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Intra-Ring Tracheid Length Variations in Khasi pine (*Pinus kesiya* Royle ex Gordon) at Breast Height

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***Abstract*: The present study was conducted on straight trees of *P. kesiya* at breast height selected from natural stands of Jaintia Hills (Meghalaya), NE India. The main objective was to study tracheid length variation across different types of annual rings (narrow, medium and large) and around the circumference with the aim to evolve a sampling procedure for tracheid length comparison among trees. Three patterns of tracheid length variation (gradual increase, steep increase and steep decrease from earlywood to latewood) across rings were common among annual rings of both juvenile and mature wood. Pattern 4 (steep decrease in earlywood before increasing towards latewood) was observed in mature medium and large rings. There was localized increase in tracheid length in each false latewood zone and decrease in earlywood zone in double and multiple rings. But, there was localized decrease in tracheid length in compression zone. Both gradual and abrupt transitions were present in annual rings of Khasi pine. The first few layers of earlywood in all rings were free from growth related defects. The tracheid length exhibited statistically non-significant variation around the circumference.**

***Keywords: P. kesiya*, Tracheid length, Earlywood, Latewood, Annual ring, Transition.**

I. INTRODUCTION

Tracheids are the main component of softwoods and constitute 90-95% volume of the wood. They help in conduction and provide mechanical support to the tree. They also carry sub annual information reflecting changes in environmental conditions [1]. Tracheid length is an important parameter in applied wood anatomy. It is one of the most important indicator of wood quality and has marked effect on quality of solid, wood product, use of wood [2] and pulp [3]. An examination of literature reveals that tracheid length varies both within and among trees. It is under strong genetic control [4] and highly variable. There is voluminous information available on tracheid length of conifers since the pioneer work of Sanio [5] on Scotch pine. A perusal of literature shows that tracheid length varies from ring to ring, pith to bark, around the circumference, bottom to top and even within a small sampling unit like an annual ring [6], [7]. These variations are mentioned as intra- ring, inter- ring radial and inter- ring longitudinal variations [8]. These variations have major effect on utilization of logs to various manufacturing processes and create problems in selection of wood samples for tree to tree comparisons but they also provide considerable potential for selection of trees with wood of superior quality [7].

Pinus kesiya is an important subtropical pine of Eastern Himalaya. Its natural stands occur widely in Khasi and Jaintia Hills of Meghalaya. It has been introduced as an exotic species in many tropical countries like Phillipines, Zimbabwe, Zambia, South Africa, Malawi etc. due to its fast growth and wide adaptability [9]. It is widely planted in north eastern states by forest department to reclaim forest areas from shifting cultivation. An examination of literature reveals that tracheid length variations within a single tree, within and between trees of *P. kesiya* grown in Zambia from Assam and Burma provenances were studied [10], [11], [12] and [13]. Recently, [14] investigated radial variation in tracheid length of this species planted in Malawi with seed source from Zimbabwe. Though, there is information available on tracheid length variation from pith to bark in *P. kesiya* planted in other countries but no efforts has been made to investigate tracheid length variation in naturally grown Khasi pine in NE India. There is also no report of tracheid variation within rings of this species. Therefore, the present study on intra-ring tracheid length variation is taken up (a) to see patterns of variation in tracheid length across different types of annual rings and (b) to see variation in tracheid length around the circumference.

II. MATERIALS AND METHODS

The present study was made at breast- height level (1.37m). For this, cross- sectional discs were collected from randomly selected five trees with straight bole and uniform crown from felling site in pine forests of Jaintia Hills districts (Meghalaya). The geographical co-ordinates of the site were 25.45º N and 92.20 ºE. The age of the selected trees was 41-46 years. The average height and average diameter of trees were 23± 2.45 m and 31.07 ± 1.36 cm respectively.

A. Sample processing:

The cross sectional discs were marked into eight cardinal directions and narrow wedges were sawn out from pith to bark in each directions. Each radial wedge was smoothened to end grain.

For intra-ring radial variation, different types of annual rings namely normal rings, double, multiple and compression wood rings were selected from different directions of discs. Small blocks containing complete annual ring along with a portion of adjacent rings on either side were selected. These rings were further cut into number of tangential strips depending on the width of annual rings. Thus, a total of 146 annual rings representing 75 normal rings from both juvenile wood and mature wood, 43 double rings, 11 multiple rings and 17 rings with compression wood were selected to intra-ring radial variation. To study tracheid length variations around the circumference, 56 normal rings (7×8 directions) were selected randomly from each tree. Thus, a total of 280 rings were selected from five trees.

