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Intra-ring wood density variations in Khasi pine (*Pinus kesiya* Royle ex Gordon)

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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 wood density variation across different types of annual rings (narrow, medium and large). Three patterns of wood density variation from earlywood to latewood were observed in normal rings. But, there was localized increase in wood density in each false latewood zone and compression wood zone.

Keywords: wood density, earlywood, latewood, compression wood, annual rings

Introduction
Wood density is one of the most important properties of wood. It is related with many other physical and mechanical properties of wood like strength, stiffness and affects the physical and mechanical properties of solid wood products. It affects the shrinking and swelling behaviour of wood and thus, related to suitability of wood to different end uses (Saranpää, 2003) [23]. It is an important indicator of pulp and paper yield and physical properties of paper products (Wimmer *et al*., 2002; Molteberg and Høibø, 2007) [27, 19]. Intra-ring wood density variations is an indicator of wood uniformity (Koubaa *et al.*, 2002) [14] and determines the suitability of wood for specific end uses particularly for high value added application (Zhang *et al.*, 1994; Koubaa *et al.*, 2002; Fujimoto *et al.*, 2008) [29, 14, 10]. It provides considerable information on formation of wood and change involved in physiological processes during the growing season in an annual ring (Koubaa *et al.*, 2002; Lachenbruch *et al*., 2011) [14].

Pinus kesiya is an important subtropical pine of Eastern Himalaya. Its natural stands occur widely in Khasi and Jaintia Hills of Meghalaya. An examination of literature reveals that wood density variations within a single tree, within and between trees of *P. kesiya* grown in Zambia from Assam and Burma provenances were studied (Burley, 1970; Burley and Andrew 1970) [4, 5]. Recently, Missanjo and Matsumura (2016) [17] investigated radial variation in wood density of this species planted in Malawi. There is no report of wood density variation within rings of this species. Therefore, the present study on intra-ring wood density variation is taken up to see patterns of variation in wood density across different types of annual rings.

Material 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 25.45 ºN 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.

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. 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. Normal rings were classified as narrow, medium and large rings on the basis of ring width by the formulae given by Xu *et al* 2014 [28].

Wood density of selected annual rings was determined by Water displacement method (Smith, 1955) [26]. Graphs were plotted by using Origin 8.0 software package.

Results
Intra-ring radial variation in wood density
a) Normal rings
Normal rings near the pith (Juvenile rings) were mostly medium and large. The mature wood consisted of all narrow, medium and large rings. Three patterns of variations from first- formed earlywood to last formed latewood were observed.

- **Pattern I:** There was steep increase in wood density from earlywood to latewood (Fig. 1). In this pattern percentage increase in wood density values from earlywood to latewood was 45-61 % in juvenile wood rings and 37-59% in mature wood rings.
- **Pattern II:** Wood density first decreased in earlywood, increased gradually or remained almost constant in

earlywood before showing an increase in latewood (Fig. 2). The percentage increase in wood density values from earlywood to latewood was 30-54% in juvenile wood rings and 30-55 % in mature wood rings.

- **Pattern III**: Wood density increased gradually in earlywood and steeply in latewood (Fig. 3).The percentage increase in wood density from earlywood to latewood was 19-54 % in juvenile wood rings and 17-55% in mature wood rings.

