	2.32	33.6	11.1	377	208	3.00	3.24	101
6	1	358	.221	2.46	32.9	11.6	379	218	3.35	3.05	90
6	2	352	.219	2.56	32.1	11.7	377	213	3.29	2.94	89
7	B¶	356	.226	2.69	33.1	12.2	405	217	3.17	2.91	83
7	B¶	356	.222	2.59	34.0	12.0	412	222	3.18	3.01	84
8	1	372	.203	2.28	33.8	11.7	399	221	3.16	3.14	96
8	2	384	.219	2.49	32.3	12.9	422	241	3.66	2.67	81
9	1	393	.205	2.52	31.8	11.4	366	201	3.11	3.00	97
9	2	386	.219	2.51	31.3	11.9	378	218	3.42	2.80	89
10	1	388	.208	2.57	29.4	11.7	350	202	3.33	2.65	93
10	2	371	.199	2.40	31.2	11.4	355	198	3.12	2.93	102
11	1	417	.205	2.31	32.6	11.8	385	216	3.26	2.94	97
11	2	418	.212	2.36	31.4	11.8	378	201	2.99	2.80	102
LSD‡					1.8	0.7	33	16	0.17	0.23	

* Length weighted fibre length: Confidence limits ±0.05 mm at the 95% level of significance based on the PAPRO Standard Medium calibration pulp. Two length determinations made for each pulp, with 10 000 – 15 000 particles measured in each (PAPRO Laboratory Manual Method 1.306).
† Fibre coarseness: Confidence limits ±0.015 mg/m at the 95% level of significance based on the PAPRO Standard Medium calibration pulp. Two determinations made for each pulp (PAPRO Laboratory Manual Method 1.306).
‡ Least significant difference between means at the 95% level of significance. The mean value of each fibre cross-section dimension is based on the measurement of 200 fibres (4).
¶ Bulked chip sample of chips from 4 individual trees from the same clone. Two kraft pulps were made from chips taken from the bulked sample.

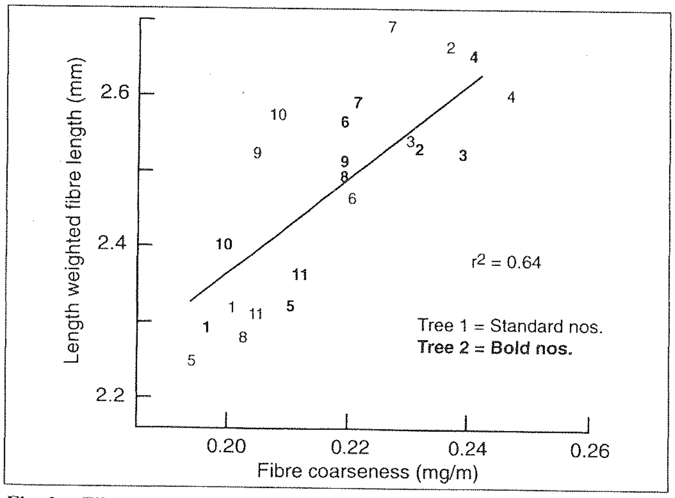

Fig. 2 Fibre length and fibre coarseness.

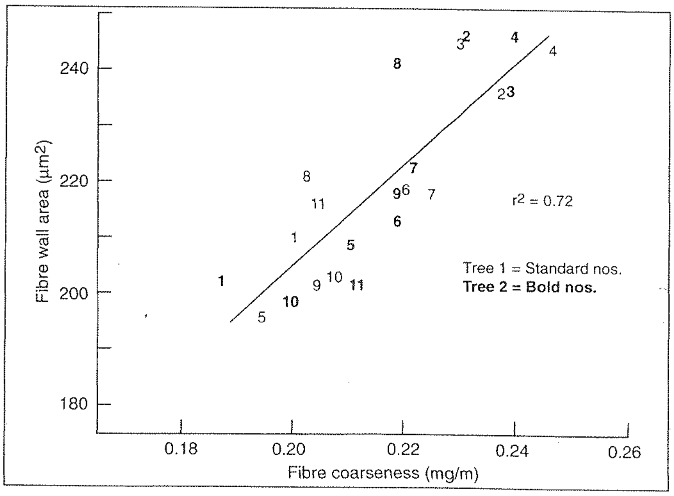

Fig. 3 Fibre wall area and fibre coarseness.

broad and large fibres of intermediate-high collapse potential eg. clones 2, 3, and 4.