B. Maceration:

Small radial strips taken from selected annual rings (in case of circumferential variation) and from each tangential strip in case of intra-radial variations across the annual ring were macerated with Franklin's method [15]. For circumferential variation, 50 numbers of unbroken tracheids for each annual ring and each tangential strip were measured from tip to tip at 40X. The number of cells across the annual rings were counted with the help of image analysis system and determined by taking average of selected five radial files across annual ring. Normal rings were classified as narrow, medium and large rings on the basis of ring width by the formulae given by [16].

C. Statistical analysis:

It was performed by using SPSS 18.0 software and graphs were plotted by using Origin 8.0 software package. Only graphs of 20 annual rings have been presented here.

III. RESULTS

A. Intra- ring radial variation in tracheid length:

(a) Normal rings:

The present study showed that normal rings near the pith (Juvenile rings) were mostly large and medium and rarely narrow rings while the mature wood consisted of all large, medium and narrow rings. Four patterns of variations from earlywood to latewood were observed.

Pattern 1: There was gradual increase in tracheid length from earlywood to latewood (Figures 1-4). In this pattern percentage increase in tracheid length values from earlywood to latewood was 6-10% in juvenile wood rings and 2-21% in mature wood rings.

Pattern 2: It showed steep increase in tracheid length from earlywood to latewood (Figures 5-8). The percentage increase in tracheid length values from earlywood to latewood were 9 -30 % in juvenile wood rings and 5-16% in mature wood rings.

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Pattern 3: Tracheid length decreased from earlywood to latewood (Figures 9 & 10). The percentage decrease in tracheid length from earlywood to latewood was 3 to 13% in juvenile wood rings and 4-18% in mature wood rings. All these three patterns of tracheid length variations were observed in both juvenile and mature rings.

Pattern 4: It was observed only in mature large and medium rings. In this pattern, there was steep decrease in tracheid length values in earlywood and increase in latewood (Figures 11 & 12). The percentage of decrease in tracheid length value in earlywood zone was 10 to 20 % and increase from earlywood to latewood 5 to 15 %.

All selected annual rings showed either gradual or abrupt transition in their cross- sectional cell dimensions from earlywood to latewood.

(b) Double and multiple rings:

Such types of rings were observed in large and medium rings of mature wood. Double ring was represented by single band of false latewood located either in the middle of earlywood zone or 2/3 part of an annual ring. Whereas, multiple rings consisted of two or more bands of false latewood located in middle of earlywood zone. In both double rings (Figures 13 & 14) and multiple rings (Figures 15 & 16) there was localized increase in tracheid length in false latewood zone and decrease in each earlywood zone.

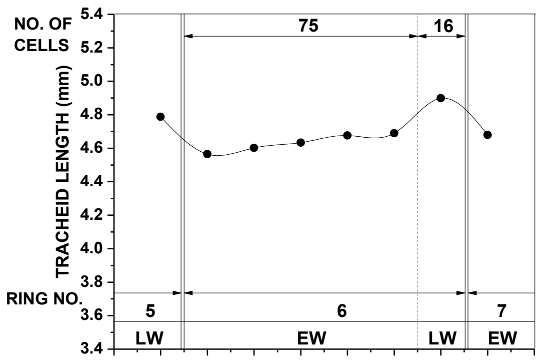

Figure 1: Medium ring (RW 3.30mm)

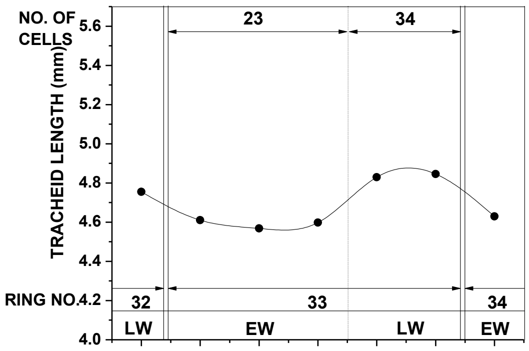

Figure 2: Medium ring (RW 2.52mm)

