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Radial and Among-Family Variations of Tracheid Length and the Relationships with Bending Properties in *Pinus patula*

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ABSTRACT

Wood properties affect the quality of wood products that is especially true for tracheid length regarding lumber quality. This study was conducted to investigate the radial and among-family variations in tracheid length in 5 open-pollinated families of 30 years old Pinus patula trees planted in Malawi. Furthermore, the relationship between tracheid length/wood density with modulus of elasticity (MoE) and modulus of rupture (MoR) were also evaluated. The results show that there were significant ($P<0.001$) differences in tracheid length among the families. The mean tracheid length ranged from 4.0±0.9mm to 4.7±0.9mm. Tracheid length at first increased rapidly from pith to bark and thereafter increased gradually or remains more or less constant in all the families. Tracheid length was strongly correlated with MoE ($r=0.741$, $p<0.001$) and MoR ($r=0.796$, $p<0.001$) in juvenile wood. On the other hand, wood density was strongly correlated with MoE ($r=0.812$, $p<0.001$) and MoR ($r=0.865$, $p<0.001$) in mature wood. Therefore, to improve bending properties (MoE and MoR)of P. patula wood in Malawi, tracheid length and wood density would be factors to consider in juvenile wood and mature wood, respectively.

Keywords: *Tracheid length, Modulus of Elasticity, Modulus of Rapture, Tree Breeding, Wood properties*

INTRODUCTION

Pinus patula Schiede ex Schltdl. & Cham. is a closed-cone pine native to Mexico. It grows from 24° to 18° North latitude and 1800 to 2700 m above sea level. Mean annual precipitation amounts range from 1000 to 2500 mm [1]. The species can withstand heavy frosts (-10°C) and dry periods of 4 to 5 months but grows much better under warm, humid conditions. Within its native range, it attains heights of 30 to 35 m with diameters of 50 to 90 cm [2].

Approximately one million hectares of *P. patula* have been established in the tropics and sub-tropics for saw-timber and paper products. The majority of the *P. patula* forests are located in Southern Africa [1]. The species were first introduced to Malawi in 1923. In the 1950s large-scale forestry plantings were undertaken with seeds from South Africa and Zimbabwe [3]. Currently, about 80% of the Malawi's plantation is planted with *P. patula*. The species are mainly used for saw timber. In an effort to establish Malawi's own seed source with improved traits, clonal seed orchards were established in 1970's. The main selection criteria of these early tree breeding programmes were restricted to stem volume, height and stem form [4]. To develop an appropriate tree breeding strategy and wood utilization, information on both wood properties and growth traits must be known [5]. This information would also help to monitor genetic progress. In addition, there has been an increase in building construction in Malawi. This has also increased the need to improve both productivity and wood quality traits of this species. It is therefore critically important to include wood properties in tree selection programmes of *P. patula* to ensure future wood suppliers have the appropriate mechanical properties for structural applications and other end uses. However, in *P. patula* in Malawi, only a few reports are available on the wood properties of breeding materials [6]. In a previous study, we investigated among-family variations of wood properties in five open-pollinated families of 30-year-old *P. patula* trees [6]. Our results showed significant variations among families in wood density, the modulus of elasticity (MoE), and the modulus of rupture (MoR). However, further research is required on the wood property variation of breeding materials in this species.

Tracheid length in wood is an important determinant of the use to which that wood is put. The quality of lumber is determined, in part, by the length of tracheids in the wood [7]. Thus, tracheid length is highly correlated with other important wood properties such as MoE [8]. For instance, a low tracheid length, one of the characteristics of juvenile wood, means a serious problem when the wood is utilized for construction lumber [7,8]. Therefore, by selecting genotypes with high tracheid length in juvenile wood, the MoE can be increased [7]. Furthermore, literature shows that contribution of wood density and tracheid length on MoE varies with genotypes as well as within trees [8–10]. Therefore, for evaluating the importance of tracheid length as a selection criterion for the tree breeding of wood quality in *P. patula*, further research is required to determine the differences in the contribution of tracheid length and density on MoE between juvenile and mature woods as well as among genotypes.

