Designer fibres for improved papers through exploiting genetic variation in wood microstructure

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Kraft pulp quality determinants are described for both *Pinus radiata* and *Eucalyptus nitens*: wood density and chemistry; pulp yield; the important fibre properties of length, perimeter, wall thickness, wall area (coarseness), microfibril angle, collapse resistance and relative number; and handsheet bulk. Relationships among these properties and their suitability for the manufacture of a range of product grades are discussed. Fibre length, the perimeter and wall thickness (or wall area) combination, and fibre number, are shown to be critical in the selection of 'designer fibres' for different paper and pulp grades. Interrelationships among wood tracheid /fibre properties and the critical kraft fibre properties are considered in some detail since the genetic selection of designer fibres must start with the standing tree using cheap, non-destructive test procedures.

Keywords

chemical composition, fibre dimensions, kraft pulp, microfibril angle, wood density

KRAFT FIBRE AND PULP QUALITY DETERMINANTS

The criteria for assessing kraft pulp quality can vary greatly depending on the level of interest, such as cost-driven gross wood and pulp property relationships, or fibre dimension and product suitability requirements. It is the chemistry and morphology of tracheids/fibres in wood and/or pulp that ultimately determine pulp quality and appropriate end-use (*1,2,3*). In the production of 'designer' fibres for different paper and pulp grades, therefore, the need is for low cost prediction of the fibre quality of pulps through non-destructive testing of standing trees (*1*). This will allow natural genetic variation in wood microstructure and chemistry to be exploited through selection of trees with designer fibres for quality paper and pulp production. It is recognised that such a tree selection program for pulp should be associated with comparable improvements in solid wood qualities, at least for *Pinus radiata* in New Zealand which is grown traditionally on solid wood regimes with residues only going to pulp (*4*). The situation is different for eucalypts since most New Zealand plantations are grown for pulpwood only (*4*).

WOOD AND PULP PROPERTY RELATIONSHIPS

Wood density and handsheet bulk

Wood or chip basic density is important since it can strongly influence wood handling and transport costs, and overall process throughputs based on the mass balance relationship 'wood substance in and kraft pulp or cellulose out' (*5*). Furthermore, wood/chip density is a good indicator of handsheet bulk but not necessarily of the suitability of a raw material for the manufacture of a particular paper grade (*1*). Neither wood density nor handsheet bulk are indicators of wood or kraft tracheid/fibre dimensions or numbers. Different wood samples can have the same density and different pulps can have the same handsheet bulk, but both can contain very different numbers of tracheids/fibres either within or among hardwood or softwood species (Fig. 1,2, Table 1) (*1*).

Wood/pulp chemistry

Wood/chip lignin and/or cellulose contents can separately influence pulp mill processing costs and output since they are moderate indicators of pulp yield. For example, total lignin versus pulp yield coefficients of determination (r^2) for 29 x *E. nitens* and 25 x *P. radiata* trees are respectively 0.48 and 0.61 (*3,6*).

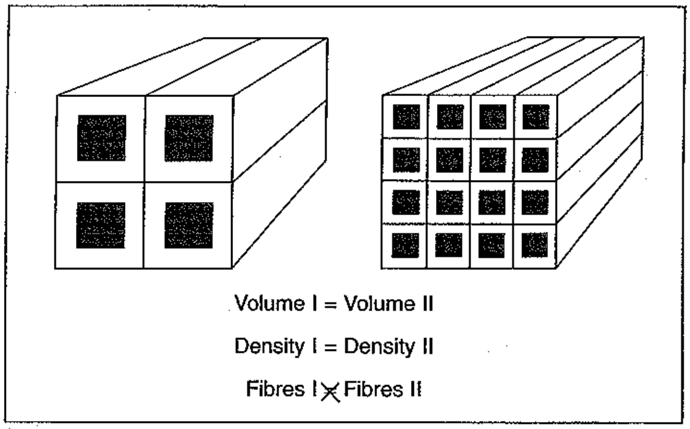

Fig. 1 Schematic diagram of wood of the same density with fibre numbers and dimensions.

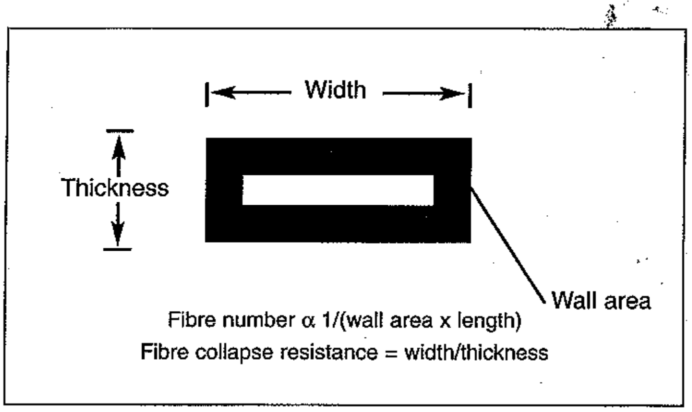

Fig. 2 Cross section diagram of a fibre dried and rewetted from a handsheet (*8*).

