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Radial Variation in Tracheid Length and Growth Ring Width of *Pinus kesiya* Royle ex Gordon in Malawi

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ABSTRACT

Wood anatomical features measured in tree-rings are useful indicators of environmental change and wood quality. This study was conducted to investigate the radial variation in tracheid length and growth ring width and to demarcate the boundary between juvenile wood and mature wood of *Pinus kesiya* Royle ex Gordon grown in Malawi. A total of 90 discs were collected from six families at breast height (1.3 m above the ground) and were measured for tracheid length and growth ring width. The results show that there were statistical significant (P<0.001) differences on tracheid length and growth ring width among the ring numbers in juvenile wood. Tracheid length at first increased rapidly from pith to bark and thereafter increased gradually or remains more or less constant, while growth ring width decreased. However, there were no significant (P>0.05) differences on tracheid length and growth ring width among families across the radius. On the basis of radial variation of tracheid length, the boundary between juvenile wood and mature wood could be marked at ring number 10 from the pith. This should be taken into account when planning for forest management and product manufacturing using *Pinus kesiya* grown in Malawi.

Keywords: Tracheid length, growth ring width, juvenile wood, mature wood, wood quality.

INTRODUCTION

Pinus kesiya Royle ex Gordon is one of the most valuable timbers in international trade and an important species for tropical forestry [1]. This species generally grows well at altitudes ranging from 300 to 2700m above the sea level. The trees usually grows up to 45m tall with straight cylindrical trunk and a bole free of branches up to 20m. *Pinus kesiya* grows on a range of soil types, but prefers well-drained, neutral to acid soils. Once established the tree is fairly resistant to drought and frost. *Pinus kesiya* grows naturally in Himalaya region of Asia, which includes: Burma, India, China, Laos, Philippines, Thailand, Tibet, and Vietnam [2]. It has also been introduced in many tropical countries, for instance, South Africa in 1906 from Assam and 1915 from Phillipines, Zimbabwe in 1935 from Phillipines, Kenya, Zambia, Tanzania and Malawi [3].

Pinus kesiya is one of the major exotic tree species in Malawi. Its success as an exotic is due to its fast growth rate and wide adaptability. It provides high class value of timber. The wood is essentially used for paneling, construction, cabinet work, joinery and sometimes poles [4 – 6]. The species was first introduced in Malawi in 1935. Then, large scale plantings were done with seeds from Zimbabwe and South Africa in 1950's. In 1970's and 1980's seed orchards were established with the aim of creating owned seed sources of improved traits [7]. There is a general agreement in literature that *Pinus kesiya* growth varies according to location [1, 8], but most of the available data comes from Asian countries, especially in India [1,9,10]. Anatomical properties such as tracheid length, and growth characteristics

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such as growth ring width are one of the most essential tools for understanding tree growth and its reaction to varying climatic settings [11, 12]. They form the basis for wood anatomy, dendroclimatology, dendrochronology and dendroecology [13,14]. They are valuable instruments in forest management as well as in product manufacturing as they are closely connected with tree growth rate and wood properties [1, 15]. This is an indication that information on radial variation pattern of ring width and tracheid length can facilitate tree growth and wood quality in forest management and wood utilization [16 – 18].

Despite these facts no information is available on radial variation pattern in growth ring width and tracheid length of *Pinus kesiya* in Malawi. Thus no effort has been made to investigate the radial variation pattern of growth ring width and tracheid length in this species. Reports from different research has shown that radial variation in anatomical properties and growth characteristics are caused by both specific environmental factors, forest management practices and within controlled genetic factors [8, 10, 14, 15, 19].Therefore, the purpose of this study was to investigate the radial variation in growth ring width and tracheid length and to demarcate the boundary between juvenile wood and mature wood for *Pinus kesiya* in Malawi. The knowledge on radial variation pattern in tracheid length and growth ring width and the boundary between juvenile wood and mature wood would be incorporated into decision support system in Malawi to assist the forestry industry in planning and developing tree improvement programmes and wood utilization for *Pinus kesiya* and thus anticipating the impacts.