The objective of this study was to determine the radial and among-family variations of tracheid length in 5 open-pollinated families of *P. patula* in Malawi as well as to determine the relationships between tracheid length/wood density with bending properties (MoE and MoR).

MATERIALS AND METHODS

Study Area

The study used an open pollinated progeny trial of *P. patula* at 30 years of age that was established by Forestry Research Institute of Malawi (FRIM) in a ferruginous soil in Chongoni Forest Plantation ($14^0$10’S, $34^0$09’E) in Dedza, Malawi, in 1977. Chongoni lies between 1570 m and 1690 m above the sea level. It receives about 1200 to 1800 mm rainfall per annum, with a mean annual temperature ranging from 7 to 25^0C. It is located about 85 km southeast of the capital, Lilongwe. The progeny trial comprised 42 families with seed source from South Africa and Zimbabwe. The test stand was established using seven-tree plots laid out in a completely randomized design in four replicates. The initial planting density was 1320 stems/ha. The entire experiment was surrounded by 5-8 rows of surplus trees. All the silvicultural treatments were done on the instruction of the breeder [11].

Plant Material and Assessment

In April 2007, five families were chosen based on straightness. A sample of 15 trees (3 trees from each family) with no major defects were randomly selected for the study. The growth traits (diameter at breast height and total height) data measured are presented in Table 1. The north side of each tree was marked before felling. After felling, cross-sectional discs of 5 cm thickness and 40-cm-logs were collected at breast height (1.3 m above the ground) from each tree.

Sample Measurement

Pith-to-bark strips (20 mm in thickness and 10 mm in width) from the north side were collected from each disk and air dried for measuring tracheid length. The outermost latewood at ring number 2 and thereafter every third ring was macerated. The procedure for maceration is as outlined by Missanjo and Matsumura [12]. Briefly, maceration was prepared by dipping the wood pieces in a 1:1 solution of 65% nitric acid (HNO_3) and distilled water (H_2O) plus potassium chlorate ($KClO_3$) (3g/100 ml solution) for 5 days. After maceration the elements were rinsed with distilled water, stained with safranin, and then mounted on a glass slide. Lengths of fifty randomly selected tracheids were measured using a Nikon V-12 profile projector at a fifty-fold magnification.

Small clear specimens (20 mm x 20 mm x 320 mm) were prepared from the logs. The specimens were conditioned to about 12% moisture content in the laboratory by oven-drying at 105°C to constant weight. Wood density was calculated as oven dry mass of the specimen divided by wood oven dry volume. Volume was obtained by displacement method. There after the specimens were subjected to bending test using Instron Tester over a span length of 300 mm.

Statistical Analysis

Data obtained on tracheid length, wood density, MoE and MoR were tested for normality and homogeneity with Kolmogorov-Smirnov D and normal probability plot tests using Statistical Analysis of Systems software version 9.1.3 [13]. After the two criteria were met data on tracheid length were subjected to analysis of variance (ANOVA) with family and wood zone as fixed factors. Differences between treatments means were separated using Fischer’s least significant difference (LSD) at the 0.05 level. Wood zone was classified as juvenile wood and mature wood. Basing on our previous study [3], the boundary between juvenile wood and mature wood for *P. patula* in Malawi is ring number 10 from the pith. These findings were adapted for the present study; therefore, data collected from the 1st ring to 9th ring were regarded as representing juvenile wood. On the other hand, data collected from the 10th ring to the bark were regarded as representing mature wood. Simple correlation analysis was used to determine the relationship between tracheid length/wood density with MoE/MoR. In this analysis, MoE and MoR were used as dependent variables, whereas tracheid length and wood density were used as independent variables. Although the specimens for determining tracheid length were not exactly the same specimens for determining wood properties, the data were collected from the same growth annual rings.

