Ann Sci For (1994) 51, 203-212

Original article

The quality and wood properties of 4 provenances of South-African-grown *Pinus tecunumanii*

FS Malan

Division of Forest Science and Technology, CSIR, Box 395, Pretoria, South Africa

(Received 1st September 1992; accepted 25 June 1993)

Summary — The wood properties of 4 provenances of South-African-grown *Pinus tecunumanii* (*ie* Yucul, Camelias, Mountain Pine Ridge and St Rafael) were examined and compared with those of 3 commercial controls, *ie Pinus patula, Pinus elliottii* and *Pinus taeda*. Trials planted at 2 sites were evaluated. The rate of growth and stem form of the 4 *P tecunumanii* provenances were found to be very similar to that of the 3 controls used in the study, but crown breaks were very common, probably due to the tendency of *P tecunumanii* to develop heavy branch whorls. Tracheid lengths and the pattern of within-tree variation were found largely similar among the various groups of trees studied, but in comparison with the controls, the tracheid cells of *P tecunumanii* were markedly larger in cross-sectional diameter because of their thicker walls and larger lumen diameters. However, differences in the proportion of cell-wall material among the groups of trees studied were small. At both sites the annual ring structure of the wood of *P tecunumanii* differed pronouncedly from that of the controls, having a mean latewood percentage of only about half of that of *P patula* and about one-third of that of *P taeda* and *P elliottii*. In spite of the large relative proportion of earlywood characterising the wood of *P tecunumanii*, it produces wood very similar in density to that of *P patula* and *P taeda* and slightly higher than that of *P elliottii*. This was found due mainly to the fact that the broad earlywood zones of the *Pinus tecunumanii* provenances were substantially more dense than those of the commercial controls while differences in latewood densities among the various groups considered were small and non-significant. Apart from the relatively low intra-ring varability characterising the wood of *P tecunumanii*, all provenances of this species were found to be less variable in density in both the radial and axial directions in the stem, compared to the control species. The higher degree of uniformity of the wood produced by this species makes it a very promising alternative to some other South-African-grown pines, especially on productive, frost-free sites.

***Pinus tecunumanii* / wood density / tracheid length / tracheid cross-sectional dimensions / ring width / latewood percentage**

Résumé — Les qualités et propriétés du bois de 4 provenançes de *Pinus tecunumanii* d'Afrique du Sud. *Les propriétés du bois de 4 provenances de* Pinus tecunumanii *d'Afrique du Sud (ie Yucul, Camelias, Mountain Pine Ridge et Saint-Rafael) ont été examinées et comparées à celles de 3 standards commerciaux,* ie Pinus patula, Pinus elliottii *et* Pinus taeda. *Des échantillons prélevés sur 2 sites ont été étudiés. Les résultats sont présentés dans le tableau I. Le taux de croissance et la forme du tronc de 4 provenances de* P tecunumanii *se sont révélés très similaires* *à ceux des 3 standards commerciaux (tableau I) mais les cassures de couronnes étaient très fréquentes, probablement à cause de la tendance du* P tecunumanii *à développer de grosses branches. Les longueurs des trachéides et la forme des variations intra-arbres se sont révélées largement similaires pour les divers groupes d'arbres étudiés mais, par rapport aux standards commerciaux, les trachéides des* P tecunumanii *sont notablement plus larges en diamètre trans-section du fait de leur paroi plus large et du diamètre luminien plus important (figs 5 et 6). Cependant, les différences de proportions de leur paroi cellulaire entre les groupes d'arbres étudiés sont apparues faibles (fig 7). Sur les 2 sites, la structure du cerne annuel du bois de* P tecunumanii *diffère sensiblement de celle des espèces témoins ; le cerne du bois de* P tecunumanii *présente une proportion de bois final qui équivaut seulement à la moitié de celle du* P patula *et à peu près à 1 tiers de celle du* P taeda *et du* P elliottii *(fig 2). En dépit de la proportion de bois initial relativement importante qui caractérise le bois de* P tecunumanii, *la densité du bois est très similaire à celle du* P patula *et du* P taeda, *et sensiblement plus élevées que celle du* P elliotti *(fig 3). Cela est dû prinicipalement au fait que les zones de bois initial des provenances de* P tecunumanii *sont notablement plus denses que celles des espèces témoins alors que les différences pour la densité du bois final entre les différents groupes considérés sont faibles et non significatives (fig 4). En dehors de la variation intra-cerne relativement faible qui caractérise le bois de* P tecunumanii, *toutes les provenances de cette espèce se sont révélées peu différentes en densité dans les directions radiale et axiale du tronc en comparaison des espèces témoins. Le degré d'uniformité plus élevé pour le bois produit par cette espèce en fait une alternative très prometteuse par rapport aux autres pins sud-africains, spécialement sur les sites productifs et à l'abri des dégâts de gelée.*

