RADIAL VARIATION OF RAYS IN TWO COMMERCIAL SOFTWOODS GROWN IN KOREA

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Abstract. Radial variation of the height and number of uniseriate and fusiform rays within the stems of two typical Korean softwoods, *Pinus koraiensis* and *Larix kaempferi*, was studied. The average height of uniseriate rays was about six cells in *Pinus koraiensis* and nine cells in *Larix kaempferi*. The height of fusiform rays, including radial resin canals, was on average 20 cells in both species. The height of fusiform rays was greater than that of uniseriate rays: about 3.2 times for *Pinus koraiensis* and about 2.3 for *Larix kaempferi*. The height of uniseriate and fusiform rays was lowest near the pith and increased with age to about ring 10 – 20 and then became constant toward the bark. The number of uniseriate rays in a 0.5×0.5 mm area was about 6.5 for *Pinus koraiensis* and 9.5 for *Larix kaempferi*. The number of uniseriate rays was at a maximum near the pith and decreased to about ring 10 – 20 and was nearly constant for subsequent rings. The ratio of fusiform to uniseriate rays was 1:45 in *Pinus koraiensis* and 1:53 in *Larix kaempferi*. Consequently, it was considered that the results obtained might provide useful information for evaluating juvenile and adult wood as well as identifying both species.

Keywords: Uniseriate ray, fusiform ray, *Larix kaempferi, Pinus koraiensis,* ray height, ray number.

INTRODUCTION

Cell dimensions vary in a stem, and their patterns are important factors for indexing wood quality. Many studies on indexing the wood quality of softwoods (for example, Seth 1981; Malan 1994; Berggvist et al 1997; Herman et al 1998; Anagnost et al 2002; Rlee and Kim 2005) have focused on the variation of tracheid characteristics related to age, but fewer studies have been carried out on the variation of rays within a stem.

In softwoods, rays usually exist in two types as uniseriate and fusiform, and the volume ranges from 5 – 9% (Panshin and Zeeuw 1980). Fujiwara and Nakayama (1978) examined the distribution and total number of ray cells in a stem of *Cryptomeria japonica*. They reported that the rays varied with age and tree height. Immamura (1978) investigated the ray tissues of normal and abnormal wood in *Cryptomeria japonica* and reported that the number of rays in abnormal wood was greater. Lev-Yadun (1998) examined the radial variation of ray numbers and height in *Pinus halepensis* and *Pinus pinea* and found a gradual increase in height and a decrease in ray number per unit area from the pith outward. Some researchers (Kawamura 1979, 1984; Fujiwara 1992; Rahman et al 2005) explained the influence of rays on some physical properties. Kawamura (1979, 1984) examined anisotropic shrinkage and Young's modulus related to broad rays. Fujiwara (1992) also

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examined the relation between the variation of dimensions of ray cells and the basic density of Japanese hardwoods, concluding that basic density was closely related to the ray cell wall materials. Rahman et al (2005) also studied the variations in volume and dimensions of rays and their effect on wood properties of teak (*Tectona grandis* L.).

In Korea, *Pinus koraiensis* and *Larix kaempferi* are major commercial softwoods (Kim and Mishiro 1998; Rlee and Kim 2005; Kim and Kwon 2006); therefore, more information is needed on their characteristics. Within a stem of each species, we investigated the radial variation in height and number of uniseriate and fusiform rays.

MATERIALS AND METHODS

One 45-yr-old planted tree of *Pinus koraiensis* S. et Z. [height 16.2 m, diameter at breast height (DBH) 28.5 cm] and one 52-yr-old planted tree of *Larix kaempferi* Carr. (height 21.2 m, DBH 35.0 cm) grown in the research forest of Kangwon National University in Korea (about 300 m above sea level) were used for the experiments. Discs were taken at breast height (1.2 m above ground level) and microtome sections of 10 – 20 μm thick on the cross-section and tangential section were prepared from pith to bark. The sections were stained with safranin solution and mounted in Canada balsam on microscopic slides. Measurements were performed with a light microscope and an image analysis system.

Ray height was expressed in the number of cells in tangential–longitudinal (T-L) sections. To estimate average ray height in each annual ring, 50 uniseriate and 25 fusiform rays were measured at a magnification of 400×. The numbers of uniseriate and fusiform rays were counted in 20 0.5 × 0.5 mm microscopic screens in T-L sections of each annual ring. Data were analyzed with Excel 2003 (Microsoft, Inc., Redmond, WA).