Table1. *Means values and standard deviation of diameter (at 1.3 m above the ground) and height*

Family name	DBH (cm)	Height (m)
PPF10	27.5±1.2	23.2±1.9
PPF11	30.0±1.7	26.0±1.3
PPF12	30.9±1.5	23.5±1.4
PPF21	33.8±0.8	27.7±1.6
PPF24	26.6±1.1	23.0±1.3

RESULTS AND DISCUSSION

Radial and Among Family Variations of Tracheid Length

Summary of the results on mean values of tracheid length for the 5 open-pollinated families are presented in Table 2. Significant (P<0.001) differences among the families in tracheid length were observed. Family, PPF21 had the highest tracheid length (4.7±0.9 mm) followed by PPF24 (4.5±0.9 mm). On the other hand, family PPF10 had the lowest tracheid length (4.0±0.9 mm).Furthermore, there were significant (P<0.001) differences in tracheid length between juvenile wood and mature wood. Mature wood was 48.5% higher than juvenile wood in tracheid length. In contrast, larger CV values were observed in juvenile wood (Table 2). This suggests that the variation of tracheid length among families was substantial within the juvenile wood of *P. patula*. Therefore, improvement of juvenile wood is a beneficial strategy in tree breeding for wood quality in this species.

Figure 1 shows the radial variation of tracheid length in each family. For all the 5 families assessed, there was a similar radial trend of tracheid length although tracheid length values differed slightly. Tracheid length at first increased rapidly from pith to bark, then more slowly. Families PPF10 and PPF11 showed lower values (below 2 mm) around the pith. On the other hand, PPF12, PPF21 and PPF24 families showed relatively higher tracheid length values (above 2 mm) around the pith. However, after the 11th growth annual ring, the differences in mean tracheid values became smaller, except for PPF10. Conversely, at the bark, family PPF12 showed the lowest mean tracheid length (4.8 mm). In addition, some families, such as PPF21 and PPF24, showed small variations in tracheid length from pith to bark. This indicate that a more uniform quality of wood can be obtained by selecting these families for plantation. Radial increase in tracheid length from pith to bark in all families is due to increase in length with cambial age [14].The present findings are in agreement with general trend of tracheid length in softwood species [7, 15,16].

Table2. *Means values and standard deviation of tracheid length (mm) at different woods and among family*

Family name	Juvenile Wood (Ring 1-9)	Mature Wood (Ring 10-27)	Mean
PPF10	2.9±0.9	4.5±0.3	4.0 ± 0.9^{b}
PPF11	3.2±1.0	4.9±0.2	4.3 ± 1.0^{ab}
PPF12	3.4±0.6	4.7±0.1	4.3 ± 0.7^{ab}
PPF21	3.7±0.9	5.2±0.2	4.7 ± 0.9^{a}
PPF24	3.5±0.9	5.0±0.3	4.5 ± 0.9^{ab}
Mean	$\mathbf{3.3\pm0.9^{y}}$	$\mathbf{4.9\pm0.3^{x}}$	
CV(%)	**26.5**	**6.8**	**12.3**

^{a,b}*means with different superscript within a column significantly differ (P<0.001),* ^{x,y}*means with different superscript within a row for significantly differ (P<0.001), CV is coefficient of variation.*

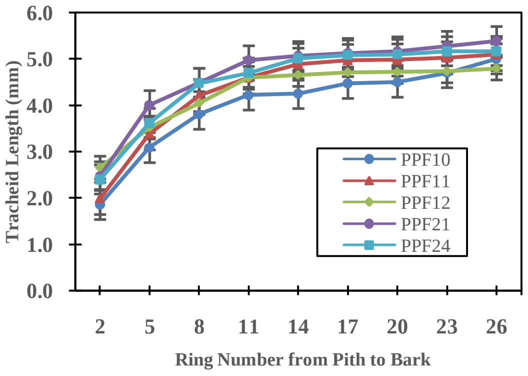

Figure1. *Radial variations of family mean values in tracheid length of P. patula*

