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GENETIC SELECTION OF TREES WITH DESIGNER FIBRES FOR DIFFERENT PAPER AND PULP GRADES

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SUMMARY

Pinus radiata and eucalypts are fast-grown species, well suited to plantation forestry in New Zealand and elsewhere, and for the manufacture of a wide range of solid wood and reconstituted wood products, including pulp and paper.

This paper examines the variation and end-use potential of the individual-tree kraft fibre and handsheet properties of 25 trees of 13-year-old *P. radiata* and 29 trees of 15-year-old *Eucalyptus nitens*. Individual-tree fibre property differences are assessed with reference to the fibre quality requirements of a range of wood-free paper grades. Strategies and procedures are also described which will enable parent trees with desired fibre properties to be identified, propagated and mass produced.

In selecting fibre types for different paper and pulp grades, the apparent density of "unrefined" pulps (500 PFI mill rev) is the base against which other "unrefined" handsheet properties are compared. Apparent density is a direct measure of fibre packing density and arrangements in handsheets, and is determined by fibre length and cross-section dimensions, and the related morphological configurations of collapse and straightness. Although the individual-tree pulps of both species can normally be refined to the same tensile index, apparent density values can be very different depending on their fibre properties. Thus, minimal pulp refining is preferred for comparing individual-tree pulps for tree selection.

Apparent density is best predicted by the kraft fibre property combination of the fibre width/thickness ratio and length. The combination of chip basic density and kraft fibre length is also a good predictor of handsheet apparent density but not necessarily of the best fibres

for the manufacture of particular products. Wood density is a measure of the ratio of wood substance to void space in each individual-tree chip sample and is not indicative of the numbers of fibres which make up a unit volume.

Kraft handsheet properties varied widely among trees for both species and were well-predicted by kraft-fibre dimensions. The high broad-sense heritabilities[1] shown for these traits in *P. radiata* mean that clonal forestry could provide pulpwood of uniform and predictable pulping performance from monoclonal forest blocks. The high narrow-sense heritabilities[2] shown so far for wood properties in *P. radiata* (and for some wood properties in *E. nitens)* indicate that planting control-pollinated families[3] of known characteristics could have a similar though less uniform result.

INTRODUCTION

Pinus radiata and eucalypts are fast-grown species, well suited for plantation forestry in New Zealand and elsewhere, and for the manufacture of a wide range of solid wood and reconstituted wood products, including pulp and paper. One of the aims of an ongoing multi-disciplinary research programme at the New Zealand Forest Research Institute is to determine the technical requirements for different end-products in terms of the wood properties of certain species. This is being done by estimating the variation between individual trees in wood and chemical properties and relating these to their end-product characteristics of solid wood, TMP, and kraft pulp and paper.

The species chosen for these studies were *P. radiata* and *Eucalyptus nitens. Pinus radiata*

1 Broad-sense heritability, a ratio of variance among clones in a population to variance among clones plus variance among trees within clones, expresses the level of genetic determination of a trait and only applies to clonal propagation.

2 Narrow-sense heritability, the ratio of additive genetic variance to total variance in a population for a trait, expresses the degree to which a trait is passed from parent to offspring.

3 A "family" constitutes a group of individual-tree offspring deriving from a single common seed parent (open-pollinated or half-sib family), or from two common parents (full-sib family).

makes up more than 90% of the exotic forest estate planted in New Zealand for a wide range of end-products; *E. nitens* is a fast-grown, frost-tolerant eucalypt that is now being established in New Zealand, primarily for pulpwood (1).

This paper reports results of individual-tree wood density, and kraft fibre and handsheet properties of 25 trees of 13-year-old *P. radiata* (4,5) and 29 trees of 15-year-old *Eucalyptus nitens (6),* as well as reviewing another related study on 16-year-old *P. radiata* clones (2,3) in which predictive relationships are quantified linking kraft fibre and handsheet properties. Individual-tree fibre property differences are assessed with reference to the fibre quality requirements of a range of wood-free paper grades. Strategies and procedures are described which will enable parent trees with desired fibre properties (and of good form and growth) to be identified, propagated and mass produced.

When mass clonal propagation becomes feasible (as for *P. radiata* (7,8)), selection and propagation of clones with specific sets of wood-tracheid and other wood and end-product traits can be effected without much difficulty. However, *E. nitens* is one eucalypt which is difficult to propagate clonally although several other members of the genus are routinely propagated this way. In both species modification of specific wood traits can also be achieved by mating desired parents in control- or open-pollinated seed orchards, with mass propagation by seed.

EXPERIMENTAL METHODS

Population Sampling

In the prediction of kraft handsheet properties from kraft-fibre dimensions, or from wood-tracheid dimensions, it is necessary to define the purpose for which the prediction is required. For a pulp mill that draws its wood from several species of softwoods and/or hardwoods, defining and characterising the wood and pulping properties of the species involved is a first step. Differences between softwoods and hardwoods, and among species, can be very large and will determine the appropriate end use of those particular types of fibres. For a given species, there will be major differences in wood and fibre properties, and resulting pulping characteristics, caused by wood age (growth layers from pith) and different tree-growing environments (9,10).

In this paper, the variation among individual trees within an even-aged population growing in a single, reasonably uniform environment is the main issue because the aim is to modify future populations of this kind through genetic selection. For this objective, individual trees will be selected either as seed parents or as vegetatively multiplied clones for planting new stands. With this purpose in mind, the effects of local microsite of each tree in the study populations will be minimised; where feasible, planting several individual-tree replicates of a clone will enable the separation of genetic and environmental effects.

Accordingly, the individual trees sampled in these studies have been selected from a single site from replicated and randomised progeny and clonal tests, with trees of the same age, of known family (4,5,6) or clone (2,3). Each tree has been selected for a range of wood properties to provide the best possible population in which to determine regression relationships through choice of a range of independent (wood property) variables on which to regress dependent (kraff handsheet) variables. The 25 trees of *P. radiata* and 29 of *E. nitens* that were evaluated are seedling trees of known provenance and family *(4,5,6)*, growing in genetic tests:

- ***P. radiata;*** Twenty-five 13-year-old trees growing in an open-pollinated progeny test at Rotoehu Forest, Cpt 29 were selected from 25 families;[1] their female parents had also been selected for extremes of both tracheid perimeter and wall thickness, based on the assessment of breast-height pith-to-bark radial strips using SilviScan (4,11). Each tree was whole-tree-chipped (all merchantable log material) after removal of a basal 1-m bolt and 5-cm thick discs at 5.5-m intervals up the stem.
- ***E. nitens;*** Twenty-nine 15-year-old *E. nitens* trees of central Victorian provenances were selected from a provenance-progeny trial at Cpt 1217, Kaingaroa Forest. The 29 trees were selected from 100 well-grown dominant or co-dominant trees without forking, previously increment-core-sampled, to cover a full range of basic density. Twenty of these trees were felled in late 1994 and the remaining nine in mid 1995 (6), disc-sampled as for *P. radiata* and whole-tree chipped.

1 A "family" constitutes a group of individual-tree offspring deriving from a single common parent (open-pollinated or half-sib family), or from two common seed parents (full-sib family).