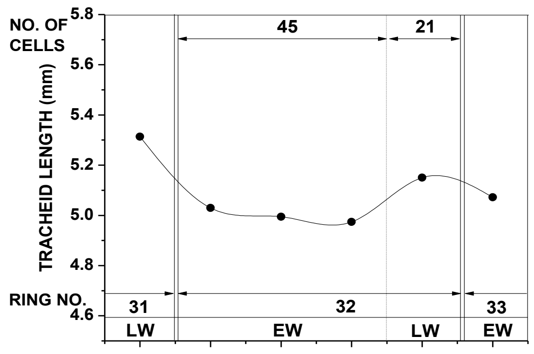

Figure 3: Medium ring (RW 2.74mm)

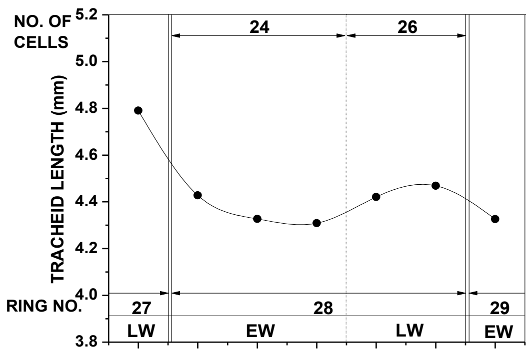

Figure 4: Medium ring (RW 2.02mm)

Double vertical lines - Annual ring boundaries; Dotted vertical line – Earlywood latewood transition; EW- Earlywood, LW- Latewood; RW – Ring width).

Figures 1-4.Intra ring radial patterns of tracheid length variation across normal rings (juvenile and mature) showing gradual increase in tracheid length from earlywood to latewood (Pattern 1).

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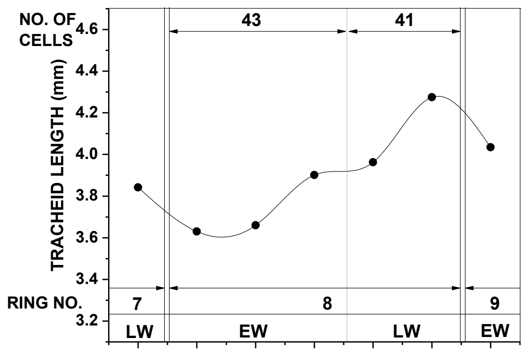


Figure 5:Medium ring (RW 3.02mm)

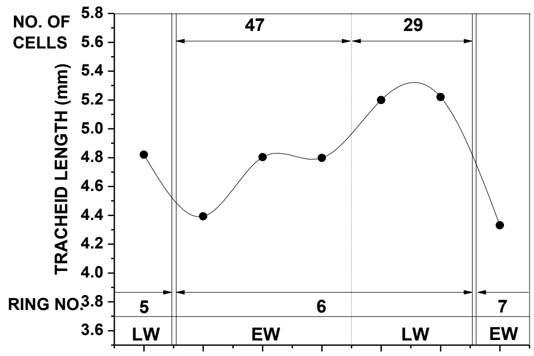


Figure 6:Medium ring (RW 2.8mm)

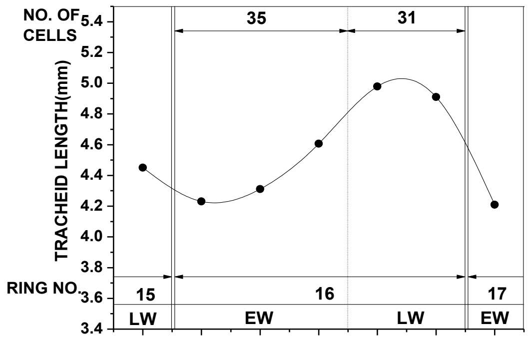


Figure 7: Medium ring (RW 2.69mm)