Pinus tecunumanii / *longueur trachéide / dimensions trans-sectionnelles trachéides / largeur des anneaux / pourcentage de bois tardif*

INTRODUCTION

Pinus tecunumanii occurs naturally in Honduras, Guatemala, El Salvador and southern Mexico. It is one of 8 species of the subsection *Oocarpae* of the family *Pinaceae* although the taxonomic status of the taxon is uncertain at this stage. Other commercially important pine species belonging to this subsection are *P patula* and *P oocarpa* (Dyer, 1989).

In 1973 *P oocarpa* provenance trials were established at 3 locations in South Africa, *ie* Tweefontein, Wilgeboom and Kwambonambi State Forests, as part of an international provenance testing programme under the auspices of the Central America and Mexico Coniferous Resources Cooperative (CAMCORE). Some of the *P oocarpa* provenances were later taxonomically reclassified as *P tecunumanii* (Dyer, 1989).

At the age of about 17 years trees from 2 of the trials were sampled from the *P tecunumanii* plots only and detailed studies carried out on the sawmilling, pulp and paper and basic wood properties. Included in these trials were control plots of the commercial species *P patula, P elliottii* and *P taeda*. The control plots were also sampled for comparison purposes.

Because of the similarity in climatic conditions between South Africa and Mexico, the former has always looked on the latter as an important area for the selection of tree species of potential value. *P patula,* which is one of the Mexican pines, is today by far one of the most important commercial pine species in South Africa, comprising about 44% of the total area under pine plantations. It yields a serviceable yellowish-white wood, which is comparatively non-resinous and has an average wood density of about 0.450 g/cc varying from about 0.350 to 0.610 g/cc within trees (Poynton, 1979; Birks and Barnes, 1991; Wright and Malan, 1991).

P elliottii is South Africa's second-most important pine species, comprising about

23% of the total area under pines. It wood has an average density of 0.510 g/cc varying from 0.410 to 0.650 g/cc. The wood is more resinous than *P patula* and is prone to the formation of star-shaped cracks filled with resin (Poynton, 1979).

P taeda comprises about 9% of the total pine plantation area. It has an average wood density of 0.480 g/cc varying from 0.370 to 0.620 g/cc. Gilmore and Pearson (1969) and Zobel *et al* (1983) (as reported by Zobel and van Buijtenen (1989)) found within-tree variations of 0.480 to 0.570 g/cc and 0.320 to 0.550 g/cc, respectively.

In South African pines the large degree of variation of wood properties within trees is of great concern. The fast growth rate of South African pine and the resulting relatively short rotation age, cause an increased proportion of juvenile wood and consequently a high degree of within-tree variability at the time of final harvest. For this reason a considerable effort was made to examine the degree and patterns of variation in *P tecunumanii* in great detail and to compare them with those in existing commercial species.

This paper summarises the results of 2 studies and are based on CSIR reports submitted by Malan and Hoon (1991a, b).

MATERIALS AND METHODS

Sampling and sample preparation

Field trials are situated on the Tweefontein and Wilgeboom State Forests in the eastern Transvaal. The trials consist of various provenances of *P oocarpa* and *P tecunumanii* as well as a number of commercial controls, *ie P patula, P elliottii* and *P taeda.* The experimental lay-out is a 4 x 4 lattice design with 5 replications and 25-tree square experimental plots.