- Low chip basic density with low-medium fibre coarseness is indicative of broad fibres of extremely high collapse potential e.g. clone 1.
- High chip basic density with low-medium fibre coarseness is indicative of relatively narrow fibres of low collapse potential with thick walls relative to their size e.g clones 9, 10. and 11.

Based on their fibre properties the pulps of the 11 clones can be grouped into four broad categories, (Table 3, Figs. 1,2,3):

- High coarseness, long and large fibres of high collapse potential – Clones 2, 3, and 4.
- Low-medium coarseness and short fibres of high collapse potential – Clones 1 and 5.
- Low-medium coarseness, relatively narrow fibres of low collapse potential – Clones 8, 9, 10 and 11.
- Long fibres of medium coarseness and other properties – Clones 6 and 7.

Handsheet property – clone relations

The handsheet properties of tear index, tensile index, apparent density and light scattering coefficient are used as the base to explain fibre and handsheet property interrelations. One-way analysis of variance for the mean handsheet properties of apparent density, tensile index, tear index, and light scattering coefficient show highly

Table 2
One-way ANOVA for selected chip and fibre properties of the 10 clone, 20 individual-tree pulps

Fibre/chip property	Source	SS	df	MS	F	P-value	F crit
Basic density	Between clones	16798.05	9	1866	49.31	4.16E-07	3.02
	Within	378.5	10	37.85			
	Total	17176.55	19				
Fibre length	Between clones	0.26462	9	0.02940	5.29	0.007833	3.02
	Within	0.0556	10	0.00556			
	Total	0.32022	19				
Fibre coarseness	Between clones	0.004283	9	0.000476	8.02	0.001571	3.02
	Within	0.000593	10	5.93E-05			
	Total	0.004877	19				
Fibre size (width x thickness)	Between clones	21166.05	9	2352	15.05	0.000107	3.02
	Within	1562.5	10	156.3			
	Total	22728.55	19				

Table 3
Fibre property trends

Clone	Tree	Chip basic density	Relative fibre dimensions				
			Wall area & coarseness	Length	Width & width x thickness	Collapse potential	Relative number of fibres
1	1	Low	Low-medium*	Short	Wide & small	Highest	High
1	2	Low	Low-medium*	Short	Wide & small	Highest	High
2	1	Low	High	Long	Wide & large	High	Low
2	2	Low	High	Long	Wide & large	High	Low
3	1	Low	High	Long	Wide & large	Intermediate	Low
3	2	Low	High	Long	Wide & large	Intermediate	Low
4	1	Low	High	Long	Wide & large	High	Lowest
4	2	Low	High	Long	Wide & large	High	Lowest
5	1	Intermediate	Low-medium*	Short	Narrow† & small	High	High
5	2	Intermediate	Low-medium*	Short	Intermediate & small	High	High
6	1	Intermediate	Medium	Long	Narrow† & small	Intermediate	Intermediate
6	2	Intermediate	Medium	Long	Narrow† & small	Intermediate	Intermediate
7	B1	Intermediate	Medium	Long	Intermediate	Intermediate	Low
7	B7	Intermediate	Medium	Long	Intermediate	Intermediate	Low
8	1	High	Medium	Short	Intermediate	High	Intermediate
8	2	High	High	Long	Intermediate	Low	Low
9	1	High	Low-medium*	Long	Narrow† & small	Low	Intermediate
9	2	High	Medium	Long	Narrow† & small	Low	Intermediate
10	1	High	Low-medium*	Long	Narrow† & small	Low	Intermediate
10	2	High	Low-medium*	Intermediate	Narrow† & small	Low	High
11	1	Highest	Low-medium*	Short	Narrow† & small	Low	Intermediate
11	2	Highest	Low-medium*	Short	Narrow† & small	Low	High

* Low-medium wall area/coarseness category necessary to distinguish between the lower values of thinnings and young toplogs of previous studies (Appendix I (1)).

† Narrow only in the context of the clonal pulps. Other softwood (4) and other radiata pine (Appendix I (1)) kraft fibres can be more narrower than those of the 22 clones (Table 1).

significant differences between clones, with very small error for between-tree differences (Table 4). Handsheet property values included in the analyses are the means of mean property values at four PFI mill refining levels.