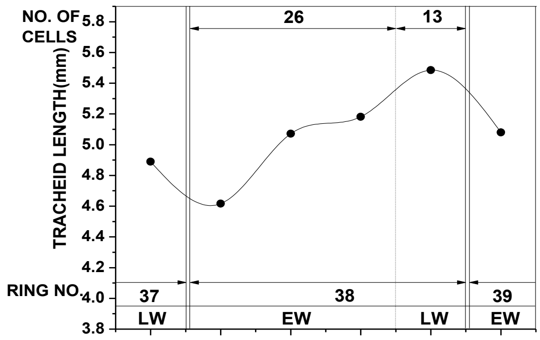
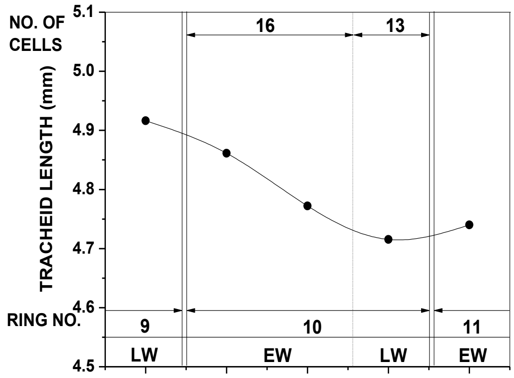


Figure 8: Narrow ring (RW 1.40mm)

Double vertical lines - Annual ring boundaries; Dotted vertical line – Earlywood latewood transition; EW- Earlywood, LW- Latewood; RW – Ring width).

Figures5-8.Intra ring radial patterns of tracheid length variation across normal rings (juvenile and mature) showing steep increase in tracheid length from earlywood to latewood (Pattern 2).



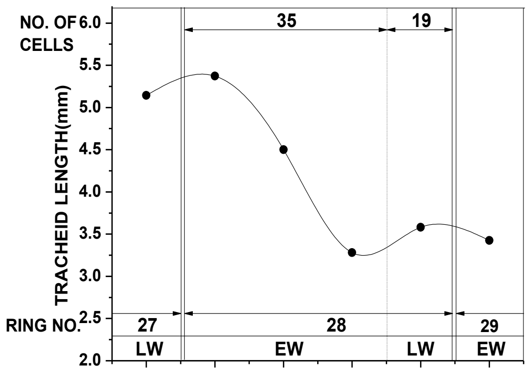


Figure9: Narrow ring(RW 1.01mm)

Figure 10: Medium ring (RW 1.68mm)

Figures 9-10.Intra ring radial patterns of tracheid length variation across normal rings (juvenile and mature) showing decreasein tracheid length from earlywood to latewood (Pattern 3).

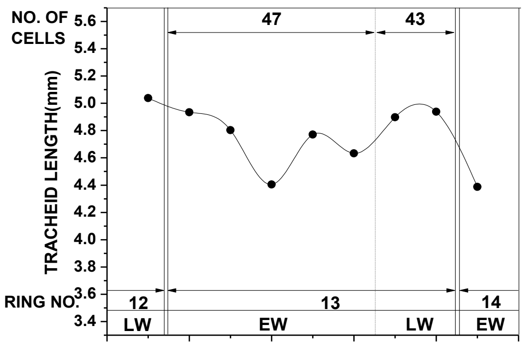


Figure 11: Medium ring (RW 3.47mm)

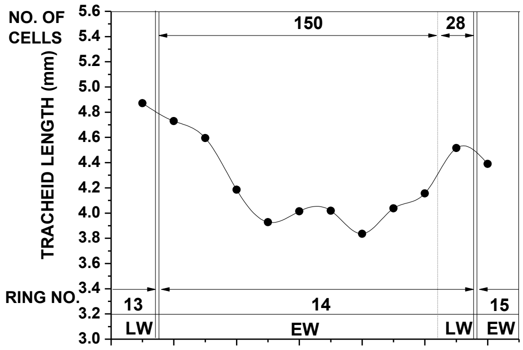


Figure 12: Large ring (RW 7.56mm)

Double vertical lines - Annual ring boundaries; Dotted vertical line – Earlywood latewood transition; EW- Earlywood, LW- Latewood; RW – Ring width).

Figures 11-12.Intra ring radial patterns of tracheid length variation across normal rings (juvenile and mature) showing steep decrease in tracheid length values in earlywood and increase in latewood (Pattern 4).