At the age of approximately 17 yr, field sampling was carried out by taking 2 representative trees from each *P tecunumanii* experimental plot as well as from the control plots, giving a total of 10 trees to represent each provenance and control. Tree data collected at the time of felling included diameter at breast height, total tree height, height to the first branch and tree lean. The latter served as a measure of butt sweep.

Three transverse discs per height level, 20 mm thick, were cut from all trees at 0, 25, 50, 75 and 100% height level. A stem diameter of 80 mm, which is the minimum top diameter for pulpwood logs, was taken as the 100% height level for the purpose of this study. Two of these discs were used for pulp and paper studies (Robertson, 1991) and the third for carrying out basic wood property studies, such as air-dry wood density, tracheid length, ring width, latewood percentage, spirality and the cross-sectional dimensions of tracheids.

The sampling strategy followed enabled the preparation of 4,1 m logs for a comprehensive sawmilling and timber quality study (Marais, 1991).

Data acquisition

Eccentricity, ovality and taper

Disc samples were subjected to image analysis to determine cross-sectional area, diameters in the north-south and east-west directions, maximum and minimum diameters, the maximum and minimum radii, and the form factor (4π x cross-sectional area/perimeter^2). In the latter, a value of 1 suggests a perfect circle (Kontron Electronics, 1989). This information was used to assess the degree of ovality, eccentricity, incidence of reaction wood and the general cross-sectional shape of the stem at various height levels in the stem.

Wood density (unextracted)

In the case of the Tweefontein material, every third ring, beginning with ring number 2 from the pith, was sampled and the basic densities of the separated rings determined using the saturated moisture content method described by Smith (1954). In the case of the material sampled in the Wilgeboom trial, air-dry densities at 10% moisture content were determined by means of a gamma-ray densitometer that had just come into operation (Malan, 1991). Mean values were calculated for each ring as well as for the latewood and earlywood zones separately. Two radii at all height levels, except the 100% height level, of all trees were studied.

In order to allow more reliable comparisons between the 2 sites, the basic densities determined on the Tweefontein material were converted to air-dry density at 10% moisture content. Estimates of the amount of shrinkage needed to convert basic density to air-dry density were obtained from tables compiled by van Vuuren *et al* (1978).

Tracheid length

Samples for tracheid length measurements were taken at every third ring, starting with ring number 2. Specimens for maceration, approximately 2-mm thick, were cut across the entire growth ring to ensure maceration of the complete ring. These were macerated in a 50:50 mixture of glacial acetic acid and hydrogen peroxide (30% vol) for 3 d at 60°C. On average, about 50 tracheid lengths were measured per ring using the Videoplan option of the Kontron image analysis system (Kontron Electronics, 1989).

Ring width and latewood percentage

All radially cut strips were sanded to a smooth and polished finish for measuring ring and latewood widths. Latewood widths were measured by visually assessing the boundary between earlywood and latewood. It is recognized that although the assessment of the earlywood/latewood boundary may be subject to variation when using visual assessment, the transition from earlywood to latewood was easy to distinguish in most cases.

Grain angle

In all samples grain angle was determined in the earlywood zone of every third ring starting from ring number 2 from the pith. The wood was split along the grain in a tangential direction and measured on the split surface to the nearest degree. The angle at the pith was taken as zero and used as a reference line. All measurements further away were corrected accordingly. Left-hand angles were recorded as negative and right-hand angles as positive. In the statistical analysis a constant of 20° was added to all grain angle values to avoid the possibility of zero means and very large coefficients of variation.

Cross-sectional dimensions of tracheids

The cross-sectional dimensions, lumen diameter and double-wall thickness of tracheids, were measured in both the earlywood and latewood zones on highly polished transverse surfaces following a technique based on that developed by Lantican (1972). A thin layer of microscope slide mounting medium was applied to the polished surface to enhance the images of the cells. Measurements were taken both in the radial and tangential directions of the tracheids using the videoplan option of the Kontron Image Analysis system (Kontron Electronics, 1989).