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Table 1
Chip density, handsheet bulk and fibre dimension interrelations.

	Chip density (kg/m³)	Handsheet bulk* (cm³/g)	Fibre length** (mm)	Fibre width + thickness (µm)	Fibre wall thickness (µm)	Fibre width /thickness	Relative fibre number ***
Comparison base: Near equivalent individual-tree chip density							
P radiata	**401**	1.61	2.42	44.2	3.29	2.64	75
	401	1.52	2.27	45.4	3.88	2.59	69
	407	1.59	2.46	41.8	3.52	2.52	76
	392	1.54	2.40	43.5	3.76	2.63	70
	406	1.54	2.30	44.6	3.3	22.83	78
E. nitens	**411**	1.40	0.83	19.7	2.32	2.03	830
	390	1.37	0.78	20.3	2.32	2.09	839
Comparison base: Near equivalent individual-tree kraft handsheet bulk							
P.radiata	401	**1.61**	2.42	44.2	3.29	2.64	75
	407	**1.59**	2.46	41.8	3.52	2.52	76
	359	**1.56**	2.66	46.4	3.65	2.74	59
E. nitens	556	**1.59**	0.83	19.8	2.43	1.86	789
	533	**1.58**	0.88	19.9	2.70	1.80	697
	492	**1.56**	0.87	19.5	2.51	1.88	765

* Determined after 500 PFI mill rev.
** Length weighted fibre length determined with a Kajaani FS 200 instrument.
*** Determined using the reciprocal of the product fibre wall area x fibre length (*1*)

KRAFT FIBRE DIMENSIONS AND PRODUCT SUITABILITIES

Kraft fibre dimensions

Fibre dimensions determine to a large extent the optimum end use for a particular kraft pulp whether it is of softwood or hardwood origin (*1*). For a softwood 'carrier' pulp, long fibres and high relative numbers of fibres together are critical to achieve good web reinforcement and formation in many low grammage grades. Such a pulp must necessarily contain a relatively uniform population of long, slender fibres of low coarseness. For less demanding grades the fibre dimension requirements of a pulp can be changed depending on the compromise between web reinforcement and formation, and mill costs and constraints of furnish, processing and papermaking. At the other extreme there are specialty products that demand long, coarse, tough and/or absorbent fibres.

For hardwood pulps, on the other hand, web reinforcement is unimportant with web formation, stiffness, porosity and opacity of critical importance depending on product type and grade (*1,7*). For example, eucalypt fibres of low coarseness, with thick walls relative to their perimeter, will resist collapse and be present in relatively large numbers. Such a pulp will give webs of good formation, and high porosity and opacity. Choosing an equivalent eucalypt pulp with relatively short fibres that in turn could lower bulk and porosity could further enhance formation. Thus, important kraft fibre determinants are collapse resistance (width/thickness), the fibre perimeter and wall thickness or wall area combinations, relative number of fibres, and fibre length (Fig. 2) (*1,8*).

Wood and kraft tracheid/fibre dimensions

Whole-tree estimates of *P. radiata* wood tracheid and kraft fibre properties of perimeter, coarseness and wall area have been shown to be correlated one with another using pith-to-bark wood samples taken at breast-height (1.4 m) and individual-tree kraft pulps (*3,9,10*). In contrast, wood tracheid and kraft fibre wall thickness values are consistently poorly correlated, either with or without adjustment for pulp yield (*3,9*). This inability to predict kraft fibre wall thickness from wood tracheid values is believed to be associated with the moisture and wall density assumptions made with the kraft fibre dimension measurement procedure (*11,12*), and intensive research is continuing. Fortunately, the wood tracheid wall thickness/perimeter ratio, which can be used as a measure of collapse resistance (*9*), is a reasonable predictor of kraft fibre width/thickness, a measure of the extent of collapse in kraft fibres reconstituted from handsheets (Fig. 3) (*3,9*). Thus, the kraft fibre dimensions of perimeter and coarseness, together with the width /thickness ratio, can be predicted from wood properties using SilviScan technology (*13*). Such values can in turn be used to select and grow *P. radiata* trees with designer fibres for different paper and pulp grades (*1*). Effective procedures for estimating the lengths of fibres in standing trees have yet to be developed. Eucalypt wood and kraft fibre collapse resistance