Handsheet and fibre property interrelations

Three handsheet property combinations are examined; tearing resistance versus tensile strength, tensile strength versus apparent density, and light scattering coefficient versus apparent density. Such combinations of properties are necessary to assess the papermaking properties of kraft pulps (1,2,3). For example, while the tensile strengths of a range of radiata pine kraft pulps can be similar their apparent density, light scattering coefficient, and tearing resistance values can be very different (3). It is combinations of handsheet properties, and not individual properties alone, which describe the papermaking potential of a kraft pulp. In this paper handsheet property and fibre property interrelations for the 22 pulps are assessed and interpreted. Rigorous statistical analyses are used in a parallel paper to further quantify relations between the handsheet and fibre properties (6).

Handsheet data for the 22 pulps are presented in paired graphs for each of the three combinations of properties – tearing resistatnce; tensile strength tensile strength-apparent density; and light scattering coefficient/apparent density. The first graph of each pair shows enveloped pulps with extreme high or low values for all three property combinations (Fig. 4,6,8). The second graph of each pair shows the positions of the remaining pulps relative to the envelopes of the first graph (Fig. 5,7,9).

Tearing resistance for given tensile strengths are high for the low-medium coarseness, long, and relatively narrow fibres of low collapse potential (clones 9, tree 2 of clone 8, and tree 1 of clone 10), and low for the short fibre, low-medium coarseness pulps of high collapse potential (clones 1 and 5) (Fig 4) (Table 2). Corresponding short fibre pulps of low-medium coarseness, but with relatively narrow fibres of low collapse potential (clone 11, tree 1 of clone 8, and tree 2 of clone 10), have somewhat intermediate tearing resistances for given tensile values (Fig 5). Such handsheet properties are also obtained with the pulps of intermediate fibre quality (clones 6 and 7), and the high coarseness, large and long fibre pulps of clone 4 and to a lesser extent clones 2 and 3.

Handsheet tensile strengths at given apparent density values are highest for the long and relatively narrow fibres of clone 9, tree 2 of clone 8, and tree 1 of clone 10, and lowest for the short and highly collapsed fibres of clones 1 and 5 (Fig. 6). The remaining clones and/or trees give intermediate level handsheet tensile strengths (Fig. 7). Tensile strength and apparent density trends for the various clones closely parallel corresponding tearing resistance and tensile strength relations (Fig. 4,5,6,7).

Somewhat different handsheet tear-tensile and tensile-apparent density properties are obtained for the two trees of clone 8, and for the two trees of clone 10 (Fig. 4,5,6,7). These differences are explained by the different fibre properties of the pulps (Tables 1,2) The high tearing resistance

Table 4
One-way ANOVA for selected mean handsheet properties of the 10 clone, 20 individual-tree pulps.

Handsheet property	Source	SS	df	MS	F	P-value	F crit
Apparent density	Between clones	8045.066	9	893.9	10.00	0.00063	3.02
	Within	893.4688	10	89.35			
	Total	8938.534	19				
Tensile index	Between clones	298.6906	9	33.19	9.95	0.000644	3.02
	Within	33.34375	10	3.334			
	Total	332.0344	19				
Tear index	Between clones	32.635528	9	3.626	10.57	0.0005	3.02
	Within	3.431563	10	0.3432			
	Total	36.06684	19				
Light scattering coefficient	Between clones	6.481281	9	0.7201	5.20	0.008337	3.02
	Within	1.385312	10	0.1385			
	Total	7.866594	19				

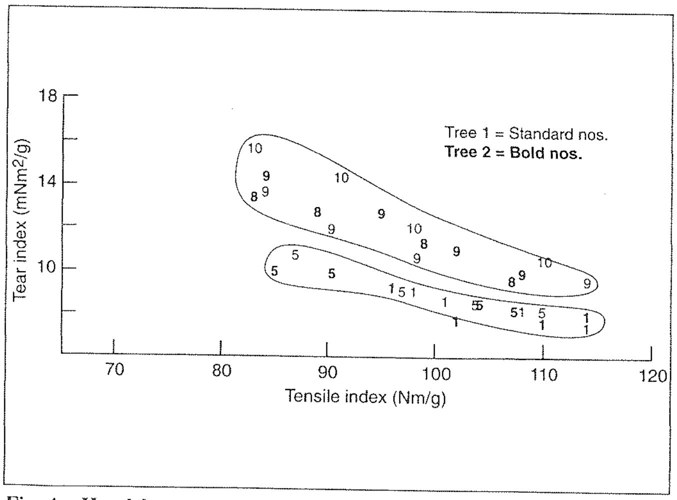

Fig. 4 Handsheet tear and tensile strengths for pulps of 'high' and 'low' tear strength.