The mean amount of cell-wall material in relation to the voids (fractional wall volume) for each group was estimated using calculations based on the wall thickness, lumen diameter and the proportion of latewood. Tracheid cross-sectional properties were studied on material from the Tweefontein site only.

Statistical analyses

Statistical analyses were performed to test differences among groups, the effect of age and height in tree and their interactions. A mixed linear model was assumed in this study, in which the effects of heights and rings and their interaction are all fixed, and those of provenances/species, trees and radii and all other interactions are random. Orthogonality was obtained by rejecting data from the outer rings in the lower discs as well as the 2 top discs, utilising the inner 8–11 rings which were represented by 3–4 sampling positions, respectively.

Regression equations based on a full set of data from each provenance/species were developed for each property, using several models, which include all linear and quadratic effects of ring number and percentage height above ground level and their interactions. The forward selection procedure of multiple stepwise regression analysis was used.

Due to the lack of space the statistical results are not presented in this document. Full details can be obtained from the various reports that were submitted (Malan and Hoon, 1991a,b; Robertson, 1991 and Marais, 1991).

RESULTS AND DISCUSSION

The results are summarised in table I. For the sake of simplicity, the 3 control species and 4 provenances of *P tecunumanii* con-

Table I. Mean values for wood properties of 4 *P tecunumanii (P tec)* provenances and 3 commercial controls.

Property	*Tweefontein site*					*Wilgeboom site*				
	P patula	P taeda	P tec *(Camelias)*	P tec *(Yucul)*	P tec *(MPR)**	P elliottii	P tec *(Camelias)*	P tec *(Yucul)*	P tec *(MPR)*	P tec *(St Rafael)*
Eccentricity	1.20	1.17	1.28	1.29	1.37	1.15	1.28	1.17	1.21	1.16
Ovality	1.05	1.02	1.03	1.03	1.05	1.03	1.03	1.05	1.06	1.04
Wood density (air-dry) (g/cc)	0.487	0.507	0.509	0.520	0.501	0.446	0.509	0.512	0.523	0.521
Tracheid length (μ)	3 232	2 937	3 477	3 351	3 187	3 354	3 477	3 902	3 776	3 697
Ring width (mm)	9.2	9.5	8.3	8.9	9.3	8.5	8.3	8.6	7.9	7.8
Latewood percentage	19.7	31.2	10.3	12.0	11.5	30.9	10.3	11.3	10.5	11.4
Grain angle (degrees)	4.7	3.4	3.8	3.5	3.3	nd	nd	nd	nd	nd
Tracheid wall thickness (earlywood) (μ)	2.3	2.0	3.4	4.3	4.0	nd	nd	nd	nd	nd
Tracheid wall thickness (latewood) (μ)	4.7	4.1	6.5	6.4	6.8	nd	nd	nd	nd	nd
Tracheid radial lumen diameter (earlywood) (μ)	40.0	36.5	45.8	62.5	54.8	nd	nd	nd	nd	nd
Tracheid radial lumen diameter (latewood) (μ)	21.0	20.3	21.7	43.3	26.3	nd	nd	nd	nd	nd
Tracheid tangential lumen diameter (EW) (μ)	28.9	28.7	31.8	39.1	40.4	nd	nd	nd	nd	nd
Tracheid tangential lumen diameter (LW) (μ)	21.3	19.6	21.1	27.4	25.4	nd	nd	nd	nd	nd

* MPR: mountain pine ridge; nd: not determined.

sidered in this study will be referred to as 'groups' in the rest of the text.

Eccentricity, ovality and taper

Differences in mean ovality (ratio of maximum and minimum diameters) within individual trees, between trees of the same species, and between groups, were small and non-significant.