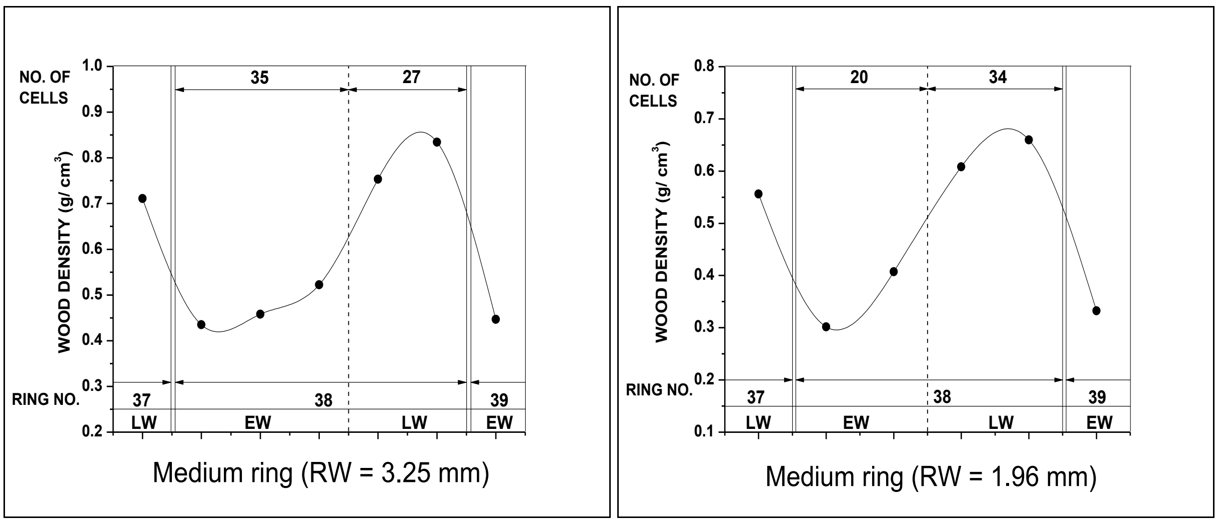
b) Double and multiple rings

These rings were observed in medium and large rings of mature wood. Double ring was represented by single band of false latewood located either in the middle of earlywood zone or 2/3rd 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 (Fig. 4) and multiple rings (Fig. 5) there was localized increase in wood density in false latewood zone and decrease in each earlywood zone.

c) Compression wood rings

These rings were present in both juvenile and mature rings. In some of the rings, normal latewood was also replaced by compression wood (Fig. 6). In other rings, compression wood was present either in the middle of the earlywood zone along with normal latewood. There was localized increase in wood density in compression wood zone.

In addition, some double rings with both false latewood and compression wood were also observed (Fig. 7). In such rings, compression wood was present in place of normal latewood. The pattern of variation in wood density in false latewood and compression wood was similar as in double ring and compression wood rings.



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

Fig 1: Intra-ring radial patterns of wood density variation across normal rings showing steep increase in wood density from earlywood to latewood (Pattern I).