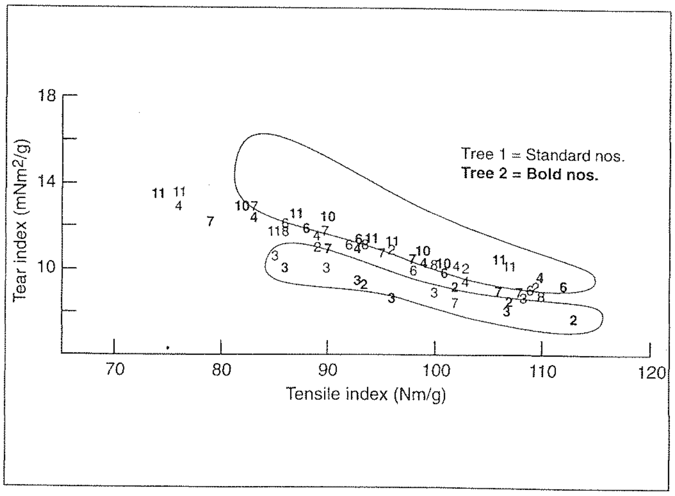

Fig. 5 Handsheet tearing resistance and tensile strengths for pulps of 'low and intermediate' tearing resistance compared with those of Fig. 4.

obtained with tree 8-2 is explained by long fibres of intermediate to high coarseness (1). For tree 2 of clone 10, the low tearing resistance for a given tensile strength, and the low tensile strength for a given apparent density of pulp 10-2, are explained by short and high numbers of fibres when compared with pulp 10-1.

The length, coarseness, and size but not collapse potential of the fibres of clone 5 are similar to those of clone 11 (Table 2). The papermaking properties of the two clones are however very different with the clone 5 pulps having high bonding potentials giving handsheets of high density (low bulk) and low tearing resistance (Fig. 4,5,6,7).

Handsheet light scattering coefficient and apparent density relations also clearly separate clones 1 and 5 from all the rest (Fig 8,9). While these pulps have high light scattering properties their sheet densities and tear-tensile properties are unacceptable for most end uses of softwood kraft pulps. For the remaining pulps, those from clones 4, 8, 9, 10, and 11 form a grouping, but with pulp 8-1 and 10-2 fitting within the intermediate grouping. This grouping of pulps has the lowest light scattering properties for a given apparent density, but the most desirable tear/tensile and tensile/apparent density properties.

DISCUSSION

Chip basic density and kraft pulp quality

Extensive studies over the past 30 plus years have repeatedly confirmed close relations between kraft pulp properties and chip basic density for New Zealand's radiata pine plantation populations of different age and growing site (1,2,3). This fact is used to advantage by New Zealand kraft mills which segregate wood and chips on their basic density to produce a wide range of pulps of different fibre quality (7). For the individual trees of the clones, on the other hand, chip basic density and kraft pulp quality are poorly correlated one with another in agreement with previous studies of individual trees (2,8,9,10) and of bulked-tree samples of 22 year old progeny of clone 850-55 (1). Future implications of such individual tree effects could be significant for the New Zealand pulp and paper industry when/if the forest estate is able to be classified according to fibre properties. Wood and chip segregation will need to be based on genotype identification and their predetermined fibre properties, or through the measurement of fibre properties of incoming wood supplies. A rapid fibre property assessment procedure for either chip or wood supplies is currently unavailable, although research instrumentation developed by Evans *et al* (11) could prove to be a suitable prototype.

Fibre and handsheet property interrelations

The papermaking properties of kraft pulps made from the existing New Zealand radiata pine plantations are determined by fibre coarseness and/or fibre length (1,2,3,7). The situation for individual trees is less simple and handsheet properties are not primarily explained by fibre coarseness or length alone. Kraft pulp qualities are determined by the interactive influences of combinations of fibre length, width and coarseness or wall area. For example the fibres of clones 9, 10 and 11 are generally of low-medium coarseness, relatively narrow, and of low collapse potential, but can be long or short (Table 3). Handsheet tearing resistances, and tensile strengths for given apparent densities, are somewhat higher for clones 9 and 10 than for clone 11, probably because of their different fibre lengths (Figures 4,5). In fact, tearing resistances for given tensile