Wood and Kraft Pulp Processing Procedures

Chip basic density: Chip density was determined in accordance with Appita method Pls-79 except that the fresh chips were not given the specified soaking period (12).
Kraft pulping: A chip sample from each tree was pulped to kappa number 30±2 for *P. radiata* and to kappa number 20±2 for *E. nitens*. Further details of pulping conditions are described elsewhere (5,6).
Handsheets: Handsheets were prepared and pulp physical evaluations made in accordance with Appita standard procedures. The loads applied during pulp refining with the PFI mill were 1.8 N/mm for the eucalypt and 3.4 N/mm for the *P. radiata*. Pulps were refined at 10% stock concentration for 500, 1000, 2000 and 3000 *(P. radiata)* or 4000 (eucalypt) rev.

Fibre-Dimension Measurement

Cross-sectional kraft-fibre dimensions of thickness, width, wall area and wall thickness were measured using image processing procedures described previously (Figure 1) (13). Measurements were made on dried and rewetted fibres reconstituted from kraft handsheets. The product, fibre-width x fibre thickness is the area of the minimum fibre cross-section bounding 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 number of fibres per unit mass of pulp were 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 T27 I pm-91.

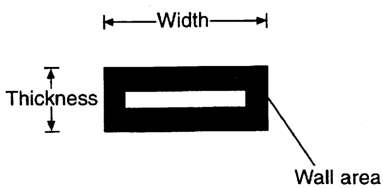


Figure 1: Cross-section diagram of a fibre dried and rewetted from a handsheet.

Terminology

Fibre and dimension abbreviations used throughout are as follows:

Fibre wall area (coarseness) μm^2	A_W
Fibre wall thickness μm	T_W
Half-fibre perimeter (width + thickness) μm	P
Fibre-length weighted length mm	L
Fibre collapse potential (width / thickness)	W/T
Half-fibre perimeter/wall thickness	P/T_W
Chip basic density kg/m^3	D

RESULTS

Variation Among Trees - The Basis for Selection

Variation in wood basic density and kraft fibre properties is high among the twenty-five 13-year-old *P. radiata* and twenty-nine 15-year-old *E. nitens* trees (Table 1) (4,5,6). Individual-tree values for chip, fibre and handsheet properties are shown in Tables 2 and 3. This provides a necessary basis for a selection and breeding programme. Other research with 11 clones of *P. radiata* also showed large variation as well as very high intra-class correlations (broad-sense heritabilities)[1] for these traits (2,3).

1 Broad-sense heritability, a ratio of variance among clones in a population to variance among clones plus variance among trees within clones, expresses the level of genetic determination of a trait and only applies to clonal propagation.

	E. nitens 15-year-old		*P. radiata* 13-year-old	
Property	**Range**	**CV* %**	**Range**	**CV* %**
Chip basic density kg/m³	390-556	8.1	300 - 407	8.4
Chip total lignin %	25.1-29.7	3.0	26.6 - 31.7	3.8
Chip total carbohydrates %	59.0-63.4	1.7	61.5 - 65.7	1.8
Pulp yield %	54-59	2.6	45 - 50	2.8
Fibre length mm	0.78-0.95	5.2	2.10 - 2.66	5.9
Half fibre perimeter (W+T) μm	19.0-21.6	2.6	40.0 - 49.5	4.6
Fibre cross-section area (WxT) μm²	83-106	5.2	315 - 466	8.7
Fibre wall area (coarseness) μm²	53-70	6.1	187 - 272	9.3
Fibre collapse potential (W/T)	1.80-2.09	3.9	2.52 - 3.56	9.0
Handsheet apparent density @ 500 PFI rev kg/m³	627-732	4.2	621 - 713	3.7

* Sample coefficient of variation (100 x σ/mean)

Table 1: Variation in selected wood chip and kraft fibre properties.

Handsheet Property Prediction from Kraft Fibre Properties

For *P. radiata* and *E. nitens* kraft-fibre properties of length, width, thickness, perimeter, wall area (coarseness), wall thickness and width/thickness (Figure 1), the width/thickness ratio (or collapse potential) is consistently the best single predictor of handsheet apparent density, tensile index, tear index *(P. radiata* only) and light-scattering coefficient *(E. nitens* only) (Table 4) (3,4,5,6). The width/thickness ratio and length combination is the best predictor of apparent density for both the eucalypt and pine pulps. In contrast, fibre length is shown to be relatively unimportant in the prediction of tensile index. The wall thickness, perimeter and length combination, and the perimeter/wall thickness ratio and length combination, are moderate predictors of the selected handsheet properties although always to lesser extent than the width/thickness ratio by itself.

Tree	Handsheet properties at 500 rev			Chip	Kraft fibre properties					
	Apparent density kg/m^3	Tear index $mN.m^2/g$	Tensile index N.m/g	density kg/m^3	L mm	P µm	A_w μm^2	T_w µm	W/T	Relative number of fibres
1	621	16.8	70	401	2.42	44.2	215	3.29	2.64	75
2	627	17.1	76	407	2.46	41.8	211	3.52	2.52	76
3	639	14.5	77	359	2.66	46.4	250	3.65	2.74	59
4	649	15.3	74	392	2.40	43.5	233	3.76	2.63	70
5	649	14.1	72	406	2.30	44.6	219	3.32	2.83	78
6	655	14.6	72	383	2.26	44.9	237	3.65	2.66	73
7	657	14.1	78	400	2.31	41.1	208	3.60	2.67	82
8	659	12.7	83	363	2.46	45.4	204	2.91	3.26	78
9	660	13.6	71	401	2.27	45.4	251	3.88	2.59	69
10	665	12.2	88	336	2.54	45.0	214	3.21	3.27	72
11	675	12.7	82	353	2.50	45.4	231	3.44	2.96	68
12	675	13.7	78	367	2.53	46.8	221	3.15	3.19	70
13	679	14.3	78	361	2.58	45.5	221	3.17	3.12	69
14	681	12.2	75	366	2.25	46.0	243	3.56	3.16	72
15	684	11.5	85	356	2.15	41.8	192	3.09	2.97	95
16	689	11.1	87	317	2.35	45.5	226	3.22	3.23	74
17	690	12.4	85	334	2.60	42.2	189	2.97	3.19	80
18	693	11.6	84	363	2.10	40.0	187	3.22	2.90	100
19	695	10.7	90	354	2.30	43.0	215	3.36	2.88	79
20	695	10.3	93	328	2.44	49.5	272	3.62	3.12	59
21	698	10.4	87	300	2.30	45.1	216	3.14	3.26	79
22	700	11.8	86	339	2.40	42.7	191	2.93	2.98	86
23	704	11.6	85	337	2.40	44.8	216	3.19	3.14	76
24	705	10.4	88	323	2.23	44.8	211	3.05	3.56	83
25	713	11.5	85	333	2.30	44.9	217	3.19	3.06	79
Lsd*					0.05	1.7	15	0.18	0.22	

* Least significant difference between means at the 95% level of significance.

Table 2: Unrefined fibre dimensions for 25 individual-tree *P. radiata* pulps arranged in increasing order of handsheet apparent density.