RESULTS AND DISCUSSION

Uniseriate Ray Height

Figure 1 shows the representative micrographs of uniseriate and fusiform rays in the T-L sections near the pith and bark of both species. The range and average of the uniseriate ray heights are summarized in Table 1. Ray height was 2 – 23+ cells in *Pinus koraiensis* and 2 – 44 + in *Larix kaempferi* with mean values of 6.4 + cells in *Pinus koraiensis* and 9.1+ in *Larix kaempferi*. As shown in Fig 1, the distribution of ray height was noticeably broad. It is clear that the range of uniseriate ray height in *Larix*

Table 1. *Ray height and ray number of* Pinus koraiensis *and* Larix kaempferi.

Ray type	*Pinus koraiensis* Earlywood	*Pinus koraiensis* Latewood	*Pinus koraiensis* Level of significance	*Larix kaempferi* Earlywood	*Larix kaempferi* Latewood	*Larix kaempferi* Level of significance	Level of significance (P/L)
Ray height (cells)							
UR	6.5 ± 0.04 (2 – 23)	6.1 ± 0.04 (2 – 21)	**	9.1 ± 0.06 (2 – 37)	8.9 ± 0.05 (2 – 44)	ns	***
FR	20.5 ± 0.15 (6 – 44)	20.0 ± 0.14 (7 – 44)	ns	20.7 ± 0.14 (7 – 43)	20.5 ± 0.13 (8 – 43)	ns	ns
Ray number[a]							
UR	6.4 ± 0.05 (3 – 16)	6.6 ± 0.04 (3 – 12)	ns	9.4 ± 0.06 (5 – 17)	9.6 ± 0.05 (5 – 16)	ns	***
FR/UR	1:46	1:42		1:57	1:49		
	1:45			1:53			

[a] In 05 × 0.5 mm area.
** Significant difference at the 0.01 confidence level.
*** Significant difference at the 0.001 confidence level.
Numbers in parentheses denote the range of ray height or ray number.
UR: uniseriate ray; FR: fusiform ray; P/L: *Pinus/Larix;* ns = no significant difference at the 0.1 confidence level.