Relationships among Wood Properties

The results on correlation analysis are presented in Table 3. The results indicate that there was a favourable relationship between tracheid length/ wood density with bending properties. However, tracheid length was strongly correlated with MoE (r=0.741, p<0.001) and MoR (r=0.796, p<0.001) in juvenile wood. On the other hand, wood density was strongly correlated with MoE (r=0.812, p<0.001) and MoR (r=0.865, p<0.001) in mature wood. These results are in agreement to those of *P. radiata* [9].

The relationships between tracheid length/ wood density with MoE in each family were also assessed (Table 4). The effect of tracheid length/ wood density in MoE differed significantly among families in juvenile wood. For instance, the effect of tracheid length on MoE was generally larger than that of wood density in PPF10, PPF12 and PPF24 families. In contrast, MoE of PPF11 and PPF21 families was strongly affected by wood density than tracheid length. This indicate that the relationship between tracheid length/ wood density with MoE in juvenile wood of *P. patula* was affected by the genotypes. In mature wood, MoE was strongly affected by wood density in all the families. The results are in agreement to those of Cown et al. [9] who reported that the relationship between tracheid length/wood density with MoE was affected by the genotype in *P. radiata*. Kijidani et al. [17] also reported that in 15 half-sib families of *Chamaecyparis obtusa*, MoE was affected by the relationship between tracheid length/wood density. The findings by Yamashita et al. [18], which shows that the relationship between tracheid length/wood density with MoE was affected by genotypes in *Picea koyamae*, also support the finding of this study. Similar results were also reported by Steffenrem et al. [19] in five full-sib families of *Picea abies*.

The present study, therefore, shows that both tracheid length and wood density are essential factors required to improve bending properties of wood in *P. patula*. However, tracheid length is the most important factor for improving juvenile wood, whereas wood density is the vital element for improving mature wood.

Table3. *Correlation analysis between bending properties and wood density/tracheid length*

Dependent Variable	Independent Variable	Correlation coefficient (r)	
		Juvenile Wood (Ring 1-9)	Mature Wood (Ring 10-27)
MoE	WD	0.696**	0.812**
	TL	0.741**	0.531*
MoR	WD	0.553*	0.865**
	TL	0.796**	0.371*

Note: _WD is wood density, TL is tracheid length, MoE is modulus of elasticity, MoR is modulus of rupture,**significant correlation (P<0.001), *significant correlation (P<0.05)_

Table4. *Correlation coefficient (r) between tracheid length/wood density with MoE in each family*

Family name	Juvenile Wood (Ring 1-9)		Mature Wood (Ring 10-27)	
	Tracheid Length	Wood Density	Tracheid Length	Wood Density
PPF10	0.800	0.616	0.803	0.844
PPF11	0.712	0.857	0.526	0.935
PPF12	0.916	0.760	0.395	0.899
PPF21	0.909	0.960	0.540	0.961
PPF24	0.951	0.645	0.447	0.916

Note: *All correlations were statistically significant (P<0.001)*

CONCLUSION

The study aimed at determining the radial and among-family variations of tracheid length in 5 open-pollinated families of *P. patula* in Malawi as well as determining the relationships between tracheid length/wood density with bending properties. The results show that tracheid length varied both in radial direction and among the families. The coefficient of variation was greater in juvenile wood than in mature wood, indicating that juvenile wood improvement is the key to tree breeding of wood quality in *P. patula*. There was a favourable relationship between tracheid length/wood density with bending properties. However, MoE and MoR were strongly affected by tracheid length in juvenile wood and wood density in mature wood. Therefore, selection of families with high values of both tracheid length and wood density should be included in tree breeding programmes of *P. patula* to increase MoE and MoR values.