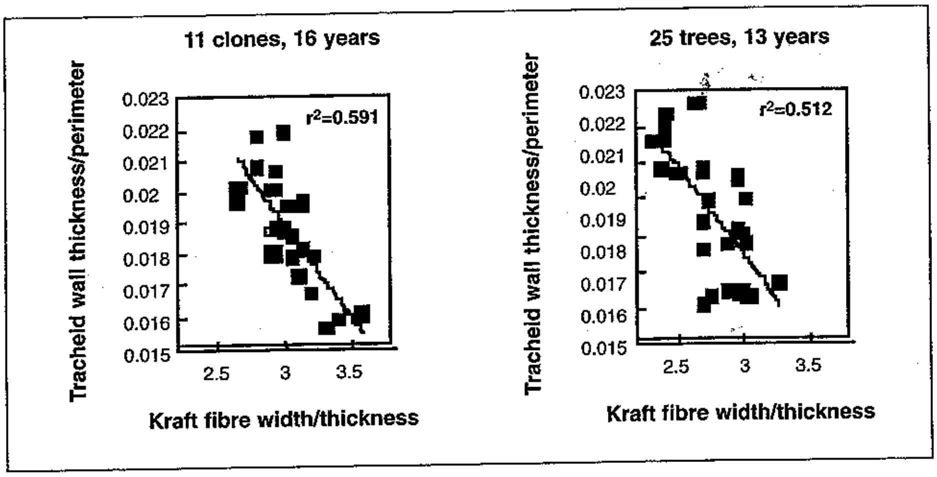

Fig. 3 Wood tracheid and kraft fibre collapse resistance relationships for a 22 and 25 individual-tree, *P. radiata* samples.

relationships are expected to be similar to those of *P. radiata* (Fig. 3) based on the wood density and kraft fibre properties of 29 individual-tree samples for both *E. nitens* and *E. fastigata* (*6,14*). Corresponding eucalypt wood fibre SilviScan measurements have yet to be made.

Kraft fibre, handsheet and end use relationships

Handsheet assessments allow the strength and optical properties of different furnishes and different pulp processing treatments to be compared. They can be useful in showing that changes occur in product /furnish qualities, but not why they have occurred. To a large extent it is the morphology and chemistry of the various components of a papermaking furnish which determine product quality and performance, and changes in furnish properties may or may not be shown with handsheet testing. Hence, there is a real need for fibre quality factors to be emphasised strongly in tree selection and product development programs. Combinations of paired handsheet variables are necessary to describe kraft pulp strength and optical properties (*1*). In the selection of trees and fibre types for paper grades, therefore, handsheet bulk is the base against which other handsheet properties are compared. This is done since bulk is a direct measure of fibre packing density and arrangements in handsheets and is influenced by fibre length, fibre cross section dimensions, fibre collapse and fibre straightness. In this way handsheet test values can be used as indicators of potential fibre property influences on machine-made papers.

Bleached eucalypt market kraft pulps are known to combine the most important pulp and paper properties in a particularly favourable way (*1*). They give good strength and formation with excellent bulk (low apparent density) 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, as illustrated with reference to Figure 4. Pulps 1 and 2 show the tensile index and apparent density relationship that is typical of quality eucalypt market kraft. Both pulps have equivalent fibre dimensions except for length (Table 2) with Pulp 2 having the shorter fibres by about 14%. Hence, Pulp 1 is of high bulk compared to Pulp 2 for a given level of refining, and is more appropriate for papers which require bulk and web porosity, and possibly when wet end drainage is critical. Pulp 2, on the other hand, could be more suitable for grades that require good strength and formation, and/or for mills with a constraint in refining capacity or energy costs. Pulp 3 is of good bulk and has fibre dimensions that are very similar to those of Pulps 1 and 2 which suggests that its low tensile properties are related to pulping and/or bleaching conditions. Pulp 4 is deficient in bulk because of high numbers of short, slender fibres of low collapse resistance and coarseness. This pulp is also of low tensile strength for a given bulk, and by itself can be considered unsuitable for most eucalypt market kraft end uses. Other examples of softwood and eucalypt fibre dimension, handsheet property and product suitability interrelationships are presented elsewhere (*1*).