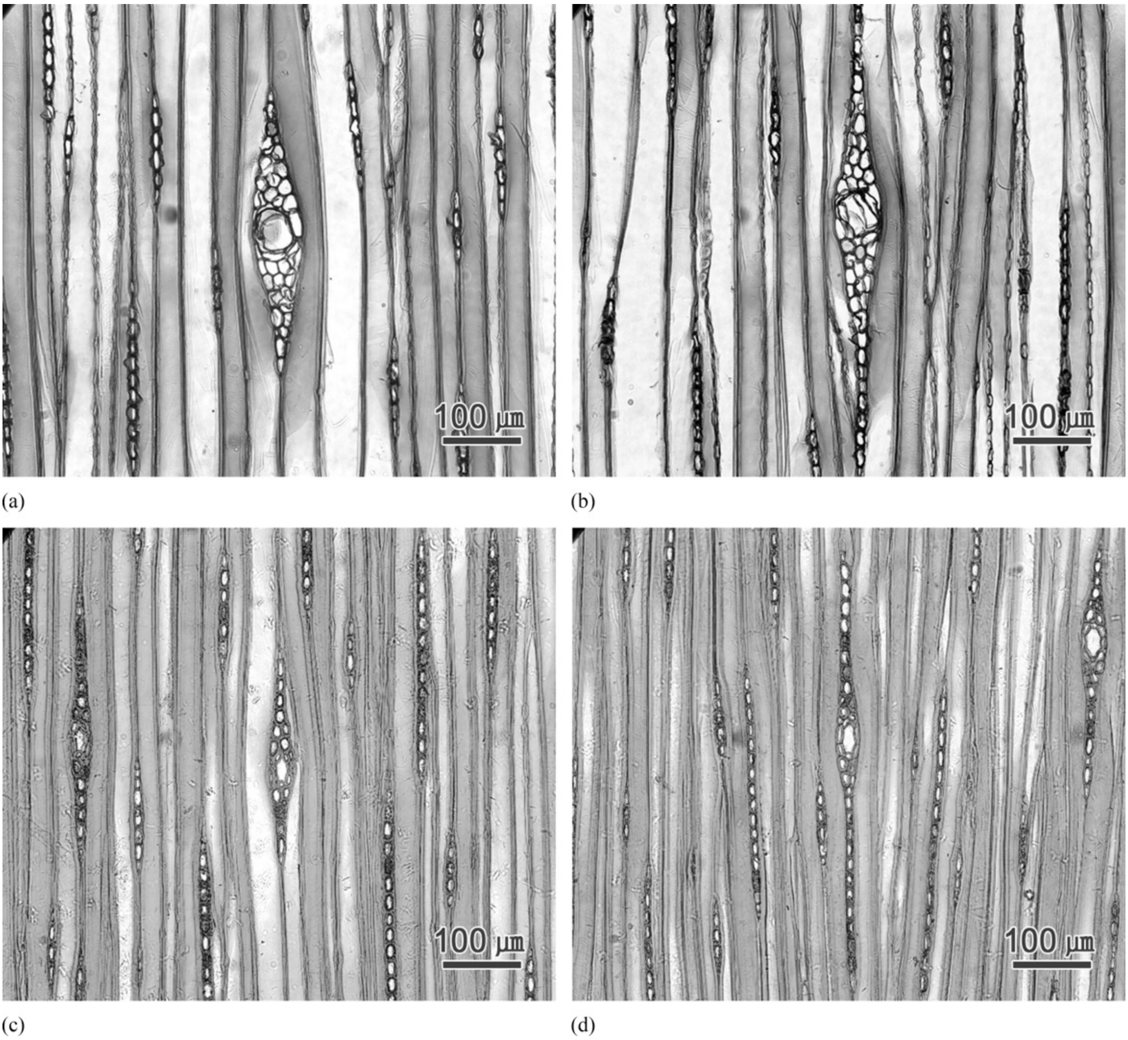

Figure 1. Representative optical micrographs of the tangential sections in *Pinus koraiensis* (a–b) and *Larix kaempferi* (c–d). (a, c) Near the pith; (b, d) near the bark.

kaempferi was larger than that of *Pinus koraiensis,* and the uniseriate ray height in *Larix kaempferi* was greater than that of *Pinus koraiensis*. Panshin and Zeeuw (1980) explained that the range of ray heights and the maximum heights were different among various softwoods.

The radial variation of uniseriate ray height in both species is shown in Fig 2. The frequencies of ray height showed a gradual change with age. The height of uniseriate rays in both species, therefore, was smallest near the pith, increased to ring 10 – 20, and then was relatively constant toward the bark. The variation of *Pinus koraiensis* was clearer than that of *Larix kaempferi*.

Figure 3 shows the variation of uniseriate ray height in earlywood and latewood of *Pinus koraiensis.* The height of uniseriate rays was less than five cells near the pith, increased to ring 10 – 20, and then became constant with 6 – 8 cells. This is most probably because the portion from the pith to ring 10 – 20 is in the juvenile stage and has not completed its full increase in ray height. Also, it has been shown that, in mature wood, the height of uniseriate rays in the earlywood is somewhat greater than in latewood. For the radial variation of ray height, Lev-Yadun (1998) examined the relationship between growth ring width and ray number and height in earlywood of *Pinus halepensis* and *Pinus pinea*. He reported that ray height was less than four cells near the pith, increased with age, and had no general direct relationship with growth ring width. Giraud (1977) reported that the ray height increased with distance from the pith in a study of *Entandrophragma utile* (Meliaceae). Rahman et al (2005) also found that ray height in teak became constant at about ring 10 from the pith.

Fusiform Ray Height

Fusiform rays were observed in T-L sections of both species, having radial resin canals surrounded by epithelial cells (Fig 1). Fusiform rays occur in four genera of Pinaceae that have normal resin canals such as *Pinus*, *Picea*, *Larix*, and *Pseudotsuga* (Panshin and Zeeuw 1980). Fusiform rays are less than 1% of the volume in softwoods (Petric and Scukanec 1973).

The range and average of the fusiform ray height in both species are given in Table 1. Fusiform ray height ranged from 6 – 44+ cells in *Pinus koraiensis* and 7 – 43+ cells in *Larix kaempferi* with an average of about 20+ for both species.

The variation of fusiform ray height with age in both species is shown in Fig 4. It shows that the height of fusiform rays in both species was

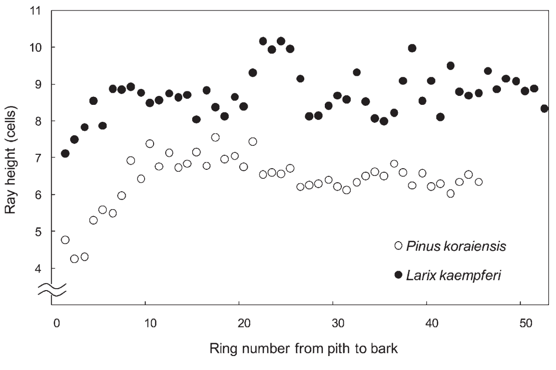

Figure 2. Variation of uniseriate ray height from pith to bark in *Pinus koraiensis* and *Larix kaempferi*.

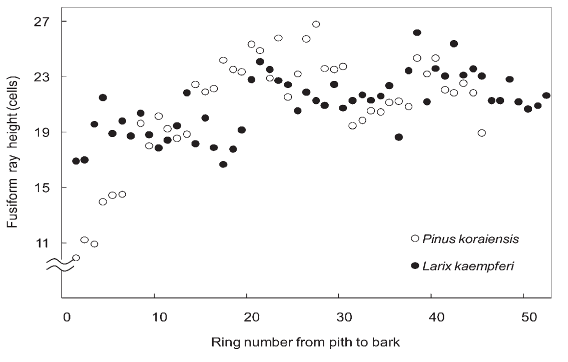

Figure 4. Variation of fusiform ray height from pith to bark in *Pinus koraiensis* and *Larix kaempferi*.