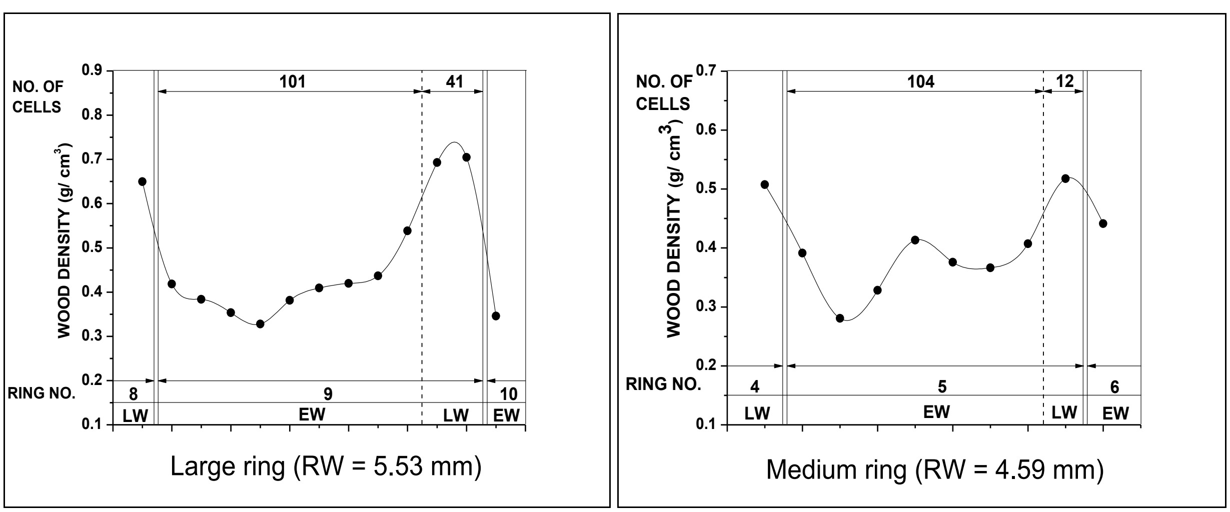
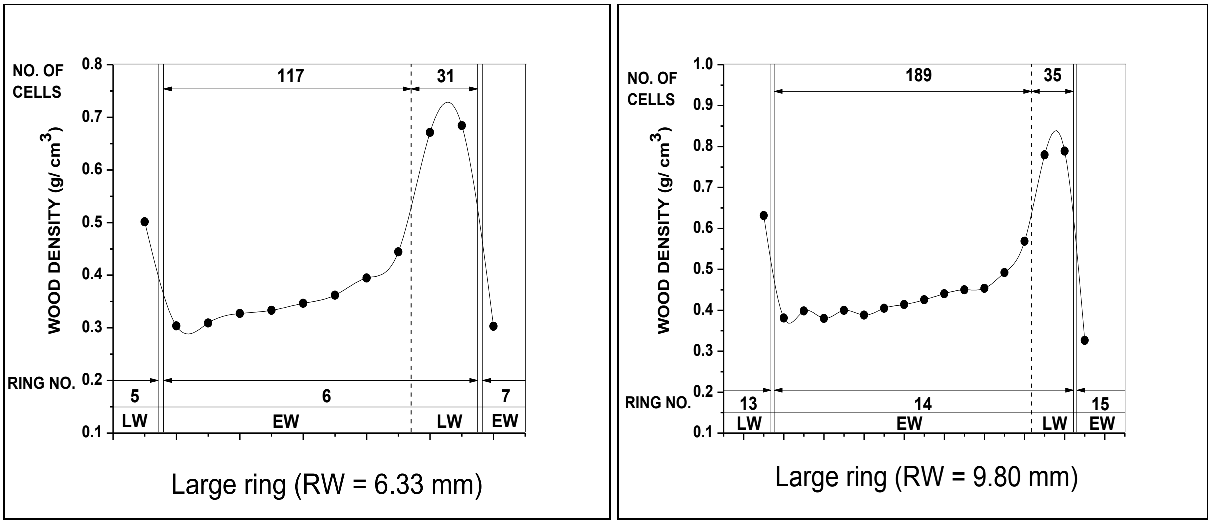


Fig 2: Intra-ring radial patterns of wood density variation across normal rings showing first decreased in earlywood, increased gradually or remained almost constant in earlywood before showing increase in latewood (Pattern II).



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

Fig 3: Intra-ring radial patterns of wood density variation across normal rings showing gradual increased in earlywood and steeply in latewood (Pattern III)