MATERIALS AND METHODS

Study Site

The study was conducted in Malawi located in Southern Africa in the tropical savannah region at Chongoni Forest Plantation in Dedza (Figure 1). Chongoni is located between latitudes 14^{o}10'S and 14^{o}21'S and longitudes 34^{o}09'E and 34^{o}17'E and 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^{o}C. It is situated about 85 km southeast of the capital Lilongwe.

Plant Material and Sampling

The materials for the study were collected from a *Pinus kesiya* seed orchard which was planted in 1984 with 18 families in a completely randomized design in four replicates. Trees were planted at a spacing of 2.75m x 2.75m with seed source from Zimbabwe. All the silvicultural treatments (weeding, slashing, pruning and thinning) were done on the instruction of the breeder.

In May 2014, six of the eighteen families were chosen and a total of ninety straight boled trees (15 trees from each family) with no major defects were randomly selected. The following growth traits were measured: diameter at breast height (dbh) using a caliper; total height using a vertex with a transponder; and merchantable height (height at 15 cm top diameter) uses a linear tape after felling. The growth data are presented in Table 1. The north side of each tree was marked before felling. The cross-sectional discs of 10 cm thickness were taken at breast height (1.3 cm above the ground).

Sample Processing and Measurement

Each cross-sectional disc was smoothened to the end grain by a sand paper. Radial strips from the north side were cut from bark to pith and air-dried. Growth ring width from pith to bark was measured in these strips by using ocular micrometer in one of the eye piece of a stereomicroscope at 20x. A total of 28 growth rings were observed for each disc.

Every third ring from the pith to the bark was carefully split from the strips and the latewood were macerated. Maceration were 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 thrice, stained with safranin, and then mounted on a glass slide and a cover-slip was placed over the specimen. Lengths of thirty randomly selected tracheids were measured using a Nikon V-12 profile projector at a fifty-fold magnification.

Statistical Analysis

Data obtained on growth ring width and tracheid length 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 [20]. After the two criteria were met the data were subjected to analysis of variance (ANOVA) using the same Statistical Analysis of Systems software with family and ring number as fixed factors. Differences between treatments means were separated using Fischer's least significant difference (LSD) at the 0.05 level. Graphs were plotted using Microsoft Excel 13.