Statistically significant differences in the degree of eccentricity (ratio of maximum and minimum radii) were found among the various groups but these differences were too small to be of any practical significance. In general *P tecunumanii* tended to be more eccentric than the species used as controls, probably due to the fact that the control species were genetically improved.

As expected the degree of eccentricity decreased with increasing height. No statistical significant interaction between groups and height level could be detected, which is an indication that the pattern of change with height does not vary from group to group.

The taper and cross-sectional form factor did not differ among the groups and was found almost constant at a mean of 0.82.

Ring structure

Ring width decreased significantly with age but no significant difference in ring width could be found among the groups of trees studied (fig 1), which is a clear indication that the various groups of trees maintained approximately similar rates of growth.

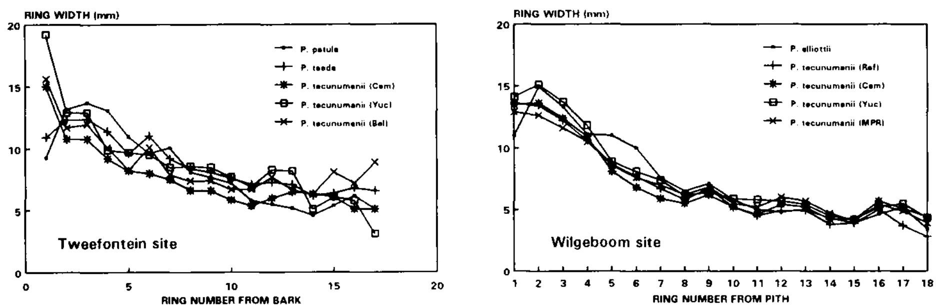

Fig 1. Variation in ring width in relation to ring number from the pith.

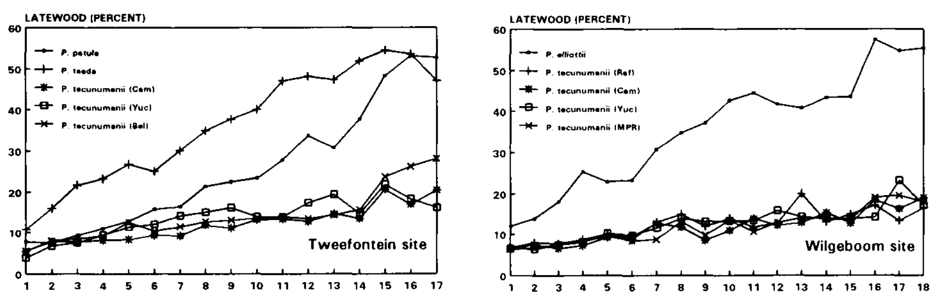

Fig 2. Radial variation in latewood percentage.

Latewood percentage was markedly lower in *P tecunumanii* with values varying from 10 to 12% compared with 20% in *P patula* and about 31% *P taeda* and *P elliottii* (fig 2). From figure 2 it is also clear that the radial patterns of variation in latewood percentage are virtually the same in the 4 *P tecunumanii* provenances showing as very gradual increases from pith to bark. This is in sharp contrast to the control species where rapid increases in latewood percentages occurred. This explains to a large extent the more rapid increases in pith-to-bark density that were observed in the control species. This will be discussed further in the next section.

Wood density

Density increased with age in all groups but results of the analyses of variation indicated a highly significant ring x species interaction suggesting that the pith-to-bark density gradients differ among the 5 groups of trees. Results of a 2-way classification used to examine the interactions are depicted in figure 3. From these graphs it is clear that the wood density across the radius is remarkably more uniform in the *P tecunumanii* provenances than in the control groups.

Wood density decreased rapidly and significantly with height in tree due to the increase in the proportion of juvenile wood. No among-group differences in the pattern of variation with respect to height in tree could be detected.

In spite of the low latewood percentage that characterised the wood of all *P tecunumanii* provenances, this species produced wood of about the same density as those of *P patula* and *P taeda*. In the case of the Wilgeboom material the wood densities of the 4 *P tecunumanii* provenances were significantly higher than that of the *P elliottii* control, in spite of the fact that the latter species exhibited a mean latewood percentage of almost 3 times that of *P tecunumanii* (table I, fig 2).