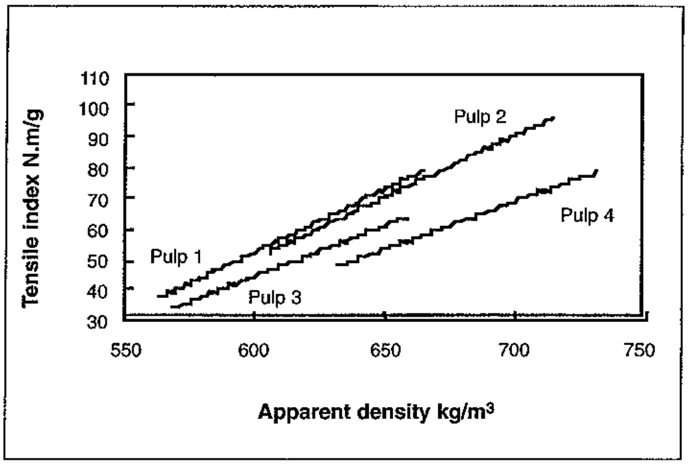

Fig. 4 Handsheet tensile index and apparent density relationships for PFI mill refining levels 500 to 4000 rev.

Identifying designer fibres from wood microstructure variation

Kraft pulp mills traditionally require low cost raw material and processing operations. For this reason high wood /chip density is a requirement to ensure maximum wood handling and processing throughputs. Softwood mills have a fibre length requirement since a critical minimum length is necessary to ensure that a pulp has adequate levels of bulk and reinforcement strength. For *P. radiata* kraft pulps, the minimum length weighted fibre length is 2.05 mm to ensure the retention of traditional softwood market kraft tensile strength and bulk relationships (*1,15,16*). Fibre length is less critical for hardwood pulps since reinforcement is normally supplied by the softwood furnish component (*17*). These kraft pulp mill requirements can be expected to hold well into the next century, but with the added

Table 2
Fibre dimensions of some eucalypt market kraft pulps.

Market pulp origin	Length mm	Width µm	Thickness µm	Width x thickness µm²	Wall area µm²	Wall thickness µm	Width/ thickness	Relative number
Pulp 1	0.78	12.6	6.9	87	60	2.60	1.90	97
Pulp 2	0.67	12.4	7.0	88	61	2.65	1.83	110
Pulp 3	0.72	12.7	6.7	85	60	2.67	1.98	105
Pulp 4	0.65	12.8	6.2	79	56	2.48	2.17	125
LSD#	0.03	0.6	0.3	5.8	3.5	0.1	0.13	

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

market (paper mill) demand for increased pulp uniformity (narrow fibre property distributions), and increased numbers of pulp grades based on fibre quality. Hence, the perceived need is for designer softwood and hardwood fibres for the manufacture of different paper and pulp grades (*1*).

For the past two decades wood and chip segregation (by age and growing site) prior to pulping has been used in New Zealand in the manufacture of a range of *P. radiata* market kraft pulps of different fibre length and coarseness, both mean values and population distributions (*16,18*). These different pulp grades are selectively used in the manufacture of a wide range of products. Opportunities remain for continued gains in fibre quality and uniformity through wood and chip segregation but these can be expected to be relatively small and incremental. An alternative approach is to harness the natural genetic variation in wood microstructure to produce trees that contain relatively uniform populations of fibres with properties which make them valued for both solid wood and pulp end uses.

The within-tree wood property variation can vary greatly depending on species, tree age and growing site. For example, wood basic density increases from pith-to-bark, but decreases and increases respectively with increasing tree height, for softwood (*P. radiata* (*19,20*)) and eucalypt (*2,21-24*) trees. For this paper, the treatment of within-tree variation in wood microstructure is confined to *P. radiata*. An account of the within-tree variation in wood chemistry and microstructure among nine trees of *E. nitens* is presented elsewhere (*2*).

Traditionally, the assessment of wood property variation within trees has been primarily confined to the relatively easy to measure property of basic density and to a lesser extent tracheid length (*19,20*). The general pattern is as shown in Figure 5 for *P. radiata* with a central core of low density and short tracheids, both of which increase from pith-to-bark. Within the central core tracheid length increases and density changes minimally with tree height (*20*). The central core is nominally set at the first 10 growth layers from the pith with a transition region between corewood and true slabwood or outerwood.

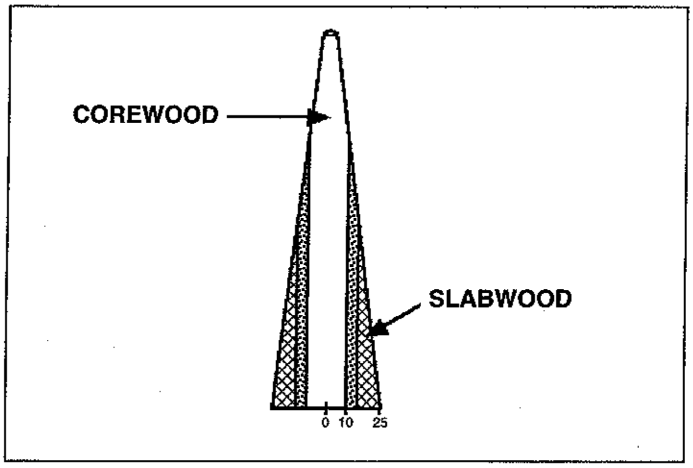

Fig. 5 General basic density zones for a typical *P. radiata* tree, with density increasing from pith-to-bark through corewood to slabwood (*19,20*).