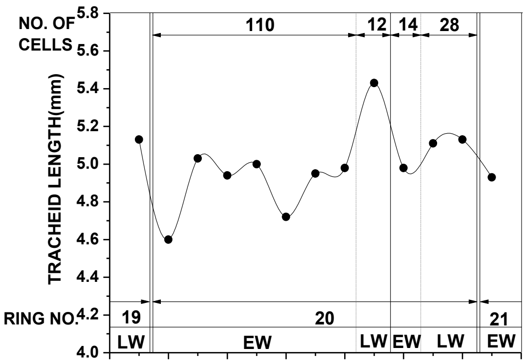


Figure 13: Large ring (RW 6.61mm)

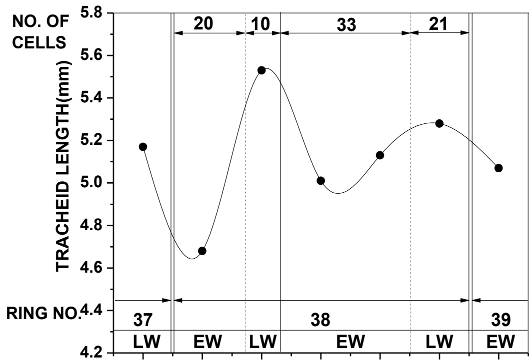


Figure 14: Medium ring (RW 3.92mm)

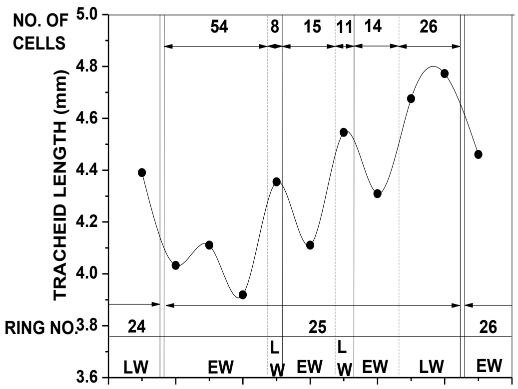


Figure 15: Medium ring (RW 5.38mm)

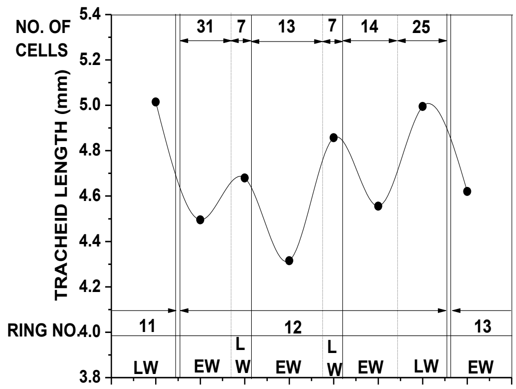


Figure 16: Medium ring (RW 3.64mm)

Double vertical lines - Annual ring boundaries; Dotted vertical line – Earlywood latewood transition; EW- Earlywood, LW- Latewood; RW – Ring width).

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Figures 13-16.Intra ring radial patterns of tracheid length variation across double and multiple rings.

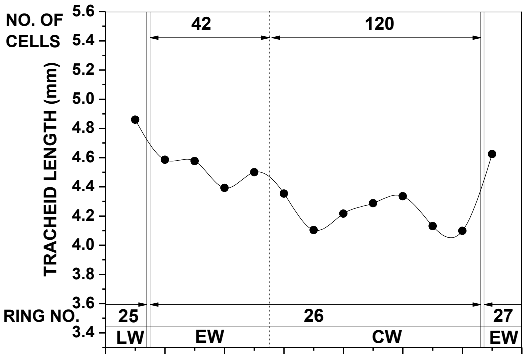

Figure 17: Large ring(RW 6.33mm)

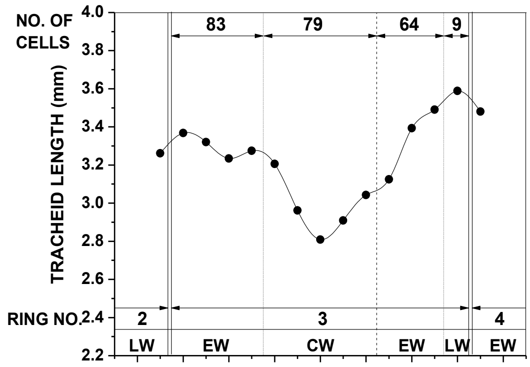

Figure 18: Large ring (RW 9.63mm)