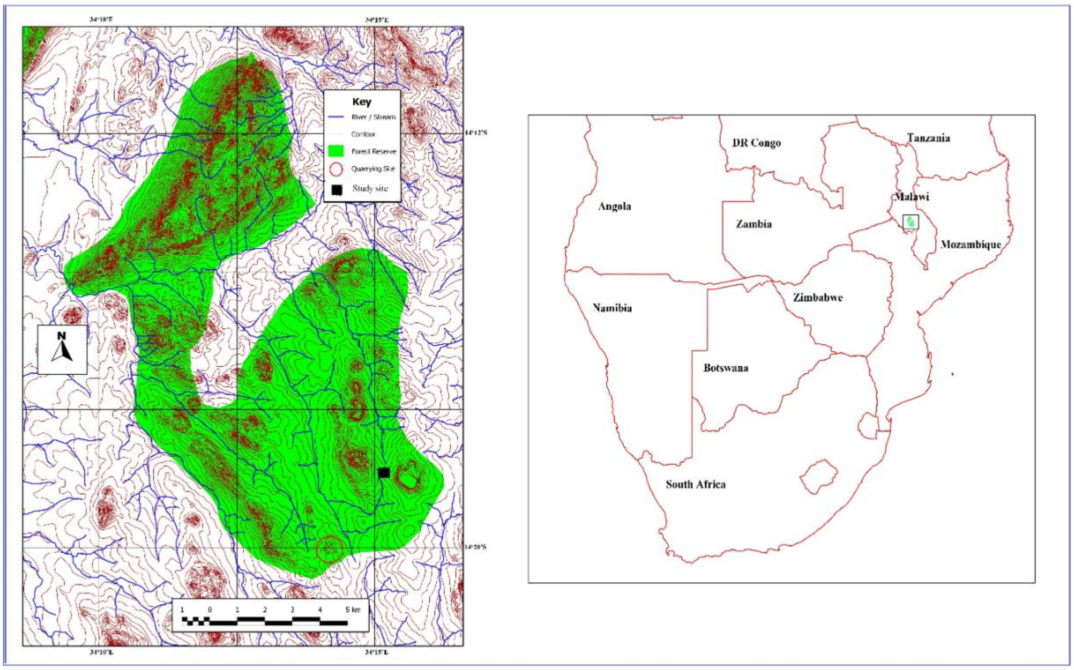

Figure1. *Location of Chongoni Forest Plantation in Southern Africa*

Table1. *Characteristics of growth data set*

Family	Variable	Mean	Minimum	Maximum	SD
n = 15 trees per family					
A	Diameter at breast height (cm)	36.1	32.0	39.0	2.22
	Total height (m)	29.3	24.6	34.2	2.55
	Merchantable height (m)	24.3	20.4	27.4	1.92
B	Diameter at breast height (cm)	28.0	23.0	32.0	2.51
	Total height (m)	24.3	19.8	28.3	2.25
	Merchantable height (m)	18.4	16.3	21.8	1.60
C	Diameter at breast height (cm)	34.6	29.0	38.0	2.75
	Total height (m)	27.5	24.7	29.5	1.62
	Merchantable height (m)	21.0	19.2	23.8	1.41
D	Diameter at breast height (cm)	33.0	28.0	38.0	2.70
	Total height (m)	25.3	23.1	29.8	2.04
	Merchantable height (m)	20.0	17.2	22.6	1.58
E	Diameter at breast height (cm)	31.0	26.0	36.0	2.51
	Total height (m)	24.5	21.4	27.4	1.97
	Merchantable height (m)	19.3	16.5	22.3	1.70
F	Diameter at breast height (cm)	29.1	24.0	34.0	3.45
	Total height (m)	24.7	19.6	26.9	2.37
	Merchantable height (m)	18.9	16.2	21.4	1.42

Note. *Merchantable height is the height of the tree at 15 cm top diameter, SD = Standard deviation.*

RESULTS AND DISCUSSION

Radiation Variation in Tracheid Length and Growth Ring Width

The length of tracheids in wood is an important determinant of the use to which that wood is put. The quality of both lumber and pulp is determined, in part, by the length of tracheids in the wood. Long fibres give lumber greater strength and papers produced from pulp of long fibres are of more strength and fold-resistance [21]. The variation in patterns of tracheid length and growth ring width as a function of ring number from pith to bark are given in Table 2 and Figures 2 and 3, respectively.The results presented in Table 2 indicates that there were statistical significant (P<0.001) differences on tracheid length and growth ring width among the ring numbers from pith to bark. Tracheid length at first increased rapidly from pith to bark, then more slowly, while annual ring width decreased. Radial increase in tracheid length from pith to bark is due to increase in length with cambial age [22]. The average growth ring of *Pinus kesiya* for the present study has been found to be 4.28±0.18 mm, which is higher than the mean growth ring width for *Pinus kesiya* (3.81 mm) reported by [1] and lower than those of *Pinus eldarica* (4.95 mm) [23]. This difference may be attributed to initial plant spacing. There is acceleration of growth for widely spaced trees than crowded trees, because widely spaced trees do not compete for growth elements such as nutrients, water and sunlight, hence they tend to have wider growth ring width [24]. In the present study, trees were planted at a spacing of 2.75 m x 2.75 m, which was wider than for [1] which were planted at a spacing of 1.8 m x 1.8 m, while for [23] trees were planted at a spacing of 3.0 m x 3.0 m. There were no significant (P>0.05) differences on tracheid length and growth ring width among families across the radius. Thus, the pattern of variation was the same (Figures 2 and 3). This is an indication that any tree among the families can be selected for tree improvement programs if tracheid length is considered as a variable.