A comparative study of the earlywood and latewood densities of the various groups involved explains the reason for this. Results indicated no significant differences in latewood density among the 5 groups but the densities of the broad earlywood zones of *P tecunumanii* were considerably higher (fig 4).

No site effects on the wood density of *P tecunumanii* could be detected.

Tracheid length

In all species tracheid lengths increased rapidly with age, especially in the first 8–11 yr, slowing off towards the outer rings. With respect to height in tree, tracheid lengths increased rapidly from ground level to 25% height, followed by a decrease.

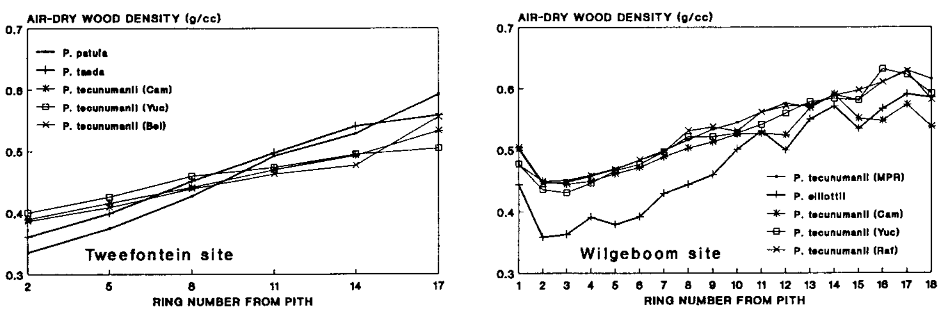

Fig 3. Variation in wood density in relation to ring number from the pith.

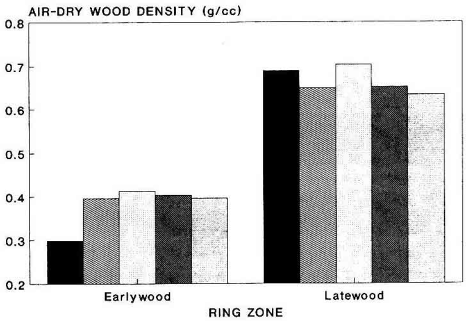

Fig. 4 Differences in earlywood and latewood wood density. ■ *P elliottii*; ▨ *P tecunumanii* (Cam); ⊡ *P tecunumanii* (Yuc); ▧ *P tecunumanii* (Raf); ▦ *P tecunumanii* (MPR).

Although differences observed in tracheid length could not be proven statistically, the *P tecunumanii* from both sites produced tracheids of slightly longer length than the controls at all height levels. Furthermore, the *P tecunumanii* from the Wilgeboom site produced tracheids that were substantially longer, suggesting some site effect, but a larger number of trees per species needs to be examined before reliable deductions can be made in this regard.

Tracheid cross dimensions

In the technology of pulp and paper making, there is increasing evidence that tracheid cross-sectional dimensions influence paper properties more than tracheid length (Haygreen and Bowyer, 1989).

Marked differences among the groups of trees studied were found for almost all of the cross-sectional dimensions examined. Both tracheid wall thickness and lumen diameter of *P tecunumanii* wood exceeded those of *P patula* and *P taeda* (fig 5), resulting in tracheids that were generally larger in diameter in *P tecunumanii* (fig 6).

Small differences in the mean fractional wall volume of the wood were among the 5 groups of trees studied (fig 7). Calculated values varied in a very close range of 0.28 to 0.32 explaining the small density differences observed among the 5 groups of trees obtained from the Tweefontein trial. Wood density is normally a good measure of the amount of cell-wall material in relation to the voids in the wood.