Tree	Handsheet properties at 500 rev		Chip	Kraft fibre properties					
	Apparent density kg/m^3	Tensile index N.m/g	density kg/m^3	L mm	P μm	A_w μm^2	T_w μm	W/T	Relative number of fibres
1	627	84	556	0.83	19.8	60	2.43	1.86	789
2	631	93	533	0.88	19.9	64	2.70	1.80	697
3	641	85	492	0.87	19.5	59	2.51	1.88	765
4	642	91	498	0.87	20.4	61	2.32	1.85	740
5	643	91	497	0.93	19.0	53	2.14	1.91	797
6	648	100	484	0.95	19.8	61	2.52	1.94	678
7	649	95	456	0.90	20.5	62	2.33	1.95	704
8	651	97	480	0.87	20.2	65	2.62	1.91	697
9	657	102	475	0.90	20.6	64	2.45	1.96	682
10	668	96	494	0.83	19.9	59	2.40	1.95	802
11	671	104	492	0.85	19.6	59	2.47	1.93	783
12	673	112	466	0.94	19.3	56	2.31	2.00	746
13	677	110	488	0.85	20.5	66	2.76	2.00	697
14	677	101	406	0.95	20.0	56	2.11	2.02	740
15	678	101	454	0.85	20.8	65	2.54	2.07	711
16	678	102	431	0.88	20.6	63	2.43	1.99	711
17	681	89	542	0.82	20.2	64	2.68	1.84	746
18	681	103	464	0.92	19.7	59	2.44	1.96	723
19	685	106	490	0.84	20.3	62	2.24	2.07	754
20	693	93	506	0.85	19.5	57	2.40	1.90	811
21	693	111	479	0.87	21.6	70	2.65	1.96	644
22	694	109	456	0.81	20.3	61	2.37	2.05	797
23	700	98	435	0.87	20.8	66	2.52	2.00	682
24	702	106	484	0.82	20.0	57	2.15	2.04	839
25	705	106	494	0.81	20.4	62	2.47	2.01	783
26	715	114	462	0.82	20.0	59	2.32	2.03	811
27	716	107	411	0.83	19.7	57	2.32	2.03	830
28	731	117	390	0.78	20.3	60	2.32	2.09	839
29	732	121	437	0.86	20.1	59	2.35	2.06	774
Lsd*				0.03	0.70	4	0.11	0.11	

* Least significant difference between means at the 95% level of significance.

Table 3: Unrefined fibre dimensions for 29 individual-tree *E. nitens* pulps arranged in increasing order of handsheet apparent density.

		25 *P. radiata*		29 *E. nitens*	
		r^2	Std error##	r^2	Std error##
Apparent density	T_W	0.23	22.6	#ns	
	L	#ns		0.24	25.34
	$T_W + P$	0.25	22.7	0.16	27.2
	$T_W + P + L$	0.43	20.4	0.37	24.1
	W/T	0.48	18.6	0.57	19.0
	W/T + L	0.59	16.8	0.68	16.9
	P/T_W	0.20	23.0	0.13	27.2
	$P/T_W + L$	0.37	20.8	0.37	23.5
Tensile index	T_W	0.26	5.75	#ns	
	L	#ns		#ns	
	$T_W + P$	0.29	5.8	0.14	8.9
	$T_W + P + L$	0.30	5.9	0.16	9.0
	W/T	0.45	5.0	0.64	5.7
	W/T + L	0.46	5.0	0.64	5.8
	P/T_W	0.26	5.8	#ns	
	$P/T_W + L$	0.28	5.8	0.14	9.0
Tear index	L	#ns			
	T_W	0.17	1.77		
	$T_W + P$	0.23	1.74		
	$T_W + P + L$	0.47	1.48		
	W/T	0.53	1.34		
	W/T + L	0.67	1.13		
	P/T_W	0.21	1.73		
	$P/T_W + L$	0.42	1.51		
Light scattering coefficient	L			#ns	
	P			0.12	1.47
	P +L			0.15	1.48
	$P+T_W$			0.12	1.50
	$P+T_W$ +L			0.15	1.51
	W/T			0.19	1.41
	W/T + L			0.21	1.42

#ns: Not significant. No correlation at the 95% level of significance if $r^2 < 0.16$ (*P. radiata*) and $r^2 < 0.12$ (*E. nitens*)
RMS error for each regression equation.

Table 4: Kraft-fibre property prediction of handsheet properties at 500 PFI mill rev.

The ratio width/thickness reflects the collapsed configuration of the kraft fibres in handsheets, and a high correlation with handsheet apparent density is therefore to be expected since high and low collapse potentials can be expected to give high and low sheet densities respectively (Figure 1). The pulp rewetting process is considered to have a negligible effect on fibre wall swelling or fibre collapse. Fibre width/thickness is a measure of the interactive influences of fibre perimeter and fibre wall area (coarseness) since a fibre of high wall area and small perimeter will be thick-walled and resist collapse, and a fibre of low wall area and large perimeter will be thin-walled and more able to collapse. Unrefined fibre properties are compared with handsheet properties after 500 PFI mill revolutions at applied loads of 1.8 N/mm for the eucalypt and 3.4 N/mm for the pine pulps. Thus, handsheets are made with relatively straight fibres (14) and minimised refining response (15) and property test data variability (16).

DISCUSSION

Some General Observations on the Fibre Property Determinants of Softwood and Hardwood Kraft Pulp Quality

The end-use potentials of softwood and hardwood market kraft pulp are determined primarily by their fibre properties (17,18).

Softwood
Softwood kraft pulp qualities are normally determined by the handsheet properties of apparent density or bulk, tensile strength and out-of-plane tear strength (17,18). Fibre length is the critical softwood kraft pulp fibre determinant. With too little length, such pulps lose their characteristic softwood reinforcement properties. However, with too much length they are prone to flocculation and formation becomes a problem. Other fibre properties are also important but only after fibre length requirements are met; these are perimeter, wall area (coarseness), collapse potential (width/thickness) and fibre number per gram.

The reinforcement qualities of softwood kraft pulps are traditionally determined by handsheet tensile index/tear index relationships (17,18). A high tear index at a given tensile strength is normally taken as an indication of high reinforcement potential. Unfortunately, such a pulp classification by reinforcement potential is fraught with inconsistency since separate effects of fibre length, wall area and perimeter are ignored and allowed to be confounded one with another (18). Seth (19) has recently outlined a process whereby softwood kraft pulp reinforcement potential in furnish blends can be optimised using tensile strength and other in-plane sheet properties such as elongation, Young's modulus and fracture toughness, rather than tensile index and the out-of-plane tear strength relationships. Seth convincingly demonstrates the inadequacies of the out-of-plane Elmendorf tear test for optimising furnish blend compositions, processing requirements, and ultimate machine and paper conversion process runnabilities. Tear/tensile strength relationships, on the other hand, remain a useful indicator of softwood pulp reinforcement potential provided fibre dimensions are also taken into account (17,18).

Tensile index is by itself also an important softwood kraft pulp quality determinant. The refining energy needed to reach a given tensile index indicates the processing requirements of a given papermaking pulp. Different softwood kraft pulps can have very different refining requirements as a result of different fibre dimensions and uniformities of fibre length, wall area and perimeter (17,20).

Apparent density or bulk is also an important softwood pulp quality determinant since it is a measure of the fibre structure/packing base upon which most other handsheet properties are dependent-viz. tear and tensile strength. For example, softwood kraft pulps with fibre length below a critical value of 2.0-2.1 mm, have low reinforcement strength and high apparent density or low bulk (10). Such pulps are normally unsuitable for a reinforcement function but can be expected to have low refining requirements and improved formation compared to pulps of fibre length greater than the critical value. Such pulps are suitable for the manufacture of high density papers and as a component of some tissue furnishes.

Eucalypt

Eucalypt market kraft pulps are known to combine the most important pulp and paper properties of hardwood pulps in a particularly favourable way (21,22,23). They give good tensile strength and formation with excellent bulk and optical properties. Handsheet bulk is particularly important since strength can normally be developed by refining, provided the resulting bulk meets the requirements of the product being manufactured.

Excellent optical properties (opacity and light-scattering coefficient) and formation are normally obtained with eucalypt market kraft pulps because their fibres are short, of low coarseness, stiff and uncollapsed, and present in large numbers compared to other hardwood fibres (21 ,22).