Table2. *Mean values of tracheid length and growth ring width of Pinus kesiya at different ring number*

Ring number from pith to bark	Tracheid length (mm)	Growth ring width (mm)
3	1.62±0.08 ^{d}	13.84±0.18 ^{a}
6	2.36±0.08 ^{c}	9.41±0.18 ^{b}
9	3.01±0.08 ^{b}	5.33±0.18 ^{c}
12	3.93±0.08 ^{a}	2.02±0.18 ^{d}
15	3.97±0.08 ^{a}	1.71±0.18 ^{d}
18	4.02±0.08 ^{a}	1.66±0.18 ^{d}
21	4.14±0.08 ^{a}	1.60±0.18 ^{d}
24	4.29±0.08 ^{a}	1.52±0.18 ^{d}
27	4.36±0.08^{a}	1.44±0.18 ^{d}
CV (%)	5.6	8.2
R^2	0.97	0.95

Note. ^{a,b,c,d} *means with different superscript within a column significantly differ (P<0.001)*

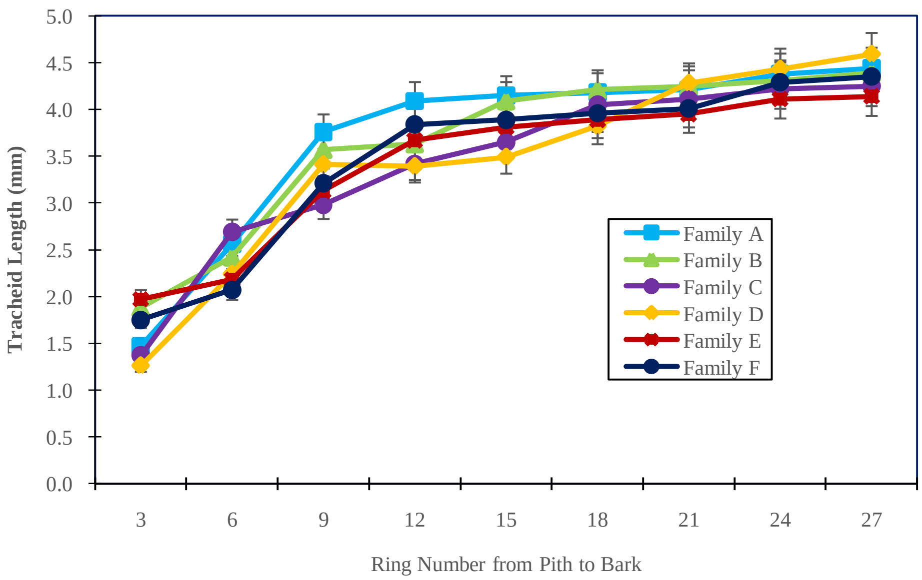

Figure2. *Radial variation of tracheid length for different six families of Pinus kesiya*