REFERENCES

[1] Stanger, T.K., 2013, Variation and Genetic Control of Wood Properties in the Juvenile Core of *Pinus patula* Grown in South Africa. PhD

Thesis, Department of Forestry, Graduate Faculty of North Carolina State University, Raleigh, NC, USA.

[2] Perry, J.P., 1991, The Pines of Mexico and Central America. Timber Press Inc.Portland, Oregon, USA. 231p.

[3] Kamala, F.D., Sakagami, H., Oda, K., and Matsumura, J., 2013, Wood density and growth ring structure of *Pinus patula* planted in Malawi, Africa. IAWA Journal, *34*, 61-70.

[4] FRIM (Forestry Research Institute of Malawi). 1989, Annual Report. Zomba, Malawi.

[5] Zobel, B.J., and Talbert, J.T., 1984. Applied Forest Tree Improvement. 6thEdition. John Wiley and Sons Inc., New York.

[6] Kamala, F.D., Sakagami, H. and Matsumura, J., 2014, Mechanical properties of small clear wood specimens of *Pinus patula*planted in Malawi. Open Journal of Forestry, 4, 8–13.

[7] Zobel, B.J. and van Buijtenen, J.P., 1989,Wood Variation: Its Causes and Control; Springer-Verlag, Berlin, Germany.

[8] Dinwoodie, J.M., 1963, Variation in Tracheid length in *Picea sitchensis* Carr. Forest Product Research Laboratory, Special Report No. 16. HMSO, London.

[9] Cown, D.J.,Hebert, J. and Ball, R., 1999, Modelling *Pinus radiata* lumber characteristics. Part 1: mechanical properties of small clears.New Zealand Journal of Forestry, 29, 203 – 213.

[10] Tanabe, J, Ishiguri, F., Tamura, A., Ohshima, J., Lizuka, K. and Yokota, S., 2017, Radial and between-family variations of the microfibril angle and the relationshipswith bending properties in *Picea jezoensis* families, Scandinavian Journal of Forest Research, 32(1), 39 – 44.

[11] Ingram, C.L. and Chipompha, N.W.S., 1987,The Silvicultural Guide Book of Malawi, 2nd Ed.; FRIM, Zomba, Malawi.

[12] Missanjo, E. and Matsumura, J., 2016, Radial variation in tracheid length and growth ring width of *Pinus kesiya* Royle ex Gordon in Malawi, International Journal of Research in Agriculture and Forestry,3(1), 13–21.

[13] SAS 9.1.3., 2004, Qualification Tools User's Guide. SAS Institute Inc. Cary, NC, USA.

[14] Chalk, L., 1930, Tracheid length with special reference to Sitka spruce (*Picea sitchensis Carr*). Forestry, 4, 7-14.

[15] Panshin, A.J. and de Zeeuw, C., 1980, Textbook of wood technology. 4th Ed. New York, McGraw-Hill.

[16] Butterfield, B.G., 2003. Wood anatomy in relation to wood quality. In:Barnett JR, Jeronimidis G., editors. Wood quality and its biologicalbasis. Oxford, Blackwell Publishing; p. 30–52.

[17] Kijidani, Y., Fujii, Y., Kimura, K., Fujisawa, Y., Hiraoka, Y. and Kitahara, R., 2012, Microfibril angle and density of hinoki (*Chamaecyparis obtusa*) treesin 15 half-sib families in a progeny test stand in Kyushu, Japan,Journal of Wood Science, 58,195–202.

[18] Yamashita, K., Katsuki, T., Akashi, K. and Kubojima, Y., 2010, Wood properties ofPicea koyamae: within-tree variation of grain angle, tracheid length,microfibril angle, wood density and shrinkage, Bulletin of FFPRI, 9,19–29.

[19] Steffenrem, A., Saranpää, P., Lundqvist, S.O. and Skrøppa, T., 2007, Variation inwood properties among five full-sib families of Norway spruce (*Piceaabies*). Annals of Forest Science, 64,799–806.

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