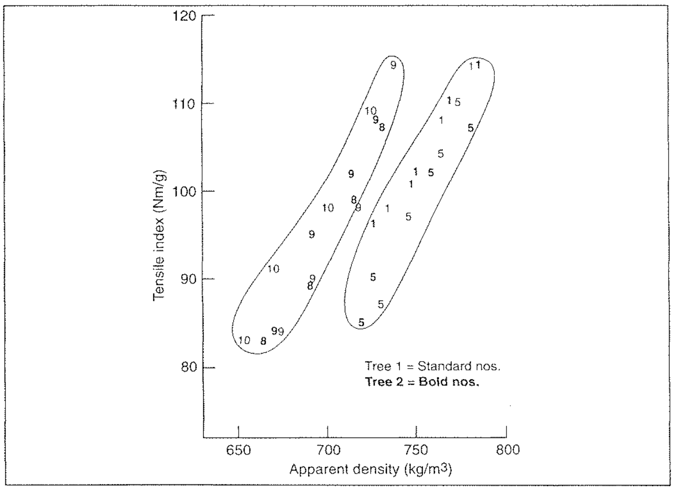

Fig. 6 **Handsheet tensile strength and apparent density for pulps of 'high' and 'low' density.**

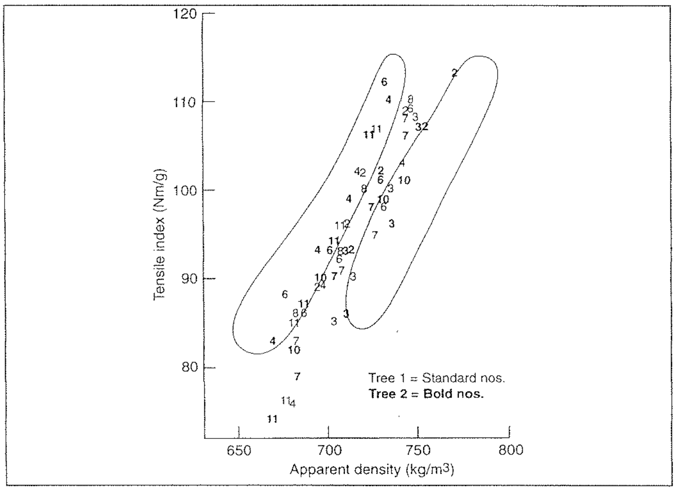

Fig. 7 **Handsheet tensile strength and apparent density for pulps of 'intermediate' density compared with those of Figure 6.**

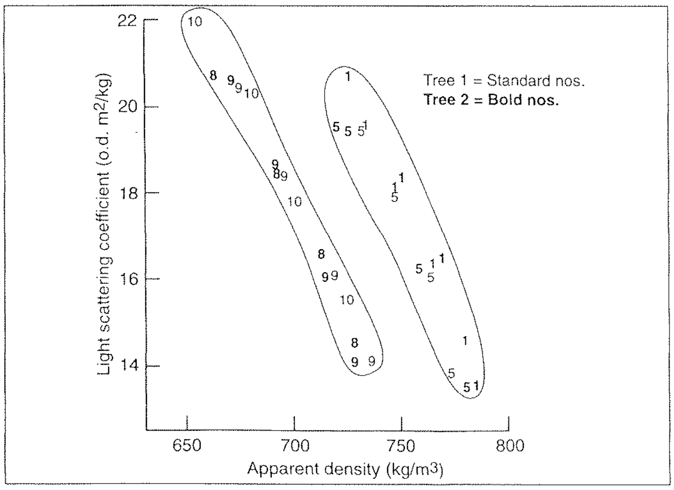

Fig. 8 **Handsheet light scattering coefficient and apparent density for pulps of high and low density.**

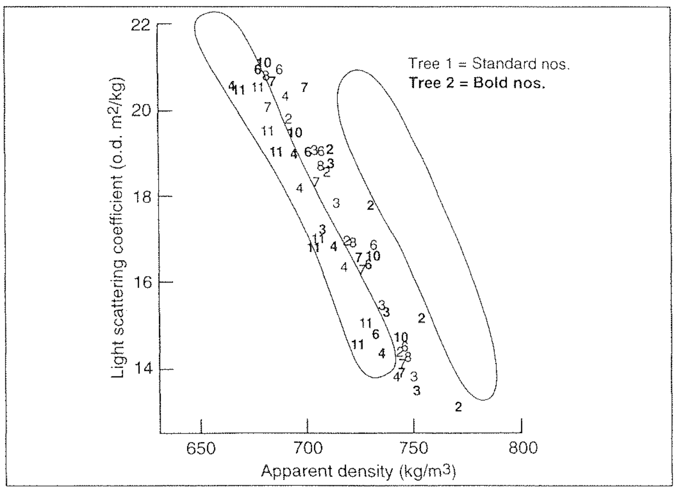

Fig. 9 **Handsheet light scattering**

strengths, and tensile strengths for given apparent densities, decrease with decreasing fibre length for the low-medium coarseness and relatively narrow fibres of clones 9, 10 and 11 (Table 3). Tree 2 of clone 8 shows a different combination of fibre properties (medium to high coarseness and intermediate size), but generally similar apparent density and tear-tensile to those of clones 9, 10, and 11.