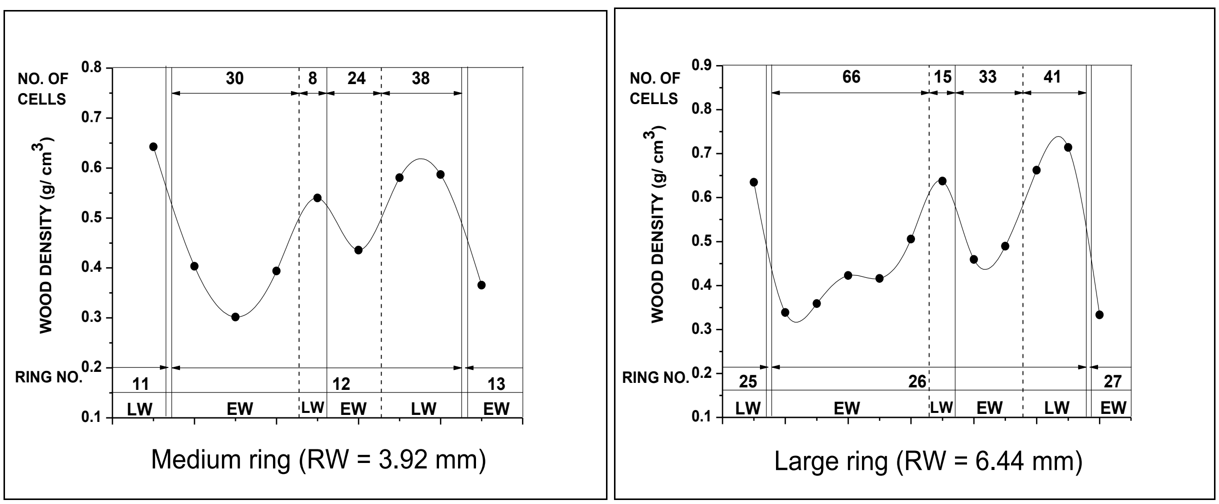
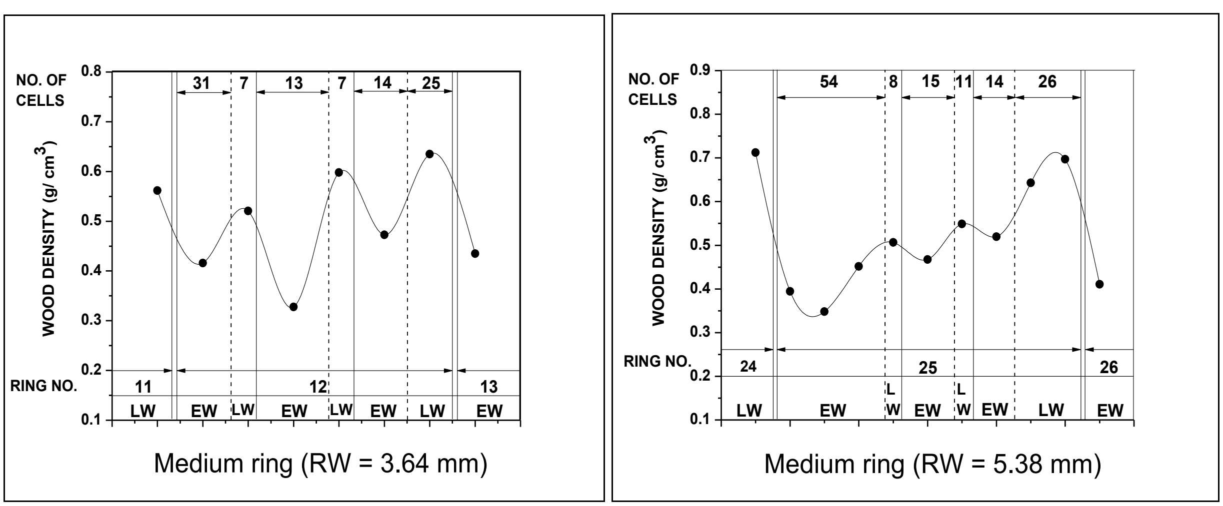


Fig 4: Intra-ring radial patterns of wood density variation across double rings



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

Fig 5: Intra-ring radial patterns of wood density variation across multiple rings.