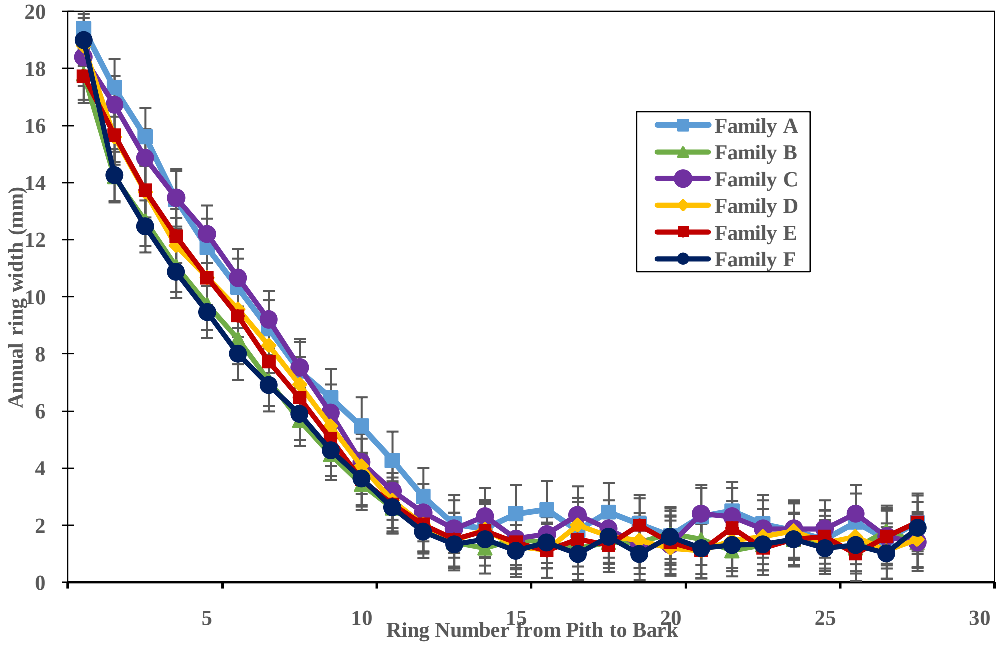

Figure3. *Radial variation of growth ring width for different six families of Pinus kesiya*

Juvenile and Mature Woods Boundary

Radial variations in anatomical properties are greatly essential to observe the degree of variation from pith to bark and to demarcate the boundary between juvenile wood and mature wood [21, 25, 26]. Juvenile wood is a term derived to clarify why growth rings close to the pith have certainly different wood properties [9]. The concept of juvenile wood is an important consideration in relation to wood properties and explains why upper logs in mature stands have juvenile characteristics. In comparison to mature wood, juvenile wood is characterized by disadvantageous traits reducing its quality, thus limiting their potential processability [27]. Therefore, demarcation of the boundary between juvenile wood and mature wood is essential for the optimization of timber utilization, quality and value of final products [15, 27]. Juvenile wood tends to have higher microfibril angles, lower wood density, thinner cell walls, shorter tracheid lengths, greater spiral grain, lower cellulose to lignin ratio, higher longitudinal shrinkage, lower latewood percentage and higher growth ring width [12, 14]. Basing on these parameters, various methods have been used to demarcate the boundary between juvenile wood and mature wood. The simplest graphic method has been used by few researchers [28], while linear regression model, non-linear and polynomial models were opted by other researchers [24, 29, 30]. The present study used Yang et al. [31] method and logarithm regression model for latewood tracheid length to demarcate the boundary between juvenile wood and mature wood. For the Yang et al. [31] method, two linear regression models, one for the juvenile wood and one for mature wood were used. Juvenile wood was defined as the zone where the length of fusiform initial (cambial cell) increased rapidly with cambial age, while the mature wood was defined as the zone where the length of cambial cell was stable. The intersection between the two graphs was taken as the demarcation point between juvenile and mature woods.

Figure 4 shows that the intersection between the two linear graphs was at ring number 10 from the pith and Figure 5 shows lower tracheid length near the pith and then increased rapidly and nonlinearly up to ring number 10, which are the main characteristics of juvenile wood [12, 14]. Beyond ring number 10 and near the bark there was a gradual increase and stable pattern in tracheid length. Basing on these results, the boundary between juvenile and mature woods can be marked at ring number 10 from pith.Hence, rings 1–10 can be regarded as juvenile wood and ring 11 to bark as mature wood.

This indicates that efficiency of selection in tree breeding program based on the inner wood for tracheid length would generally be lower than selection based on outer wood. This should be taken into account when planning for forest management and product manufacturing using *Pinus kesiya* grown in Malawi. The present results are in agreement to those in literature [1, 32].