Spiral grain

No significant effect of species, trees within species, height in tree, age and any of the interaction terms could be detected. On average the degree of grain deviation appeared to be higher in *P patula,* but statistically this did not prove significant. The degree of grain deviation from the vertical varied considerably from ring to ring but no

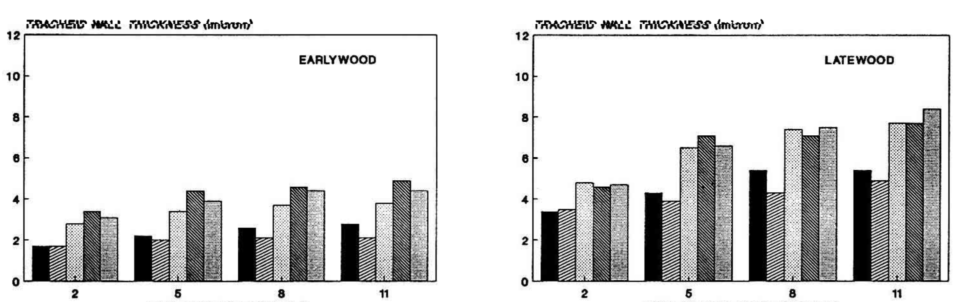

Fig 5. Variation in tracheid wall thickness. (Tweefontein site). ■ *P patula*; ▨ *P taeda*; ⊡ *P lecunumanii* (Cam); ▧ *P lecunumanii* (Yuc); ▦ *P tecunumanii* (Bel).

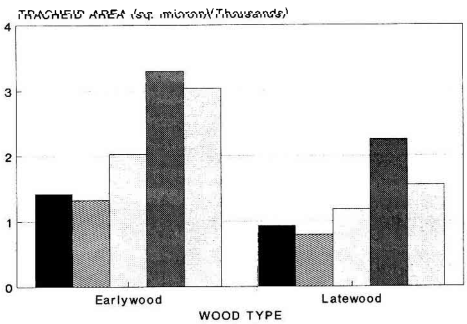

Fig 6. Variation in tracheid cross-sectional area (Tweefontein site). ■ *P patula*; ▨ *P taeda*; ⊡ *P tecunumanii* (Cam); ▧ *P tecunumanii* (Yuc); ▦ *P tecunumanii* (MPR).

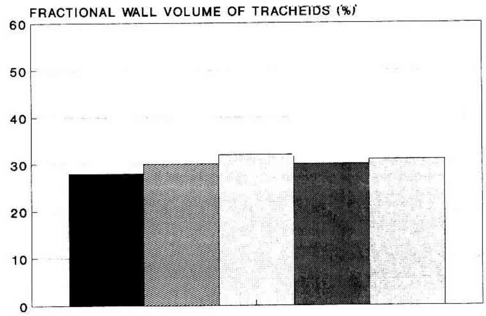

Fig 7. Variation in fractional wall volume of tracheids (Tweefontein site). ■ *P patula*; ▨ *P taeda*; ⊡ *P tecunumanii* (Cam); ▧ *P tecunumanii* (Yuc); ▦ *P tecunumanii* (MPR).

particular tendency could be observed. In other words, grain never spiralled in any one direction to cause spiral grain in the tree.

CONCLUSIONS

Due to the relatively low number of trees per species used in this study, the mean values obtained should be regarded with some caution. Statistically the differences between the 4 *P tecunumanii* provenances could not be substantiated, but in general, the differences between the 4 provenances were small and probably of little practical significance. However, as species *P tecunumanii* exhibited some important and significant differences from the 3 commercial species used as controls.

Compared to the commercial controls, *P tecunumanii* was found to be largely similar as far as rate of growth and the cross-sectional shape of the stems are concerned. In general, *P tecunumanii* produced wood of similar or slightly higher density than that of the control species, but more importantly, the wood of all the *P tecunumanii* provenances was less variable in density both within and between annual rings.

Tracheid lengths did not differ statistically between the 5 groups of trees studied, but judging from the mean values obtained, the *P tecunumanii* provenances produced wood of slightly longer tracheid lengths. Variation patterns in the radial and axial direction were largely similar among the 5 groups. In *P tecunumanii* tracheid cells were markedly larger in cross-sectional diameter since the walls were thicker and the lumens larger in diameter.