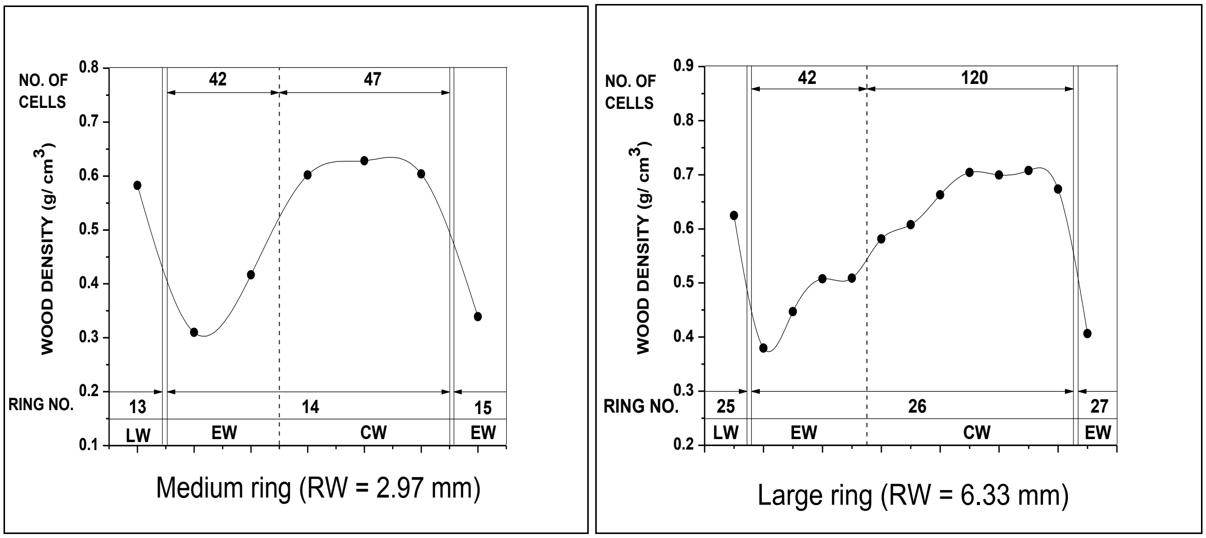
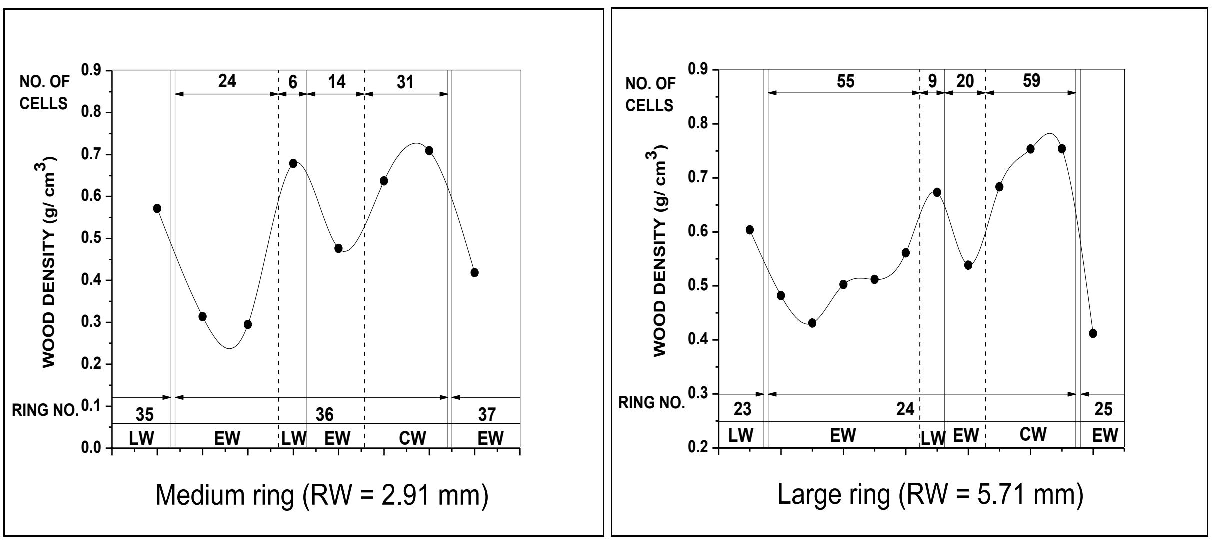


Fig 6: Intra-ring radial patterns of wood density variation across compression wood rings.



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

Fig 7: Intra-ring radial patterns of wood density variation across compression wood rings with false late wood.