A further example of the interactive influence of different fibre properties are the similar tensile strengths and/or light scattering coefficients for given apparent densities obtained with pulps of clones 9, 10, 11, and 4 (Fig. 4,5,6,7). Clone 4 has exceptionally large and coarse fibres of high collapse potential when compared with those of clones 9,10 and 11. Furthermore, clone 4 contains significantly fewer fibres per unit mass of pulp than clones 9,10 and 11 – about 76 compared with about 97 (Tables 1,3). While different combinations of fibre properties can be used to give handsheets with selected properties, only some will be suitable for the manufacture of certain paper products. Thus it will be found that clone 4-type fibres will be suitable for certain products only, and clone 9, 10, and 11–type fibres suitable for alternative products, irrespective of their similar handsheet properties.

Fibre properties of clones propagated from cuttings versus seedling trees

The fibres from the 16-year-old clones are generally wide, large and of high wall area (coarseness) and wall thickness, when compared with seedling trees of the same age utilised as thinnings, as well as toplogs and slabwood from older seedling trees (Table 1, Appendix I) (1). It is significant that the fibres of clones 9, 10 and 11, which are narrow and of low coarseness (Table 3), have cross section fibre dimension and handsheet tearing resistances and tensile strength properties which are almost equivalent to those of normal radiata pine slabwood, particularly those of the longer fibre pulps of clones 9 and 10 (Fig. 10 and Appendix I).

Pulp uniformity based on fibre wall area and fibre size population distributions are also similar for the pulps of slabwood from 26 and 33 year old trees (1) and the 16 year old trees of clones 9,10, and 11 (Tables 5,6).

In fact, overall mean distribution values for these clone and slabwood pulps are almost identical. It is noteworthy that such slabwood fibre and handsheet characteristics are being obtained from whole-tree pulps prepared from clones of age 16 years only.

The slabwood fibres are longer (by 12–16 percent) than those of clones 9, 10, and 11, and this is reflected in slightly higher tearing resistances for given tensile strengths, and higher apparent densities (Tables 1,3, Appendix I, Fig. 10,11,12). Hence, handsheet density could be expected to be decreased (bulk increased) with retention of tensile strength and light scattering coefficient if clones or individual genotypes could be found with the fibre cross-section dimensions of clones 9, 10, and 11, but with increased fibre length.

It is noteworthy that the fibres of pulp made from the 16 year old clones are generally wider, larger and of higher wall area (coarseness) and wall thickness compared with those made from thinnings, toplogs and slabwood (1,3) (Table 1 and Appendix I). The fibres are closer in their characteristics to slabwood fibres than those from 18-year-old thinnings. This difference may be caused by physiological ageing of the 11 clones which were roughly equivalent in 'age' at time of setting to cuttings taken from five year old trees (C.J.A. Shelbourne, pers. comm.).

Commercial implications

Radiata pine kraft pulps from slabwood are of premium quality for the manufacture of certain products such

Table 5
Fibre wall area population distributions

Pulp sample		Per cent fibre wall area classes (µm²) 70	150	230	310	390	470
Clone 9	Tree 1	10	43	32	10	5	
	Tree 2	11	32	27	23	5	2
Clone 10	Tree 1	9	38	35	14	4	
	Tree 2	6	44	34	13	3	
Clone 11	Tree 1	5	32	43	15	3	2
	Tree 2	11	39	31	15	2	2
Mean for clones		9	38	34	15	3	1
Slabwood 1013		10	38	36	12	3	1
Slabwood 1060		7	33	39	17	3	1
Slabwood		13	41	30	14	2	
Slabwood mean		10	37	35	14	3	1

Table 6
Fibre size (width x thickness) population distributions

Pulp sample		Per cent fibre size classes (µm²) 100	300	500	700	900
Clone 9	Tree 1	11	60	20	7	2
	Tree 2	14	42	35	7	2
Clone 10	Tree 1	13	53	28	6	
	Tree 2	10	60	24	5	1
Clone 11	Tree 1	7	52	33	6	2
	Tree 2	12	49	31	6	2
Mean for clones		11	53	29	6	1
Slabwood 1013		12	52	28	7	1
Slabwood 1060		11	46	35	8	
Slabwood		15	53	27	5	
Slabwood mean		13	50	30	7	