Fibre and Handsheet Property Relationships

Apparent density or bulk

Apparent density is a measure of fibre packing density and arrangement in handsheets. To a large extent handsheet apparent density can be envisaged as being determined by fibre length and cross-section dimensions, and the related morphological configurations of collapse and straightness. In the selection of fibre types for different paper and pulp grades, therefore, the apparent density of "unrefined" pulps (500 rev) is used as the base against which other "unrefined" handsheet properties are compared. Furthermore, the dimensions of unrefined fibres from rewetted handsheets are compared to handsheet properties of pulps refined to a minimum extent.

For the 29 *E. nitens* and the 25 *P. radiata* pulps, as well as for the pulps of the previously reported study of eleven 16-year-old *P. radiata* clones (2,3), the fibre width/thickness ratio increases linearly with increasing apparent density (Figure 2). Coefficients of determination (r^2) are relatively high for both sets of data, although the width/thickness range for any given handsheet density is large. For example, at an apparent density of about 660 kg/m^3 width/thickness ratios can range from 2.59 to 3.27 for the *P. radiata* pulps (Table 2). Width/thickness ratios are substantially lower for the eucalypt and range from 1.84 to 2.07 at an apparent density of about 680 kg/m^3 (Table 3). Such variation in the width/thickness ratio for roughly the same sheet density is explained primarily by differences in fibre length (Figure 2, Tables 2,3,4). Thus, for pulps of roughly the same apparent density those with the lowest width/thickness ratio normally have the shortest fibres (radiata pine trees 6-10 and eucalypt trees 13-19 to a lesser extent ((Tables 2,3)). Other fibre properties such as fibre wall area and its influence on numbers of fibres per unit mass of pulp can also be expected to partly determine handsheet apparent density, although to a small extent compared to the width/thickness and length combination (Tables 2,3,4). For example, the pulp of eucalypt tree 1 is made up of a large number of short and uncollapsed (stiff) fibres and has high handsheet bulk properties.

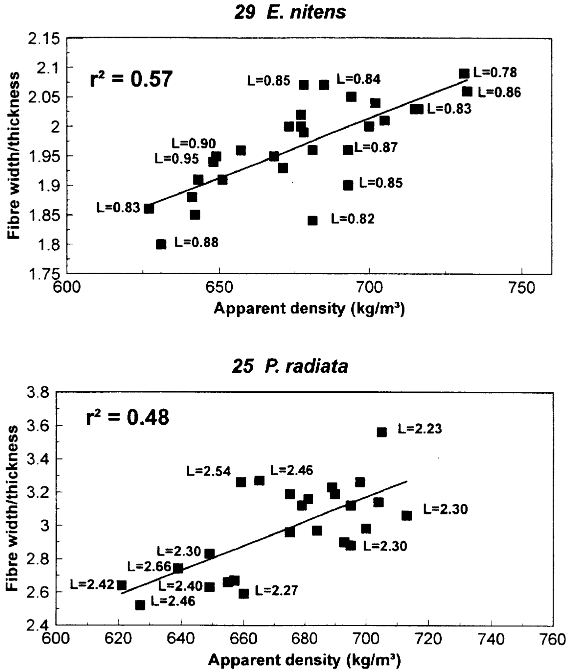
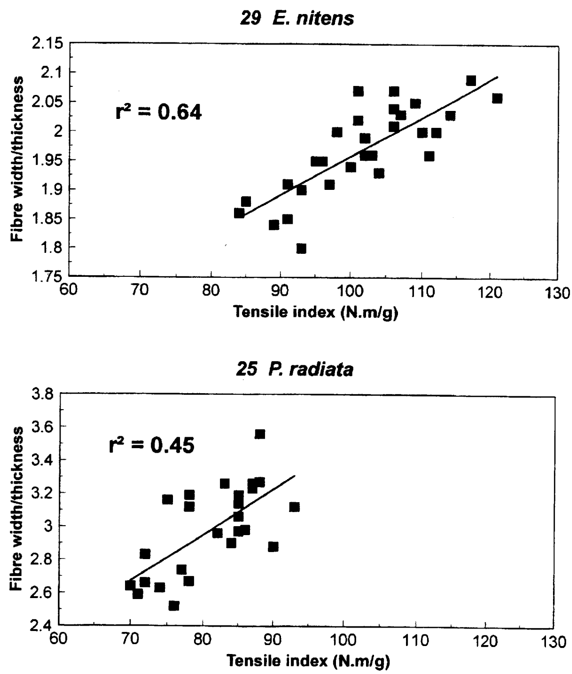


Figure 2: Fibre width/thickness and handsheet apparent density for 25 *P. radiata* and 29 *E. nitens* individual-tree pulps.

Tensile index

Tensile index increases with increasing width/thickness in a manner similar to that of apparent density (Figure 3). In contrast to handsheet apparent density, however, tensile index is best predicted by width/thickness only and is not improved with the inclusion of fibre length in the relationship (Table 4). A similar wide range in width/thickness values is obtained for a given tensile index as for the apparent density (Figures 2,3). This is explained by the fact that handsheet tensile index values are of limited meaning unless compared to other handsheet properties, in particular to the fibre packing density and arrangement indicator, apparent density (24). Thus, tensile index which increases with increasing apparent density (Figure 4) must also be indirectly influenced by fibre properties, other than width/thickness, which determine handsheet structural organisations. For example, the *P. radiata* and eucalypt pulps of high tensile strength are normally of high apparent density with fibres which are normally of high width/thickness and/or of short length (Tables 2,3). Alternatively, *P. radiata* and *E. nitens* pulps of low tensile strength are normally of low apparent density with fibres which are of low width/thickness and/or of relatively long length.

Figure 3: Fibre width/thickness and handsheet tensile index for 25 *P. radiata* and 29 *E. nitens* individual-tree pulps.



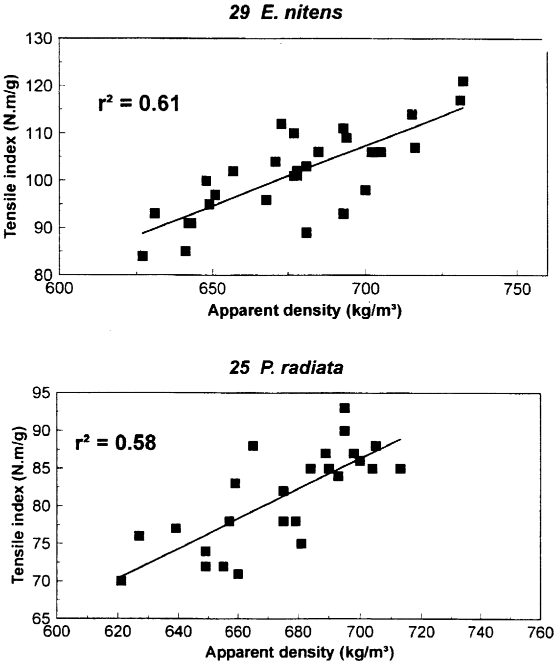


Figure 4: Handsheet tensile index and apparent density for 25 *P. radiata* and 29 *E. nitens* individual-tree pulps.

Tear index

The same arguments hold for tear index as for tensile index since tear index is also dependent on apparent density or fibre packing densities and arrangements in handsheets (Figure 5, Table 2). It is of interest to note the clear influence of fibre length on tear index when considered in combination with the width/thickness ratio but not when by itself (Table 4).