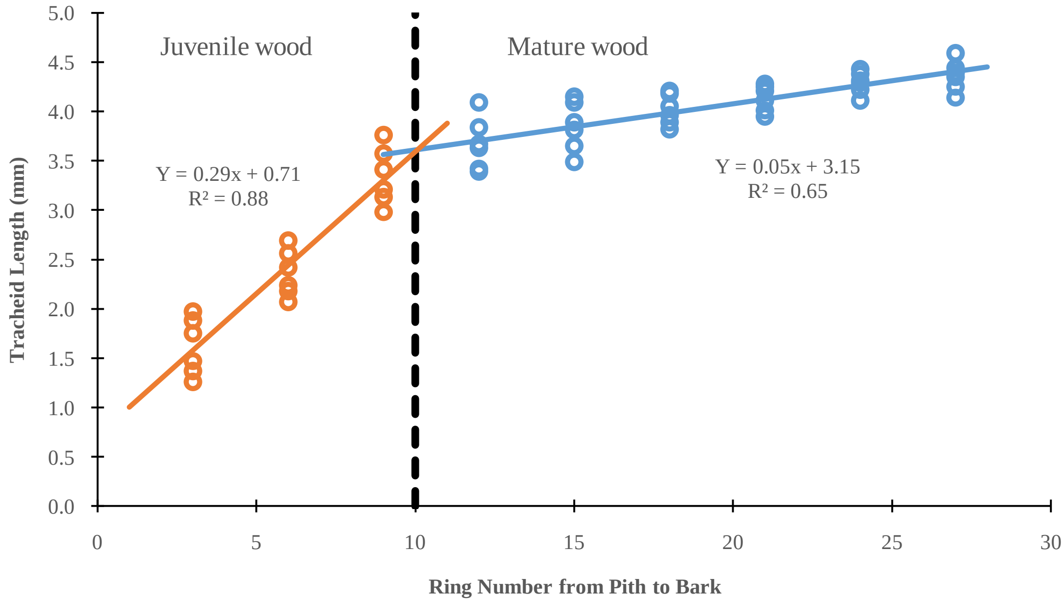

Figure4. *The boundary between juvenile wood and mature wood in Pinus kesiya*

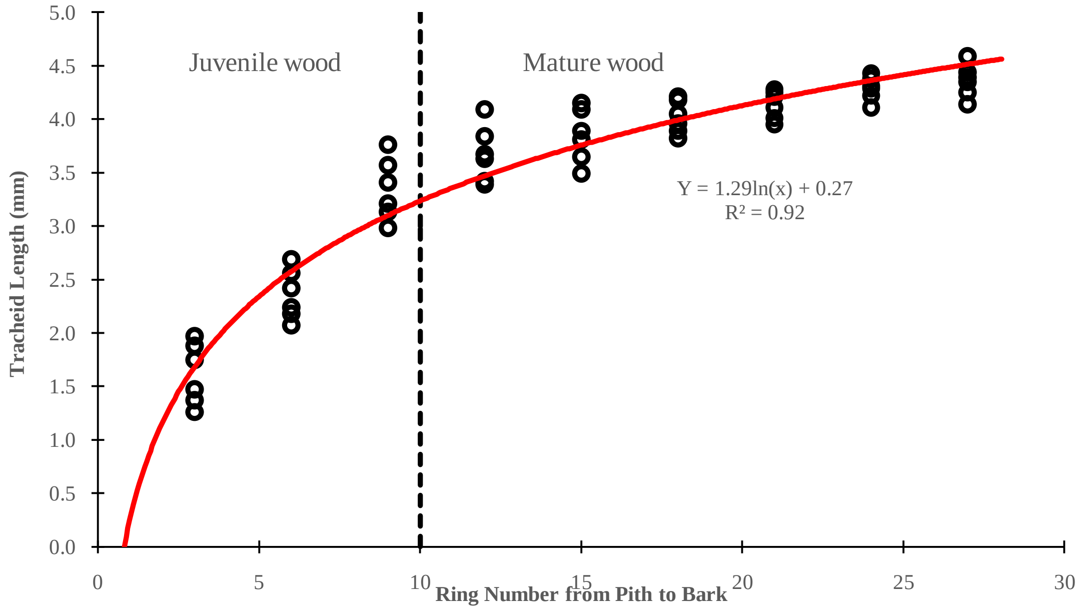

Figure 5.*Predictive model for tracheid length based on ring number from pith to bark*

CONCLUSION

The study has revealed that there were statistical significant differences on tracheid length and growth ring width among the ring numbers in juvenile wood.Tracheid length at first increased rapidly from pith to bark and thereafter increased gradually or remains more or less constant, while growth ring width decreased. However, there were no significant differences on tracheid length and growth ring width among families across the radius. This is an indication that any tree among the families can be selected for tree improvement programs if tracheid length is considered as a variable. On the basis of radial variation of tracheid length, the boundary between juvenile wood and mature wood could be marked at ring number 10 from the pith. This should be taken into account when planning for forest management and product manufacturing using *Pinus kesiya* grown in Malawi.

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