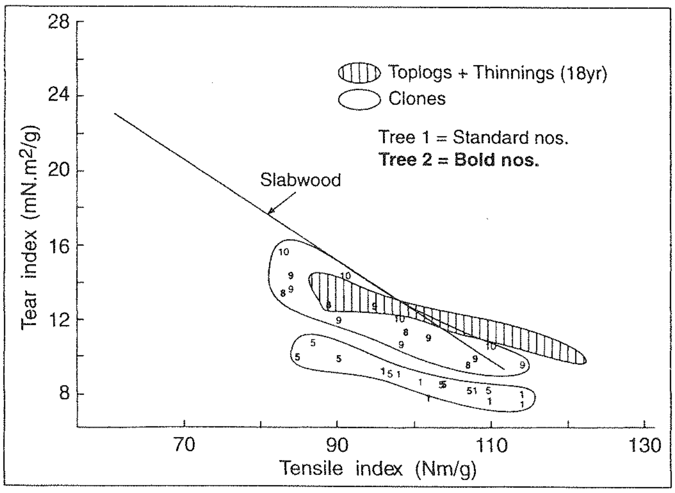

Fig. 10 Handsheet tearing resistance and tensile strengths for the clones from Figures 5,6, and slabwood and toplogs (1).

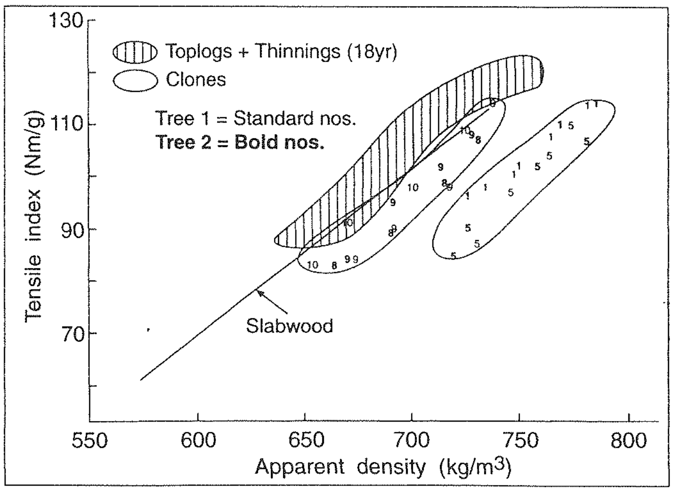

Fig. 11 Handsheet tensile strength and apparent density for the clones from Figures 7,8, and slabwood and toplogs (1).

as fibre cement panels. Thus, the production of 16-year-old whole-trees with kraft fibre dimensions (other than length) which are equivalent to those of normal slabwood is noteworthy. The end-use potential of such pulps would be further enhanced if fibre length could be increased by 12–16%, from about 2.5 mm to about 2.9 (Table 1, Appendix I). Furthermore, any decrease in tree age, with continued production of long slabwood-type fibres, would have significant cost advantages. Recognition of a possible physiological ageing effect for the 11 clones has implications for tree propagation, and crop rotation periods and fibre qualities.

For the manufacture of many paper grades (printings, and writings, and tissue) the fibre quality requirements of the softwood kraft component are for slender and long fibres of low coarseness. The converse occurs with the pulps from the 11 clones since their fibres are generally wide, large, and of high wall area (coarseness) and wall thickness, when compared with those from seedling trees of radiata pine utilized as thinnings, toplogs, and slabwood (Tables 1,3 and Appendix I). Radiata pine pulps prepared from seedling trees from plantation thinnings show the desired trends in fibre width, wall area, and wall thickness but are deficient in length (1,3). From a forest grower's perspective there is therefore a need to select and grow young trees which have longer fibres. Confirmation of a physiological ageing effect for the clones can also be expected to have implications in the selective production of plantation crops with desired fibre properties.