Pulp refining effects

Pulps were refined to a minimum extent only in the assessment of unrefined individual-tree fibre and "unrefined" handsheet property (500 PFI mill rev) relationships (15,3). It is of

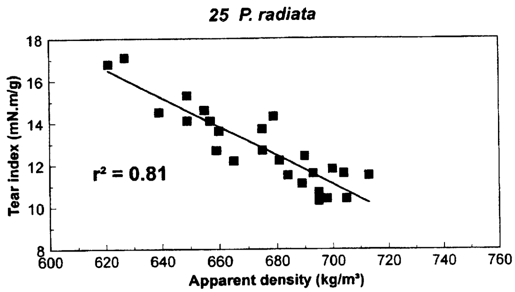
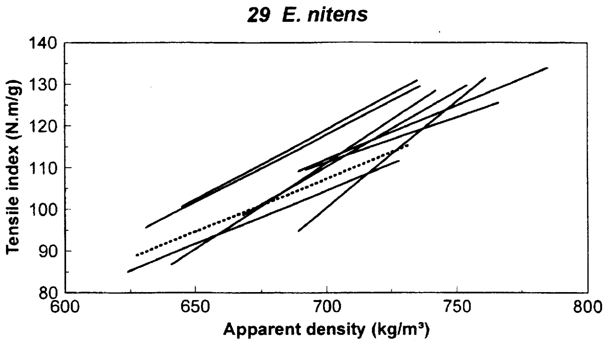


Figure 5: Handsheet tear index and apparent density for 25 *P. radiata* individual-tree pulps.

interest, however, to examine influences of pulp refining on handsheet property relationships (Figure 6). The solid regression lines are based on four PFI mill refining levels (500, 1000, 2000, 3000 *(P. radiata)* and 4000 (eucalypt)), and show a clear dependence of tensile strength on apparent density and, hence, the width/thickness and length of the fibres in the "unrefined" pulp (500 rev). Furthermore, initial bulk (apparent density) and/or tensile strength advantages existing in the "unrefined" individual-tree *P. radiata* and eucalypt pulps are normally retained with extended refining. For *P. radiata,* regression slopes for the refined individual-tree pulps (solid lines) are roughly parallel one to another and normally steeper than that of the "unrefined" regression (dashed line). In contrast, the regressions for the refined individual-tree eucalypt pulps (solid lines) are roughly parallel to those of the "unrefined" pulps. Irrespective of initial (500 rev) tensile index or initial apparent density, all the individual-tree pulps can normally be refined to a given tensile index but not at the same apparent density. Hence, it is recommended that effects of pulp refining be minimised as a variable in any assessment of individual-tree pulps for genetic selection. In this way fibre properties can be directly related to handsheet properties for individual-tree pulps and ultimately back to the individual-tree or genotype for selection and propagation.

Fibre Properties, Product Applicabilities and Individual-Tree Relationships

Selected fibre properties of the 25 *P. radiata* and 29 *E. nitens* individual-tree pulps are respectively arranged in order of increasing handsheet apparent density in Tables 2 and 3.



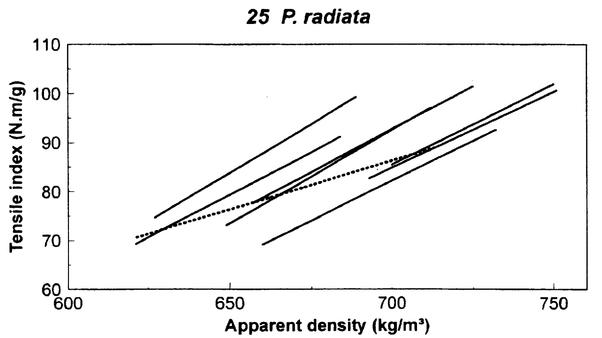


Figure *6:* Handsheet tensile index and apparent density regressions fitted for all individual-tree pulps at 500 rev (-----), and for some individual-tree pulps refined for the range of 500 to 4000 rev for *E. nitens* and up to 3000 rev for *P. radiata)* (—).

Pinus radiata

The width/thickness ratio in combination with fibre length is generally a good predictor of handsheet apparent density with the first nine pulps being of lowest apparent density and lowest width/thickness ratio, except for individual-tree 8. Tree 8 has long fibres compared to trees 7 and 9. In short, pulps with the longest fibres and lowest width/thickness ratios generally have the lowest handsheet apparent densities. Interactive effects of the width/thickness ratio and fibre length are evident for the first seven pulps listed in Table 2.

The 25 individual-tree pulps were selected for extremes of tracheid perimeter and tracheid wall thickness to allow assessment of their effects on handsheet properties (4). Kraft fibre perimeter and wall thickness measured after removal of lignin, on the other hand, can be somewhat different measures (2,5). Fibre perimeter and wall thickness by themselves influence handsheet apparent density to limited extents only, but their influence when in combination can be large (Tables 2,4). For example, the width/thickness ratio is a measure of fibre collapse and is determined by the perimeter and wall thickness combination. Thus, fibres with perimeters which are small relative to their wall thickness will have low width/thickness ratios and will be able to resist collapse. The converse also holds since fibres with large perimeters relative to their wall thickness will have high width/thickness ratios and will be less able to resist collapse. Hence fibre perimeter and wall thickness can be used as indicators of pulp qualities required for specific product types as follows:

- Long, slender *P. radiata* fibres with small perimeters and **thick** walls will resist collapse and be suitable for the manufacture of some specialty products as well as papers of high bulk. Such fibres will also be tough and sometimes hard to refine. Individual trees that best fit such a combination of properties are numbers 2, 1, 4 and 3 in that order (Table 2). Fibre length is seen as critical for this pulp category and the 2.40 mm value has been taken as the minimum acceptable. Fibre length is also critical for determining pulpwood forest rotation lengths since the longer the fibres the lower can be tree felling ages. The four pulps show excellent collapse resistance (low width/thickness) with tree 3 having the longest fibres at the expense of slenderness compared to the other three pulps. It is the larger perimeter and low relative number of fibres for tree 3 which caused it to be ranked fourth rather than first.
- Relatively long, slender *P. radiata* fibres with small perimeters, **thin** walls and of low coarseness, will be relatively easily collapsed and refined, of good bulk and will be excellent as the reinforcement component in the manufacture of wood-free printings and writings grades. To maintain handsheet bulk a critical minimum fibre length of about 2.1-mm is required for *P. radiata* reinforcement pulps (10). The extent to which

fibre length should be increased beyond the critical value is limited since sheet formation decreases as proportions of long fibre in a furnish increase. Trees which best fit such a combination of properties are numbers 17, 16, 19 and 15, in that order (Table 2). All four pulps are of good bulk, with relatively slender fibres of length >2.15 mm and reasonably high relative numbers of fibres which is necessary to achieve good formation properties. Tree number 18 has excellent fibre properties except for length. Tree 17 has exceptionally long fibres and trees of this type could be grown on shorter rotations than those of tree 15.

- Short, slender *P. radiata* fibres with thin walls of low coarseness, will be easily collapsed and refined, of low bulk and excellent for the manufacture of high density papers and as a component in some tissue grades. Individual trees of this type are numbers 18, 15 and 22 (Table 2).