Discussion

Intra-ring wood density variations are an indicator of wood uniformity (Koubaa *et al.*, 2002) [14]. Intra-ring density variations are under moderate genetic control (Abdel-Gadir *et al.*, 1993; Fujimoto *et al.*, 2008) [1, 10]. According to Megraw (1985), the seasonal climatic changes and formation of latewood accounted for maximum variation of density in each annual ring. Seth *et al.* (1989) [24] investigated specific gravity variations in different types of annual rings and observed gradual increase from earlywood to latewood in annual rings present near the pith and mature wide rings and steep increase in wood density in mature intermediate rings. Decoux *et al.* (2004) [8] made comparison of anatomical measurements to determine wood density variation within annual rings of *Picea abies*, *Pinus sylvestris* and *Abies alba*. They reported increase in wood density from earlywood to latewood as a result of anatomical modifications like increase of cell wall thickness and increase in number of cell wall rows and chemical modification like variation in structure and chemical composition of cell wall. Fujimoto *et al.* (2008) [10] reported increase in wood density from earlywood to latewood which is associated with change in both tracheid diameter and cell wall thickness. Jyske *et al.* (2008) [13] studied wood density variation within an annual ring by dividing all the annual rings into 10 equal parts. They revealed slight decrease in wood density at relative distance of 20% from the ring boundary and afterwards. They further reported higher wood density in first formed earlywood portion in the rings near the pith and latewood in outer rings. On contrary to it Bouriaud *et al.* (2005) [3] reported rather constant specific gravity in earlywood and more fluctuation in latewood due to climatic characteristics. Three patterns of wood density variation across annual rings were observed in the present investigation. In pattern I, there was steep increase in wood density variation across the rings with 45-61 % variation in juvenile rings and 37-59 % variation in mature rings. Also, there was less variations in narrow rings as compared to medium rings. There was decrease in wood density in earlywood, then it gradually increased or almost constant in earlywood before increasing towards latewood in pattern II. The percentage increase in wood density was 30-54 % and 30-55 % in medium and large juvenile and mature rings. While, there was steep increase in wood density from earlywood to latewood in pattern III. The present study is in agreement with finding of Seth *et al.* (1989) [24] who reported steep increase and gradual increase in wood density across narrow, intermediate and large rings. The increase in wood density from earlywood to latewood is due to thickening of radial and tangential diameter of latewood tracheids and confirms the findings of Rathgeber *et al.* (2006) [20]. The different patterns of variations in wood density across rings depend on cambial activity during the growing season (Mitchell and Denne, 1997) [18]. In the present study, the mature rings have more density than juvenile rings. The less proportion of latewood may be the reason for low density in juvenile wood.

False rings are formed under water stress conditions and reduce the photosynthesis and cambial activity (Cherubini *et al.*, 2003; Copenheaver *et al.*, 2006) [6, 7]. It results in the formation of thick walled xylem cells. As the favorable condition prevails, the subsequent larger cells with thin walls are formed (Wimmer *et al.*, 2000) [27]. The false rings (both double and multiple rings) were present in juvenile and mature rings of *Pinus kesiya*. In these rings, there was decrease in wood density in earlywood and an increase in false latewood and true latewood. The present investigation is in accordance with Seth *et al.*, 1989 [24]; Seth and Thakur, 2004. The density of false latewood was lesser than that of true latewood of annual rings. The presence of more number of thick walled cells in true latewood than false latewood may be the reason for lesser density. The false rings, like normal rings, also showed abrupt transition from latewood of previous ring to the earlywood of next ring.

Burley and Andrew (1970) [4, 5] reported compression wood in *Pinus kesiya* trees of Assam, Burma and Philippine provenances planted in Zambia. In the present study, mild compression wood was observed in straight trees which may be due to instability of young trees caused by basal sweep (Rune and Warensjö, 2002; Rune, 2003) [22, 21]. Jain and Seth (1979) [12] investigated wood density variation in normal and compression wood of *Pinus wallichiana* and reported higher value of wood density in compression wood. Similar results were obtained in other conifers by Bala and Seth, 1992; [2] Donaldson *et al.*, 2004 [9]; Gryc and Horáček, 2007 [11].

In the present investigation, annual rings with compression wood and double rings with compression wood zone in place of true latewood were present. The wood density of compression wood was higher than earlywood. Within the compression wood zone, the wood density either remained constant or increased steeply. The present investigation confirms the finding of Bala and Seth (1992) [2]. The higher wood density in compression wood zone may be due to presence of highly thick walled tracheids with intercellular spaces in cross- sections of the wood. Further, the present study reveals that first formed earlywood is free from growth stresses like false rings and compression wood. Hence, it can be considered as a suitable sampling stratum for comparison of wood density values among rings of same or different trees of *Pinus kesiya*.

Conclusions

The present study revealed wood density is highly variable parameter and varies from ring to ring, within same and among different trees. Three intergrading patterns of wood density variation from first formed earlywood to last formed latewood across different types of annual rings were observed. There was a localized increase in wood density in false latewood and compression wood zone. First-formed earlywood was free from growth stresses which may be suitable sampling stratum for comparison of wood density among rings

Acknowledgements

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