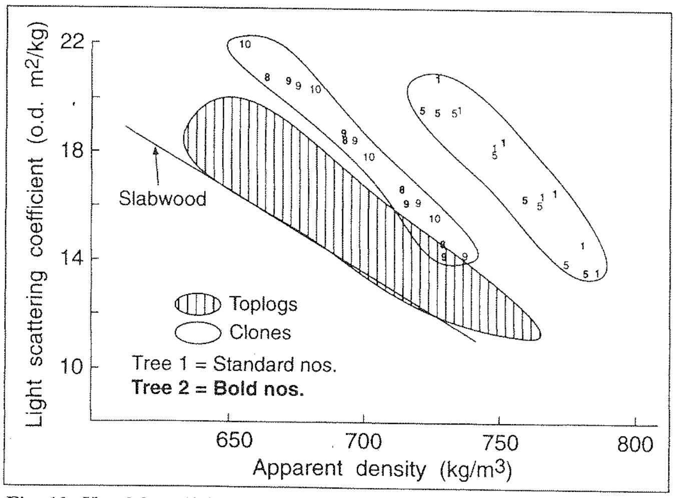

Fig. 12 Handsheet light scattering coefficient and apparent density for the clones from Figures 9,10, and slabwood and toplogs (1).

CONCLUSIONS

Between clone differences are highly significant for chip basic density, the fibre properties of length, size and coarseness, and the handsheet properties of tensile and tear strength, tearing resistances apparent density, and light scattering coefficient.

Chip basic density and kraft pulp quality are poorly correlated one to another at the individual-tree level in the eleven 16-year-old radiata pine clones.

Kraft pulp qualities of the eleven 16-year-old radiata pine clones are determined by the interactive influences of fibre coarseness, length and width, rather than by fibre coarseness or fibre length alone.

Handsheets with the most desirable tearing resistance and tensile strength, and apparent density or bulk, are obtained from kraft pulps which contain relatively long and narrow fibres of lowest coarseness.

Fibres from the 16-year-old clones are generally wider, larger and of higher wall area (coarseness) and wall thickness, when compared with those from radiata pine seedling trees of the same age. The difference between the clones and seedlings trees may be due to physiological ageing; the clones were equivalent approximately to cuttings of five year old trees at time of setting.

The fibre cross-section dimensions and handsheet properties of the best of the clones are similar to those of radiata pine slabwood, except for fibre length. Pulp uniformities based on fibre wall area (coarseness) and size (width x thickness) are also equivalent. Kraft fibre coarseness and width values for all the clones are similar to, or higher than, those which can be obtained with radiata pine seedling trees.

Slabwood-type fibre and handsheet characteristics can be obtained from whole-tree pulps prepared from the clones of age 16 years. The fibres in such pulps are shorter by 12ñ16% when compared with those from radiata pine slabwood populations based on seedling trees.

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APPENDIX 1

Mean fibre cross-section dimensions of radiata pine dried and rewetted kraft pulps ref. (1)

Wood origin	Fibre length mm	Fibre width µm	Fibre thickness µm	Width x thickness µm²	Wall area µm²	Wall thickness µm	Width/ thickness
Thinnings-9 yrs	1.97	28.0	10.3	289	155	2.73	3.00
Thinnings-12 yrs	2.02	30.2	10.8	329	178	2.80	3.04
Thinnings-15 yrs	2.26	30.6	10.7	333	174	2.71	3.12
Thinnings-18 yrs	2.40	31.7	11.4	369	191	2.85	3.03
C55-toplog	2.47	32.3	10.0	324	173	2.56	3.47
C55-toplog	2.48	33.1	10.7	356	191	2.70	3.35
Toplogs-9 yrs	2.56	30.6	11.2	350	187	2.92	2.92
Toplogs-12 yrs	2.45	28.6	11.6	340	183	3.03	2.61
Toplogs-15 yrs	2.58	32.6	11.5	380	207	3.00	3.03
Toplogs-18 yrs	2.71	31.0	12.3	388	209	3.27	2.66
Slabwood	2.88	29.7	11.5	345	192	3.11	2.79
Slabwood-Cpt. 1060	2.93	30.7	12.4	386	212	3.29	2.62
Slabwood-Cpt. 1013	2.84	30.8	11.9	370	202	3.10	2.75
C55-slabwood	3.13	33.4	12.9	428	228	3.21	2.90
C55-slabwood	3.09	34.1	13.0	444	241	3.37	2.84
LSD*		1.8	0.7	31	15	0.17	0.24

Note:

1. Fibre length and cross-section dimension values of Appendix 1 are directly comparable with those obtained for the eleven clones (Table 1).
2. Fibre coarseness values have been deleted from the above Table since they are not comparable with those obtained for the clones (Table 1). The Kajaani FS 200 fibre length and coarseness calibration was changed in the period between the two studies.