Eucalyptus nitens

The width/thickness ratio in combination with fibre length is clearly a good predictor of handsheet apparent density (r^2=0.68) since the first seven pulps are of apparent density <650 kg/m^3 and of low width/thickness ratio (Table 3). The influence of fibre length is indicated by individual-tree pulps 5, 6 and 7 with their relatively long fibres, high width/thickness ratios and sufficient bulk. Fibre wall area (coarseness), perimeter and relative number of fibres are often also required to explain differences between some individual-tree pulps. For example, the low apparent density obtained with the short fibres of tree 1 is accounted for by a low wall area and high number of fibres compared with tree 2. Hence, fibre perimeter, wall area and wall thickness can be used to further qualify the pulp quality indicators of width/thickness and length in the assessment of individual-tree pulps for the manufacture of specific product types as follows:

- Relatively **long,** slender and thick-walled eucalypt fibres to give very good bulk and stiffness, suitable as a component of wood-free printings and writings, and tissue furnishes. Trees 5, 6 and 7 fit well into this grouping with their long fibres. Maximum apparent density is set at 650 kg/m^3 (Table 3).
- Relatively **short,** slender and thick-walled eucalypt fibres to give very good bulk and stiffness with improved formation, suitable as a component of wood-free printings and writings, and tissue furnishes. Trees I to 4 fit well into this category with tree 1 expected to give the best formation as a result of short fibres, relatively low wall area (coarseness), and high number of fibres. The long-fibred pulp of tree S could also be expected to fit this grouping because of extreme low wall area and perimeter values (Table 3). Maximum apparent density is set at 650 kg/m^3.

- Relatively broad, thin-walled eucalypt fibres of high collapse potential (width/thickness) suitable for glassine-type products and as a low-bulk component in some soft tissues. Ease of refining to a given tensile index is a requirement for this category. Many of the *E. nitens* pulps fit such specifications, possibly with those in the middle range being the most appropriate - trees 11 to 16 (Table 3). Extremely high-density papers could be most easily made with the short-fibred, easily refined pulps of trees 24 to 29.

Relationships of Wood Density and Fibre Length to Handsheet Properties

Chip basic density

The individual-tree chip basic density and fibre length combination is a good predictor of handsheet apparent density (Table 5) but not necessarily of the best fibres for the manufacture of particular products (Tables 2,3). Density is a measure of the wood substance and void space in each individual-tree chip sample and is not indicative of the numbers of fibres which make up that space (Figure 7). For example, *P. radiata* tree 3, 18 and 19 are of roughly the same chip density with very different fibre lengths, perimeters, wall areas (coarseness) and

		25 *P. radiata*		29 *E. nitens*	
		r^2	Std error##	r^2	Std error##
Apparent	D	0.63	15.6	0.36	23.3
density	D + L	0.75	13.1	0.64	17.8
Tensile	D	0.71	3.6	0.37	7.5
index	D + L	0.72	3.6	0.43	7.3
Tear	D	0.69	1.1		
index	D + L	0.84	0.8		
Light scattering	D			#ns	
coefficient	D + L			#ns	

#ns: Not significant. No correlation at the 95% level of significance if $r^2 < 0.16$ *(P. radiata)* and $r^2 < 0.12$ *(E. nitens)*

RMS error for each regression equation.

Table 5: Chip basic density prediction of handsheet properties at 500 PFI mill rev -chip density (D) and length (L).

width/thickness ratios. Furthermore, each is considered to be best suited for very different product types: 18 for glassine and some tissues, 19 for wood-free printings and writings grades, and 3 for some specialty products and papers of high bulk. For the eucalypt pulps similar differences occur when wood or chip density is used as the basis for tree selection (Table 3). *Eucalyptus nitens* trees 1, 2 and 26 are of roughly the same chip densities with very different fibre and handsheet properties, and papermaking potentials.

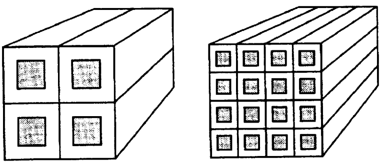


Figure 7: Schematic diagram of wood of the same density with fibre numbers and dimensions.

Fib re Length - A Critical Determinant of Softwood Kraft Pulp Quality

Fibre length is critical for the reinforcement properties of softwood kraft pulps. If pulp fibre length falls below a certain critical level of about 2.1 mm bulk is abruptly decreased and reinforcement tear/tensile strengths are correspondingly abruptly lowered (10,24). The fibres of most of the 25 individual-tree pulps from 13-year-old *P radiata* trees are substantially longer than required, except for tree 18 at 2.1 mm (Table 2). This is significant for the manufacture of printings and writings grades since it. suggests that pulps with adequate length could be produced from trees of age somewhat less than 13 years (9,25). With decreasing tree age, the fibres can also be expected to become more slender, of lower coarseness, and increase in number (10) with corresponding improvements in paper formation. Clone mean fibre lengths in the 11 clone study at age 15 on a colder, higher altitude site ranged from 2.30 to 2.62 (3,24).

Fibre length is the limiting determinant of softwood kraft pulp quality. The identification of young individual trees with long fibres will allow their selective propagation and the possibility of short-rotation pulpwood crops or use of younger thinnings. Other fibre properties can be selected/optimised once the young trees with long fibres have been identified.

Phenotypic Variation, Genetic Variation and Heritability

The high level of phenotypic variation that is being expressed in wood and chemical properties, in kraft-pulped fibre dimensions and in handsheet properties (Tables 1-3) is an indication that some at least of this variation may be genetically caused. In the preselection of the 25 *P. radiata* sample trees for a range of wood-tracheid cross-sectional dimensions, perimeter and wall thickness, that was reported elsewhere (4), eight trees from each of 25 selected open-pollinated families were evaluated for tracheid dimensions and wood density by SilviScan, an automated wood microstructure analyser(11), and one tree from each family was selected for pulping. Narrow-sense heritabilities[1] applying to seedling propagation for the tracheid cross-sectional traits and density were all high (though somewhat less for tangential diameter) and predicted genetic gains from phenotypic selection of 10 trees out of 100 for these traits were from 8 to 13% (4% for tangential diameter).

Another approach to estimating narrow-sense heritability was also used in the same study (4); the means of each family were compared with the values for corresponding growth rings from the pith of their 25-year-old female parents. This also showed a strong correlation between parent and offspring values.

In a related study of wood properties, kraft and mechanical pulping study of eleven 16-year-old clones of *P. radiata*, two trees of each clone were assessed for a wide variety of wood, chemical, wood-tracheid and kraft-fibre properties as well as for TMP and kraft pulp and handsheet properties (2,3,8,27). In all, 66 different traits were measured including chemical composition, micro-and macro-anatomical, tree-morphological, growth, kraft-fibre, and kraft-handsheet and TMP-handsheet properties. The average intra-class correlation or broad-sense heritability for all these traits was 0.66. For kraft-fibre properties the estimates ranged from 0.34 for wall thickness to 0.85 for fibre width; for tracheid cross-sectional dimensional

[1] *Narrow-sense heritability, the ratio of additive genetic variance to total variance in a population for a trait, expresses the degree to which a trait is passed from parent to offspring.*

traits all values exceeded 0.93 (wall thickness); for kraft-handsheet properties, heritabilities were from 0.70 (stretch) to 0.87 (tensile index); TMP-handsheet properties varied from 0.72 (tensile index) to 0.91 (burst index). It was concluded that most of the wood and end-product traits were under strong genotypic control with very little among-tree variation of environmental origin. This means that selection of individual trees for any of these traits can be quite effective, given reasonably high variation for the trait, and that the performance of clones, evaluating only two or three trees of each clone, can be very precisely predicted.