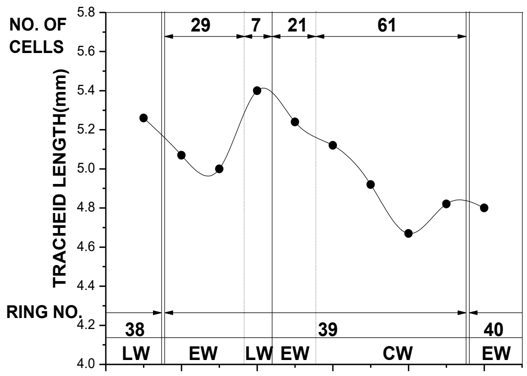

Figure 19: Medium ring(RW 4.93mm)

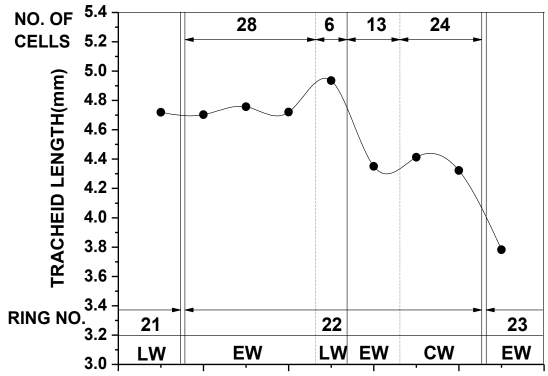

Figure 20: Medium ring(RW 4.76mm)

Double vertical lines - Annual ring boundaries; Dotted vertical line – Earlywood latewood transition; EW- Earlywood, LW- Latewood; CW- Compression wood; RW – Ring width).

Figures17-20. Intra ring radial patterns of tracheid length variation across compression wood rings.

(c) Compression wood rings:

Compression wood was observed in both juvenile and mature rings. In some of the rings, normal latewood was also replaced by compression wood (Figure 17). In other rings it was present either in the middle of the earlywood zone along with normal latewood (Figure 18). There was localized decrease in tracheid length values in compression wood zone (Figures17 & 18).

In addition, same double rings with both false latewood and compression wood were also observed (Figures19 & 20). In such rings, compression wood was present in place of normal latewood. The pattern of variation in tracheid length in false latewood and compression was similar as in double ring and compression wood rings. There was slight and gradual decrease in tracheid length from false latewood to earlywood in double and multiple rings but abrupt change in tracheid length values from latewood of one annual ring to earlywood of next ring was observed.

B. Circumferential variations in tracheid length:

Analysis of variance was carried out to see the statistical variation in tracheid length around the circumference. The results presented in Table I showed non-statistical significant differences in tracheid length variations around the circumference for all selected trees.

Table I: Circumferential variation in tracheid length in five trees of *Pinus kesiya*

Tree No.	Source of variation	Degree of freedom	Sum of squares	Mean squares	F- Value
Tree 1	Direction	7	0.341	0.049	1.161 ns
	Rings	6	2.628	0.438	10.452**
	Error	42	1.760	0.042	
	Total	56	1061.259		
Tree 2	Direction	7	0.750	0.107	1.813 ns
	Rings	6	6.405	1.067	18.064**
	Error	42	2.482	0.059	
	Total	56	1158.716		
Tree 3	Direction	7	0.535	0.076	1.373 ns
	Rings	6	4.437	0.739	13.287**
	Error	42	2.337	0.056	
	Total	56	1122.041		
Tree 4	Direction	7	0.403	0.058	1.101 ns
	Rings	6	7.855	1.309	25.047**
	Error	42	2.195	0.052	
	Total	56	1080.317		
Tree 5	Direction	7	0.593	0.085	1.168 ns
	Rings	6	3.240	0.540	7.439**
	Error	42	3.049	0.073	
	Total	56	898.169		
Pooled	Direction	7	0.301	0.043	0.724 ns
	Rings	34	34.346	1.010	16.998**
	Error	238	14.144	0.059	
	Total	280	5320.502		