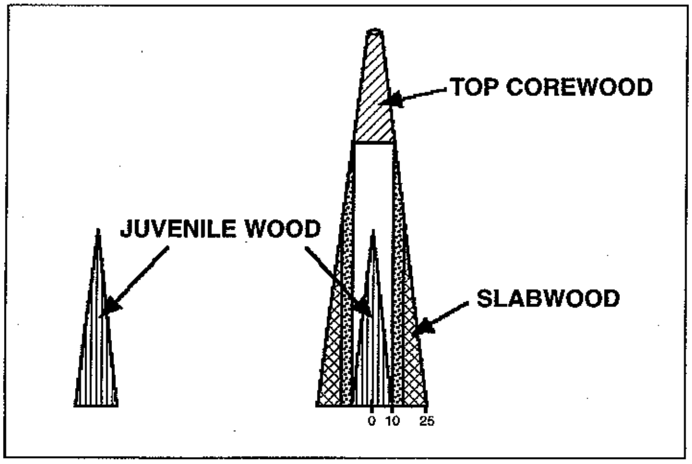

Fig. 6 Juvenile wood, top-corewood and slabwood for a typical *P. radiata* tree.

Within-tree variation in wood chemistry (*31,32*), tracheid dimensions (*3,9,13,15*) and microfibril angle (*25,26*) is far more complex than indicated for basic density in Figure 5. For this reason, it is necessary to further classify the central core into juvenile wood and top-corewood as shown in Figure 6. Juvenile wood is described as the wood or xylem material of a 10-year-old tree whether it is in a freestanding 10-year-old tree or embedded as a cone in the butt-corewood of an older tree. Top-corewood is described as all the wood or xylem at the top of a tree that is ≤ 10 growth layers from pith-to-bark.

Basic density (Fig. 5), but not wood microstructure (*3,15,25,26*), can be expected to be similar for the juvenile wood and top-corewood cones (Fig. 6). Juvenile wood microfibril angles are highest, and tracheid perimeter and wall thickness and/or wall area (coarseness) values are lowest at the base and centre of the tree. Microfibril angle decreases, and tracheid perimeter and wall area increase, with increasing height and distance from the pith of a juvenile wood tree or embedded cone (Fig. 6). These changes in wood microstructure are confined to juvenile wood and can be expected to be minimal at tree heights greater than 2 to 3 m above the ground (*3,13,25,26*). Although the direct measurement of the magnitudes of tracheid/fibre dimension differences between the juvenile wood and top-corewood cones within individual trees (Fig. 6) have yet to be made, several studies show that the corewood cylinders of upper logs have similar densities with broad, coarse and long kraft fibres compared to those in the corewood of corresponding butt logs (*15,20,27-29,33*). Tracheid/fibre dimension changes which occur with increasing tree age are indicated by a 9, 12, 15 and 18-year-old 'thinnings' series (Table 3) (*15*). Fibre perimeter and wall area (coarseness) but not wall thickness are lower for the 9-year-old tree (juvenile wood cone (Fig. 6)). For the juvenile wood cone (9 year-old tree in this instance), fibre perimeter and wall area values below 2 to 3 m can be expected to be smaller than shown in

Table 3 because of a dilution effect of fibres from above 2 to 3 m as indicated by Evans et al. (*3*). This dilution effect increases with increasing tree age since higher proportions of fibres from above 2 to 3 m and from outside the juvenile wood cone (10 growth layers at base) are progressively included in the sample (Table 3). It is noteworthy that fibre perimeter and wall area increase proportionately with increasing tree age so that wall thickness and levels of fibre collapse (width/ thickness) remain unchanged. A previously reported comparison of the thinnings trees of Table 3 and 9, 12, 15 and 18-year-old toplogs (*15,33*) is inappropriate for a juvenile wood versus top-corewood analysis (Fig. 6) since seed origins are different with that of the four thinnings (source 850) giving wood densities that are lower by about 8% (*34*).