Indirect Selection for Kraft-Handsheet Properties

Direct selection of parents or clones for specific kraft-handsheet properties for particular paper products would be expensive and time consuming and probably impractical on a large scale. Indirect selection, based on kraft-fibre properties, should be feasible provided these are good predictors of handsheet properties. Micropulping of large numbers of individual-tree chip samples would be feasible, though to obtain such samples would inevitably require felling the tree, and the kraft pulping and subsequent fibre assessment would still be costly. A better approach would be through non-destructive sampling with 12-mm increment cores taken at breast height (1 .4m), with use of an automated wood microstructure analyser such as SilviScan (11) to measure cross-sectional wood-tracheid dimensions as well as wood density and microfibril angle. This technology has been developed for *P. radiata* and by inference for other conifer species. It is still under development for hardwoods.

In the studies reported here of 25 trees of *P. radiata* and 29 trees of *E. nitens*, the dimensions of kraft-pulped fibres have been used so far to develop predictive relationships with kraft-handsheet properties. Indications from a study of 11 clones were that, as predictors of kraft-handsheet properties, tracheid cross-sectional dimensions are generally as good as kraft fibres or better (2,3).

Progress Towards Developing Wood Property Predictors of Kraft Paper Quality for Individual-Tree Selection

Wood tracheid/fibre and kraft fibre property variation among the 25 *P. radiata* and 29 *E. nitens* individual-tree chip and pulp samples is high (Tables 1,2,3). Heritability of these traits and potential gains from selection of seed parents (4) or of clones for clonal forest management (2,3,8,27) is also high.

The wide handsheet apparent density range of 627-732 kg/m^3 for the 29 *E. nitens*, and 621-713 kg/m^3 for the 25 *P. radiata* individual-tree pulps suggests a good potential for tree selection based on this pulp quality determinant. Chip basic density and kraft fibre property combinations are strongly correlated with handsheet apparent density and other handsheet properties (Tables 4,5). So also are the wood-tracheid cross-sectional dimensions (2,3). However, relationships between some individual-tree wood properties at 1.4 m above the ground in a standing tree (breast-height) with whole-tree values and hence with kraft fibre and/or handsheet properties, have yet to be determined:

- *P. radiata* outerwood density determined from increment cores taken at breast height is well known to be a good predictor of whole-tree density (9,26). Similar trends are shown for the 29 *E. nitens* trees ($r^2 = 0.70$) (6). However, wood or chip basic density alone is usually a poor indicator of kraft fibre dimensions, the ultimate determinant of product quality (Figure 7).
- Whole-tree estimates of *P. radiata* tracheid cross-section dimensions measured by SilviScan (11), have proved to be closely correlated with corresponding measurements made at breast-height and with kraft fibre dimensions (2,3). Furthermore, both tracheid and kraft fibre property combinations of wall thickness, perimeter and length, and the perimeter/wall thickness ratio and length, are reasonably good predictors of handsheet apparent density, and tensile strength and tear index. Unfortunately, the width/thickness ratio and length combination, which is normally the best fibre-property predictor (Table 4), has little meaning for wood fibres and tracheids (3); in all cases fibre length estimates were made on the individual-tree kraft pulps only, not on intact, undamaged wood tracheids. A second SilviScan model, designed to measure the dimensions of very small hardwood fibres as well as the presence of vessels is currently being commissioned (R. Evans, pers. comm.).
- Predictive relationships between breast-height and whole-tree tracheid length *(P. radiata)*, and between breast-height and whole-tree wood fibre length *(E. nitens)*, have yet to be determined, although general within-tree *P. radiata* tracheid length distributions have been documented *(9,25)*. Relatively poor correlations were obtained between breast-height tracheid length measurements and whole-tree kraft pulp fibre length estimates of 11 *P. radiata* clones (two trees per clone) (27). A critical need is to be able to correlate breast-height and whole-tree tracheid/fibre length measurements, since fibre length is an essential variable in the meaningful prediction of kraft pulp properties from wood properties (Tables 4,5). Such measurements can be made on whole tracheids or fibres (28) or on "papermaking fibres" which include intact and shortened tracheids/fibres as well as fines as measured

using a Kajaani FS 200 or equivalent (15). The development of relationships between breast-height and whole-tree wood tracheid/fibre length estimates is part of high priority research at the NZ Forest Research Institute.

Selection, Breeding and Deployment of Trees with "Designer Fibres"

For *P. radiata* it has been shown that many end-product characteristics, including kraft fibre and handsheet properties, are strongly genotypically controlled, i.e., that trees of the same genotype or clone show closely similar end-product properties. This seems to be true of most traits of *P. radiata* related to wood quality, ranging from spiral grain angle and random-width board quality of solid wood (29) to handsheet properties of kraft and TMP (2,3,27).

If forest plantations of *P. radiata* are established as blocks of different clones, a goal towards which several large forestry companies are moving, then selecting such clones for certain desirable end-product qualities, as well as fast growth, good form and disease resistance, appears quite feasible. With the high broad-sense heritabilities shown and high variability among clones, economically-important gains can be realised from moderately intense selection for end-product traits and/or for suitable wood-property predictors of these. This requires screening quite large numbers of clones (hundreds), though only a small number of individual trees per clone (2-6) need be evaluated to characterise and rank the clones. The costs of screening clones for actual sawtimber quality and kraft and mechanical-pulping characteristics would be very high.

As shown in this paper, the development of techniques for economic screening of large numbers of trees is well advanced; destructive evaluation through chipped samples and determination of kraft-fibre dimensions after pulping could be feasible using micropulping procedures; yet non-destructive evaluation of wood-tracheid dimensions via SilviScan (11) promises to be cheaper. Some combination of wood-tracheid screening and then kraft handsheet evaluation of selected candidates would probably be the best solution. Although most wood property and end-product traits have shown strong broad-sense heritabilities, as yet evidence of narrow-sense heritability is so far available for only a limited number of wood properties and no actual end-product properties. So far, wood density, tracheid length, spiral grain, compression wood, resin content and tracheid cross-sectional dimensions have all shown moderate to high narrow-sense heritabilities (0.4 and above) (4,30,31).

With such moderate to high heritabilities, simply selecting individuals for superiority in these traits suffices to give appreciable gains in their seedling offspring. Progeny-testing such parents would require measuring those traits on at least 10 trees from each family and the numbers of families needed would make this approach very costly.

Deployment of individual families as family blocks, which is being done by several plantation owners in New Zealand, would be feasible with families targeted for kraft pulping, but these would be much less uniform than clonal blocks because there is a large amount of genetic variation expected within families in addition to some environmental variation.

Currently all *P. radiata* seedlings planted in New Zealand almost without exception, come from seed orchards of known selected parent clones. Most seed produced at present comes from open-pollinated orchards where natural pollination by wind occurs.
This type of orchard is being superseded by control-pollinated seed orchards where progeny-tested parents are mated to produce seed of known crosses. Such seed is either planted directly in the forest or vegetatively multiplied by cuttings from hedged stool-beds. Such "family forestry" could be practiced with families from parents selected for kraft pulping qualities and could be expected to yield appreciable gains, depending largely on the intensity of screening and selection of the parents.

Clonal forestry is being practiced with *P. radiata* to a very limited degree so far; young seedling offspring from selected parents are first propagated individually as clones, using cuttings, tissue culture or embryogenesis. Then several copies of each clone are planted in clonal tests at several sites (e.g. six trees per clone, three sites) while other copies of the clones are kept in a juvenile state, either by hedging close to the ground or in some form of cold storage, until the clonal tests are old enough to evaluate (5-10 years). Then the better clones are essentially chosen for mass clonal propagation and planting.