ns- non significant

** 1 % at P<.01 level i.e. highly significant

IV. DISCUSSION

Since Sanio's pioneer work, a number of workers have made their remarkable contributions for variation in tracheid length in conifers and fibre length in hardwoods. Fibre length and tracheid length vary not only between different rings of a same tree but also within individual rings. [17] observed consistent difference in fibre length variations between earlywood and latewood of *Eucalyptus regnans*. Later, investigation on 28 angiosperms and 8 gymnosperms by [18] revealed a definite increase in fibre length and tracheid length from earlywood and latewood in angiosperms and gymnosperms respectively. However, there is limited information available on tracheid length variations within annual rings in conifers. [7] observed linear and gradual increase in tracheid length in rings near the pith, steep increase from earlywood to latewood tracheid length in narrow rings and gradual increase or slight decrease in tracheid length before increasing gradually towards the latewood in mature intermediate and wide rings of *Cedrus deodara*. [19] reported that first formed earlywood tracheids were longer than those in middle zone of earlywood in rings of juvenile wood. Whereas, there was gradual increase in tracheid length from earlywood to latewood in rings of transition and mature wood in *Pinus sylvestris* and *Picea abies*. The present study showed gradual increase and steep increase in tracheid length from first-formed earlywood to last formed latewood in both juvenile and mature medium rings. There was also steep decrease in tracheid length in earlywood before increasing towards the latewood in some of mature medium and wide rings. Hence, the patterns of variation in tracheid length are slightly different as reported by [7], [19]. In addition, there was also decrease in tracheid length from earlywood to latewood in narrow, medium and wide rings of both juvenile and mature wood, which is in confirmation with the findings of [20]. The decrease in fibre length in latewood of angiosperm were also reported by [18] who attributed contamination of latewood fibres with earlywood fibres of adjacent growth rings for decrease in fibre length. In the present study, some tracheids with distorted tips along with latewood tracheids were observed which might be the cause of decrease in tracheid length in latewood portion of selected annual rings.

False rings are tree anomalies [21] that are formed under stressful condition like shortage of water during growing season. They interrupt the normal radial growth of annual rings by forming latewood like cells within earlywood or earlywood like cells within latewood [22], [23]. These structures in annual rings are also known as double or multiple rings [24] and are also considered as environment indicators in pines [22]. In the present study, both double and multiple rings were present which showed localized increase in tracheid length values in each false latewood and decrease in false earlywood. The present investigation is in agreement with the finding of [7].

Compression wood is present in inclined trees. However, [25] reported the occurrence of compression wood in straight trees as a result of either corrected lean or stimulated growth. Compression wood is very common in *P. kesiya* trees of Assam, Burma and Philippine provenances planted in Zambia [12]. [26] reported high compression wood in plantation of *P. kesiya* due to stem sweep and sinuosity in younger trees. The present study revealed the presence of mild compression wood in selected naturally grown trees despite of having concentric pith. The present study is in agreement with the finding of [27], [28]. The formation of compression wood in straight trees may be due to instability of young trees caused by basal sweep [29], [30]. In the present investigation, compression wood was observed either in the middle or at the end of annual rings with or without normal latewood. Some of selected annual rings had both a band of false latewood and compression wood. True latewood was found absent across such rings. There was decrease in tracheid length in compression wood zone in selected annual rings. These tracheids were found mostly with biforked or distorted tips. The present study corroborates the findings of [31], [32], who also reported similar pattern of tracheid length variation in other conifers. The different pattern of variation shows that tracheid length is highly variable parameter across annual rings and varies from ring to ring, within and among trees.

Circumferential variation in tracheid length has been studied as it is important to determine the number of directions required for comparing tracheid length amongst rings of comparable age of different trees. Some of researchers have adopted sampling of two radial directions [7], [11], [12], [33] while others suggested any single radial direction for comparison of circumferential variation in tracheid length. The present study showed statistical non-significant variation in tracheid length among directions which indicates that directions have no influence on tracheid length. Hence, any random radial directions can be taken for comparison of tracheid length among *P. kesiya* trees in natural forest stands.

V. CONCLUSIONS

The present study revealed different patterns of tracheid length variations across normal rings which indicate that it is highly variable from ring to ring, within same and among different trees. Mild compression wood was present in some rings. All types of rings i.e. double, multiple, compression wood rings were present in straight trees of *Pinus kesiya*. There was no effect of directions on tracheid length variation around the circumference. Therefore, any random radial directions can be taken for comparison of tracheid length among *P. kesiya* trees. The first few layers of earlywood in all rings were free from growth related defects and hence can be taken for comparison among trees.

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