A strong influence of high fibre microfibril angle in the lower 2 to 3 m of the juvenile wood cone (*25,26*) is shown by high kraft handsheet stretch and low tensile strength (Fig. 7). The decreased stretch and increased tensile index with increasing tree age are explained largely by microfibril angle differences, while the displacement in apparent density for the 12, 15 and 18-year-old material is accounted for by fibre length differences (*15,33*). An even more graphic example of the influence of microfibril angle is shown in Figure 8 for kraft pulps made up from wood of butt-innerwood and topwood cylinders, each consisting of 15 growth layers from each of nine trees (*27,29*). Butt-innerwood handsheet tensile index values are very low and stretch values very high compared to those of topwood despite the dilution effect of a high proportion of fibres from outside of the juvenile wood cones (Fig. 6). The influence of fibre dimension differences is minimal since fibre lengths are well above the critical minimum value (*15,33*) and handsheet apparent densities practically identical for the two pulp sets (Fig. 8). Mean fibre lengths differ by 0.2 mm for the two pulp sets in accordance with expected trends (*20*); 2.74 mm for butt-innerwood and 2.94 mm for topwood, each of 15 growth layers.

It is reasoned that *P. radiata* solid wood and kraft fibre properties could both be improved by minimising tracheid dimension variability in juvenile wood. It is suggested that this be done through the selection of trees with juvenile wood that contains slender, thin walled and long tracheids, and deployment of single clone blocks in the forest. Such tracheids will necessarily be of low coarseness and present in large numbers (per unit mass), with the retention or enhancement of wood density (Fig. 1, Table 1). The 1.4 m sampling level is probably adequate for assessing the tracheid cross-section dimensions of the corewood cylinder in standing trees (*3,9,13*). For the assessment of tree microfibril angle, on the other hand, the

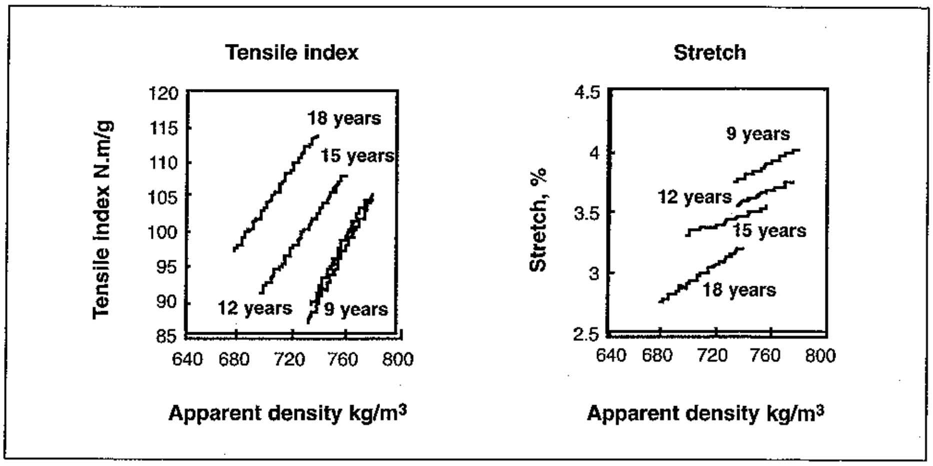

Fig. 7 Handsheet tensile index, stretch and apparent density relationships showing a decreasing influence of microfibril angle on stretch and tensile index with increasing tree age (*15,33*).

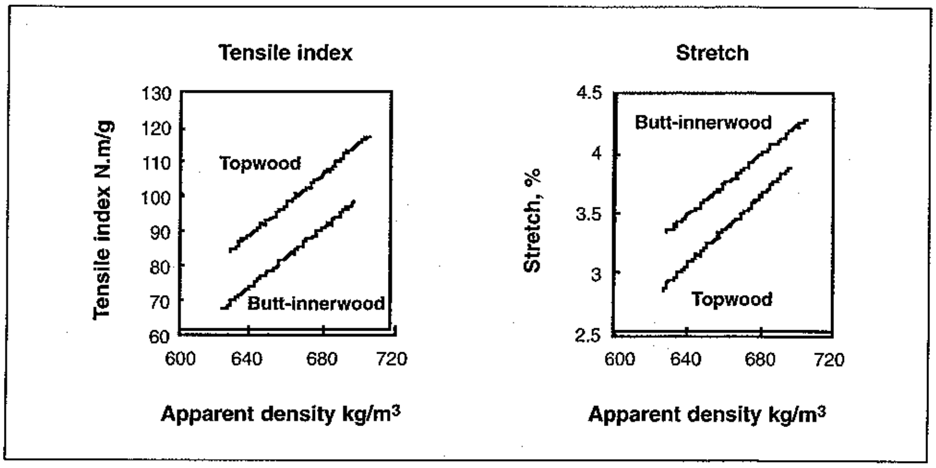

Fig. 8 Handsheet tensile index, stretch and apparent density relationships for butt-innerwood and topwood samples, each of 15 growth layers (*27*).