There are still problems concerning the ageing and maintenance of juvenility of clones but these are currently regarded as manageable. Several clonal tests, each with hundreds of clones, have been planted and from these clones will be selected for different traits and then mass propagated.

Limitations to deployment of *P. radiata* clones for specific combinations of kraft pulping traits (or of related kraft-fibre or wood-tracheid properties) are likely because of unfavourable economics of growing crops purely for kraft pulping. It is more likely that clones with desirable qualities both for kraft paper and solid wood products will be identified and deployed so that these can yield intermediate pulpwood thinnings of 10-15-year-old trees (10,15). The final crop could yield pulpwood as top logs and slabwood from sawlogs which will be of known superior and relatively uniform characteristics for particular types of pulp. The characteristics of corewood (inner 10-15 rings) are likely to be the main targets of selection as its undesirable suite of juvenile wood properties is most in need of modification. Selection for such traits as high wood density, long tracheids, low spiral grain angle, low microfibril angle and reduced compression wood incidence are likely to benefit both solid wood and kraft pulping end-uses.

A major benefit for wood processing from the use of clonal forestry will be knowledge of a clone's particular end-product and wood quality characteristics combined with uniformity amongst trees of the same clone. Wood age remains an important source of variability within the tree which must be controlled by other means. Such uniformity and "characterisability" do not depend on selection and genetic diversity among clones in plantations can still be maintained at desired levels.

For *E. nitens*, vegetative propagation has hitherto proved nearly impossible, though some recent attempts using tissue culture suggest that this may yet succeed. Thus clonal forestry has still to become feasible with *E. nitens*. Although propagation of *E. nitens* by open-pollinated seed is not a problem, production of control-pollinated seed is limited by the small number of seed (about two) produced by each flower (capsule), each of which requires emasculation through removal of the stamens, as well as isolation from other pollen and individual pollination; commercial control-pollinated seed production is also therefore impracticable.

Genetic manipulation of wood and pulping properties of this species at present can only be done through selection of parents (with or without progeny testing) and establishment of the selected parents through grafting in a clonal seed orchard. Wood density has proved to have a high narrow-sense heritability (32,33) but more information is needed about variation and heritability of other wood quality traits in *E. nitens*. With the correlations demonstrated in Table 5, some improvement in handsheet properties should be possible but selection for kraft fibre dimensions is the only practical approach available at present (apart from direct selection for handsheet properties).

With other eucalypt species such as *E. grandis* and *E. camaldulensis*, as well as some hybrids involving these species with others, vegetative propagation by cuttings is easy and effective rejuvenation of clones is possible by coppicing. Clonal forestry is being practiced with these species in South Africa and Brazil and selection for "designer fibres" combined with clonal forestry should be feasible.

CONCLUSIONS

Among-tree variation in wood basic density and in kraft fibre properties is high for the twenty-five 13-year-old *P. radiata* and twenty-nine 15-year-old *E. nitens* trees and provides a necessary basis for a selection and breeding programme.

Apparent density is a measure of fibre packing density and arrangements in handsheets which is in turn determined by fibre-length and cross-section dimensions, and the related morphological configurations of collapse and straightness. In the selection of fibre types for different paper and pulp grades, therefore, the apparent density of "unrefined" pulps (500 rev) is used as the base against which other "unrefined" handsheet properties are compared. Apparent density is best predicted by the width/thickness ratio and length of kraft fibres.

Although the eucalypt and *P. radiata* individual-tree pulps can normally be refined to the same tensile index, apparent density values can be very different depending on their fibre properties. This is because apparent density and tensile strength of unrefined individual-tree pulps can be very different one from another, and such differences are normally retained with extended refining. Hence, effects of pulp refining and other process variables need to be minimised in the assessment of individual-tree pulps for tree selection.

The individual-tree chip basic density and kraft fibre length combination is also a good predictor of handsheet apparent density but not necessarily of the best fibres for the manufacture of particular products. Wood density is a measure of the wood substance and void space in each individual-tree chip sample but is not indicative of the numbers of fibres which make up that space.

Some identified softwood and hardwood kraft fibre property/product categories based on the 25 *P. radiata* and 29 *E. nitens* individual-tree pulps are as follows:

- Long, slender softwood fibres with **thick** walls resist collapse (low width/thickness) and are suitable for the manufacture of some specialty products as well as papers of high bulk. Such fibres are also tough and hard to refine. Fibre length is seen as critical for this pulp category with 2.40 mm being the minimum acceptable for *P. radiata.*
- Relatively long, slender softwood fibres with **thin** walls of low coarseness, are relatively easily collapsed (high width/thickness) and refined, of good bulk and suitable as the reinforcement component in the manufacture of wood-free printings and writings grades. To maintain handsheet bulk a critical minimum fibre length of about 2.1 mm is required for *P. radiata* reinforcement pulps. The extent to which fibre length should be increased beyond the critical value is limited since sheet formation decreases as proportions of long fibre in a furnish increase.
- Short, slender softwood fibres with thin walls, of low coarseness, and which are easily collapsed (high width/thickness) and refined, and of low bulk are suitable for the manufacture of glassine and as a component in some tissue grades.
- Relatively long, slender and thick-walled eucalypt fibres give very good bulk and stiffness, and are suitable as the hardwood component of wood-free printings and writings, and tissue furnishes.
- Relatively short, slender and thick-walled eucalypt fibres give very good bulk and stiffness with improved formation, and are excellent as the hardwood component of wood-free printings and writings, and tissue furnishes.
- Relatively thin-walled eucalypt fibres of high collapse potential (width/thickness) are suitable for the manufacture of glassine-type products and as a low-bulk component in some soft tissues, provided they are easily refined.

High variability between trees was shown for various kraft handsheet properties which had good predictability from kraft-fibre and also wood-tracheid dimensions. The high broad-sense heritabilities of kraft-fibre and wood-tracheid dimensions (and also for handsheet properties themselves) mean that clonal forestry could provide uniform pulpwood from forest blocks of known pulping performance for species such as *P. radiata* that can be clonally propagated. A similar result can be realised through "family forestry", planting forest blocks of families from parents selected similarly, but will not give the high uniformity of monoclonal blocks.

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Transcription of Discussion

Genetic Selection of Trees with Designer Fibres for Different Paper and Pulp Grades

Paul Kibblewhite, Research Scientist, PAPRO, New Zealand

Dr Lennart Salmén, Head of Fiber Physics, STFI, Sweden

You put the main emphasis on the fibre dimensions, would you say that factors such as fibril angle and reaction wood are of no significance in this respect?

Paul Kibblewhite

Yes, definitely both and if we look at reaction wood, it is becoming a real problem now because when the trees they are felling now were planted, the growers were only interested in straightness and fast growth. They didn't look inside the bark at all even though some of us were telling them they should and the compression wood content in radiata pine resource is higher than it was in the past. This is causing problems particularly in solid wood. There is a lot of interest in microfibril angle as well, particularly for these fast growing trees. We are looking at measurements for using the Silvi Scan instrument, the new version being capable of measuring this and you can talk about it with Dr Rob Evans, (CSIRO, Australia) during the conference. The answer is yes for both microfibril angle and reaction wood.

Dr Kari Ebeling, Director, UPM Kymmene Group, Finland

Paul, you state in the printed version that whole tree chips were used to get the fibres. Does that include also the branches or only the stems?

Paul Kibblewhite

Just the logs up to say a 4" top or equivalent - so no branches and no bark.