Although the average wood properties in conifers are important, the difference between earlywood and latewood is often striking and can have an important effect on end-use characteristics. Differences in latewood percentage among the *P tecunumanii* provenances were small but their latewood percentages differed markedly from those of the controls.

In spite of the large percentage of earlywood and differences in cross-sectional dimensions of tracheid cells that characterised the wood of *P tecunumanii,* all provenances of this species produce wood of an acceptable density, mainly due to the fact that the proportion of cell-wall material is not altered to any significant degree.

Furthermore, the latewood density was virtually similar among the groups studied but the earlywood produced by *P tecunumanii* was substantially higher in density, resulting in more uniformity within rings. Thus, the wood of *P tecunumanii* is less variable in density and it can expected that the timber will also be more uniform in the properties related to wood density.

As indicated earlier, the large degree of variation of wood properties within South African pines as a result of the large juvenile core at the time of final harvest, is of great concern.

This species has proved to be a good performer on productive, frost-free sites. In view of the higher degree of within-tree uniformity of the wood produced by this species, compared with that of existing commercial species, this species can be a very promising alternative to some of the other South-African-grown pines in future, provided the problem of the high incidence of crown breakage can be solved.

ACKNOWLEDGMENTS

The author wishes to thank the CSIR executive and the South African Forestry Corporation Limited (SAFCOL) who sponsored the investigations, the staff of the Sabie Forestry Research Centre for their assistance during field sampling, and I Bruwer of the Division of Information Services of the CSIR for editing this document.

REFERENCES

Birks JS, Barnes RD (1991) Genetic control of wood density in *Pinus patula*. ODA Research Scheme R4616, Oxford Forestry Institute, Oxford University, 29 pp

Dyer ST (1989) A numerical taxonomic study of the closed cone pines (*Pinus* subsection *Oocarpae*) based on needle anatomy. MSc Thesis, Department of Botany, University of Pretoria

Haygreen JG, Bowyer JL (1989) *Forest Products and Wood Science* 2nd Edition, Iowa State University Press, Ames.

Kontron Electronics (1989) Image analysis systems: VIDAS User's manual, rel 2.0. Kontron Bildanalyse GMBH, Eching, Germany

Lantican CB (1972) Variations in some structural features and wood properties of *Pinus caribeae* Morelet from British Honduras. Unpublished D Phil thesis, University of Oxford

Malan FS (1991) Direct gamma ray densitometric system for wood. CSIR Special Report, FOR-I 158, 15 pp

Malan FS, Hoon M (1991a) The wood properties of *Pinus tecunumanii* from Tweefontein State Forest. CSIR Special Report FOR-I 146, 58 pp

Malan FS, Hoon M (1991b) The wood properties of *Pinus tecunumanii* from two locations in the Eastern Transvaal. CSIR Special Report FOR-I 162, 23 pp

Marais IP (1991) The sawmilling properties of three *Pinus tecunumanii* provenances from Tweefontein State Forest. CSIR Special Report FOR-I 162, 31 pp

Poynton RJ (1979) *Tree Planting in Southern Africa Vol. 1: The Pines*. Department of Forestry, South Africa, 576 pp

Robertson PE (1991) The pulping characteristics of *Pinus tecunumanii, P patula* and *P taeda*. CSIR Special Report FOR-I 83, 17 pp

Smith DM (1954) Maximum moisture content method for determining specific gravity of small wood samples. US Department of Agriculture, Forest Products Laboratory, Rept 2014

van Vuuren, NJJ, Banks CH, Stöhr HP (1976) Shrinkage and density of timbers used in the Republic of South Africa. Bulletin 57, Dept. of Water Affairs and Forestry

Wright JA, Malan FS (1991) Variation in wood and tracheid properties of *Pinus pseudostrobus, P maximinoi* and *P patula*. IAWA bulletin, 12, 465-467

Zobel BJ, van Buijtenen JP (1989) *Wood Variation. Its Causes and Control*. Springer-Verlag, Berlin