Table 3
Kraft fibre properties for trees aged 9-18 years.

Thinnings	Length mm	Width + thickness, µm	Wall area, µm²	Wall thickness µm	Width/thickness
9 years	1.97	38.3	155	2.73	3.00
12 years	2.02	41.0	178	2.80	3.04
15 years	2.26	41.3	174	2.71	3.12
18 years	2.40	42.1	191	2.85	3.03
LSD*	0.11	3.2	22	0.33	0.39

* Least significant difference between means at the 90% level of significance. Calculated for one chip sample and includes all sampling and analytical errors (*36*).

most appropriate sampling level could be very different, probably at 2 to 2.5 m (*25,26*). It is also suggested that such a tree selection strategy could lower some pith-to-bark tracheid property gradients and/or decrease juvenile wood and top-corewood tracheid property differences (Fig. 6-8). Some *P. radiata* trees have recently been shown to contain high numbers of long, slender and low coarseness tracheids in their corewood that is of higher than normal density (*29*). With alternative product end uses in mind, juvenile wood microstructure could be modified by selecting for long, coarse tracheids while maintaining, lowering or raising wood density, depending on tracheid perimeter and wall thickness (*1,15,35*) (Fig. 1).

Radiata pine tree carbohydrate and lignin contents can be very different for juvenile wood and slabwood with slabwood lignin and pentosan contents each being lower by about 3%, and alpha cellulose being higher by 5 to 6 % (*31,32*). The situation is less clear for top-corewood (compared to juvenile wood) since alpha cellulose contents are similar, and lignin and pentosan contents are marginally lower and higher respectively (*32*). Chemical composition changes with tree height are small compared to those that occur in the radial direction from pith-to-bark. Hence, the carbohydrate and lignin contents of juvenile wood and top-corewood are remarkably similar when compared to their variation in tracheid dimensions and microfibril angle (*3,25,26*).

Genetic variation (Table 4) and heritability (Table 5,6) are high for the critical tracheid/fibre properties of perimeter, wall area and wall thickness. Hence, there is a high potential to selectively modify juvenile wood microstructure through selection for specific tracheid dimension traits and deployment of single clone blocks in the forest. The high broad-sense heritability shown in Tables 5 and 6 indicates very low within-clone (environmentally caused) variation. The wide variation in fibre properties of the 13-year-old *P. radiata* individual-tree series of Table 4 is noteworthy since these trees consist almost totally of juvenile wood (Fig. 6). Furthermore, SilviScan technology allows the non-destructive screening of individual-tree wood tracheid /fibre dimensions (*3,9,13*). For *P. radiata*, moderate to strong correlations occur between breast-height and whole-tree wood properties (*3,9*), and between most wood tracheid and kraft fibre cross section dimensions (*3,9,15*). Parallel studies of *Eucalyptus nitens* and *E. fastigata* also show high levels of variation among individual-tree wood density and chemistry, and kraft fibre properties (*2,6,14*) (Table 4). SilviScan wood fibre property (including microfibril angle) measurements are underway for the 29 *E. nitens* trees.

DISCUSSION AND CONCLUSIONS

Market kraft pulps of the future can be expected to be more uniform with narrower fibre property distributions compared to those manufactured today. Furthermore, the number of pulp grades can be expected to increase, together with the demand for lower paper manufacturing costs, as papermills select the most appropriate and cheapest pulps available to meet their papermaking requirements. Hence, it is the role of pulp manufacturers to ensure that they have access to the most suitable fibre raw materials. Pulp mill and forest managers will, therefore, need to examine their long term requirements together with those of the solid wood industry and markets. The technology is available to select trees for breeding programs based on wood microstructure and fibre quality, although low cost test procedures remain to be developed to build on the strong research capability of SilviScan (*13*). The critical question is which fibre types and qualities will be most appropriate for papers made in the year 2025 and beyond, and how can the sawlogs of this selected /improved raw material be best utilised in the corresponding solid wood product range?

The growing of designer fibres, for different paper and pulp grades, in fast-growing softwood and/or hardwood plantations, should become a reality over the next decade. The technology is available worldwide for characterising those fibre types and dimensions most appropriate to specific papermaking systems and product types (*1*). The fibre types and genetic variation in the wood and fibre properties of *P. radiata* juvenile wood (thinnings), top-corewood and slabwood are sufficiently well characterised (Fig. 6, Table 3) (*3,25,26*) to allow consideration of tree selection for pulp based on wood microstructure. The 1.4 m sampling level is probably adequate for assessing the tracheid cross-section dimensions of the corewood cylinder in standing trees (*3,9,13*). For the assessment of tree microfibril angle, on the other hand, the most appropriate sampling level could be very different, most probably at 2 to 2.5 m (*25,26*). Any *P. radiata* tree selection program based on fibre properties must necessarily also enhance solid wood properties (*4*), and these are often strongly and negatively influenced by juvenile wood properties (*39*). A tree selection objective to decrease the tracheid perimeter, wall area and wall thickness of juvenile wood while retaining or increasing wood density, will generate increased numbers of tracheids. It is anticipated that such a tree selection strategy could also lower juvenile wood microfibril angles, and give improved fibre and solid wood qualities.

Softwood kraft pulps are long fibred and are primarily used as a component in papermaking furnishes to give web

Table 4
Kraft fibre property variation among the individual-trees of *P. radiata* (*1,3,10*) and *E. nitens* (*6*) and *E. fastigata* (*14*).

	P .radiata		***E. nitens***	***E. fastigata***
	11 clones (16 years) (9)c	**25 families (13 years) (3)**	**29 trees (15 years) (6)**	**29 trees (15 years) (14)**
Fibre length mm	2.25-2.69	2.10-2.66	0.78-0.95	0.76-0.92
Fibre wall thickness µm	2.82-3.66	2.93-3.88	2.11-2.76	2.01-2.59
Half fibre perimeter µm	41.2-49.8	40.0-49.5	19.0-21.6	18.5-21.1
Fibre wall area µm^2	196-246	187-272	53-70	54-65
Fibre width/thickness	2.82-3.66	2.52-3.56	1.80-2.09	1.81-2.30
Fibre number	74-110	59-100	92-120	96-130

Table 5
Chip and kraft fibre property broad-sense heritability for 11 x 16-year-old clones of *P. radiata* (*10,38*)

Chip or kraft fibre property	Broad-sense heritability
Chip basic density	0.96
Chip lignin content	0.53
Pulp yield	0.53
Fibre length	0.68
Fibre width/thickness	0.52
Fibre perimeter	0.89
Fibre wall area	0.79
Fibre wall thickness	0.72

Table 6
***P. radiata* wood tracheid dimension heritabilities for 11 x 16-year-old clones (broad-sense) and 13-year-old trees of 25 families (narrow-sense) (*37,38*).**

Wood property	Broad sense	Narrow sense	Narrow sense (offspring-parents)
Basic density	0.93	0.87	0.67
Tracheid perimeter	0.93	0.97	0.52
Tracheid wall area	0.94	0.82	0.49
Tracheid wall thickness	0.94	0.77	0.56

runnability when on papermachines and in converting operations (*1*). For *P. radiata* kraft pulps, the critical minimum fibre length is about 2.05 mm, and this is achieved with New Zealand grown crops at age about 15 years (*15,33*). Recent individual-tree studies of 13-year-old *P. radiata* have indicated that some trees could exist which have kraft fibre lengths ≥2.1 mm at age 8 or 9 years (*1,3*). Could a tree selection program for kraft fibre length (≥2.1 mm at 8 to 9 years) make the purpose growing of *P. radiata* in New Zealand, for pulpwood only, a viable proposition? Previous studies have indicated that the kraft pulps made from bulked chip samples of about 60 x 9-year-old thinnings trees (juvenile wood) contain the desired slender fibres of low wall area (coarseness), which without selection are deficient in fibre length (≥2.1 mm) (*15,32*).

Advantages for producing designer eucalypt fibres for different paper and pulp grades (*1*), as well as the wide fibre and chemical property variation among the trees of New Zealand-grown *E. nitens* and *E. fastigata*, have been adequately described (Table 1,5) (*1,2,6,14*). The need is to tie these kraft fibre and pulp relationships in with their corresponding wood properties, and to determine their heritabilities.

ACKNOWLEDGMENT

Permission to use the data in Table 2 and Figure 4 given by Tasman Pulp and Paper, and valuable discussions with Dr Tony Shelbourne, Dr Robert Evans and Mark Riddell, are gratefully acknowledged.

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CONCLUSIONS

Proteinase treatments yielded as much as 10% saving in energy consumption during mechanical pulping when the enzyme was added before primary refining, but not during an inter-stage treatment. The energy savings were attained without any alterations to the quality of the furnishes generated. The observed improvements indicate that further consideration should be given to the use of proteinases for the modification of mechanical pulping, particularly their use in combination with carbohydrate-solubilising and/or lignin-modifying enzymes for improving fibre processing and paper properties.

ACKNOWLEDGEMENTS

We thank Kathryn Anderson for technical assistance, and Roger Hawken, Peter Burrell, John Welten and Mick Yates for their expertise in fibre processing.

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Revised manuscript received for publication 12.9.99.