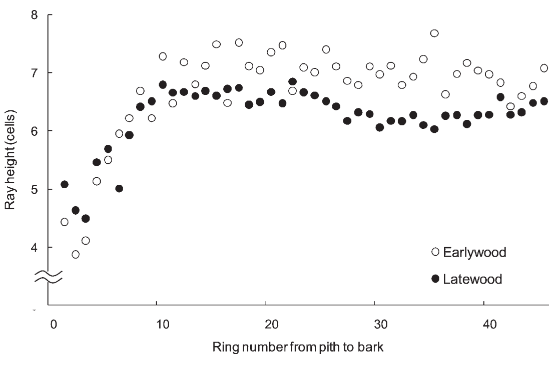

Figure 3. Variation of uniseriate ray height from pith to bark in *Pinus koraiensis*.

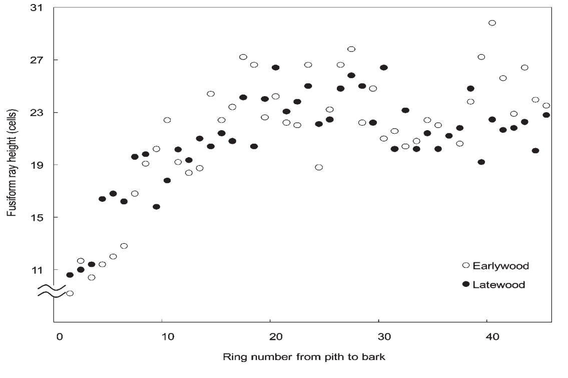

Figure 5. Variation of fusiform ray height from pith to bark in *Pinus koraiensis*.

lowest near the pith, increased to rings 15 – 20, and then had a fluctuating pattern in 19 – 26 cells toward the bark. The tendency of variation in *Pinus koraiensis* was clearer than that in *Larix kaempferi* as shown in Figs 4 and 5.

The fusiform ray height of *Pinus koraiensis* was about 11 cells near the pith and showed a steep increase to about 20 – 25 cells from ring 15. In *Larix kaempferi*, the fusiform ray height was about 17 cells near the pith and increased gradually to about ring 20. Representative micrographs of fusiform rays near the pith and bark of both species are shown in Fig 1.

Comparison of the Heights of Fusiform and Uniseriate Rays

As mentioned previously, the height of fusiform rays was greater than that of uniseriate rays. The ratio was 3.2 in *Pinus koraiensis* and 2.3 in *Larix kaempferi*. Therefore, the difference of the height between uniseriate rays and fusiform rays in *Pinus koraiensis* was greater than that in *Larix kaempferi*. It is considered that the ratio of the height of fusiform rays to uniseriate rays might be useful information to identify the species.

Ray Numbers

The number of rays in T-L sections is summarized in Table 1. They ranged 3 – 16 (average 6.50) in *Pinus koraiensis* and 5 – 17 (average 9.50) in *Larix kaempferi*. The number of uniseriate rays in *Pinus koraiensis* was fewer than that in *Larix kaempferi*.

The radial variation of the number of uniseriate rays of both species is shown in Fig 6. The frequencies of ray numbers changed with age. From the patterns, it is clear that in both species, the ray number was greatest in the pith zone, decreased gradually to ring 1 – 20, and followed a constant pattern toward the bark.

Figure 7 shows the variation of uniseriate ray number in the earlywood and latewood of *Pinus koraiensis*. The number of uniseriate rays was greatest near the pith, decreased abruptly to about ring 10, and then decreased gradually to about ring 20. Interestingly, in the pith zone, uniseriate rays were more numerous in earlywood than in latewood and decreased irregularly to about ring 10.

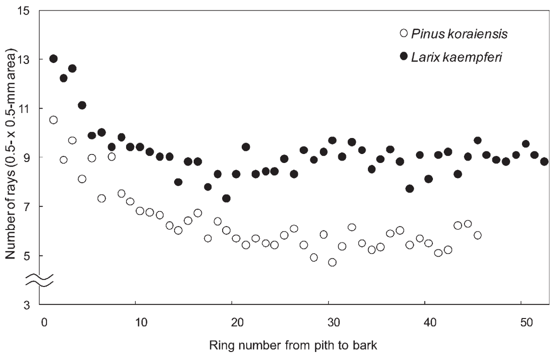

Figure 6. Variation of ray numbers from pith to bark in *Pinus koraiensis* and *Larix kaempferi*.

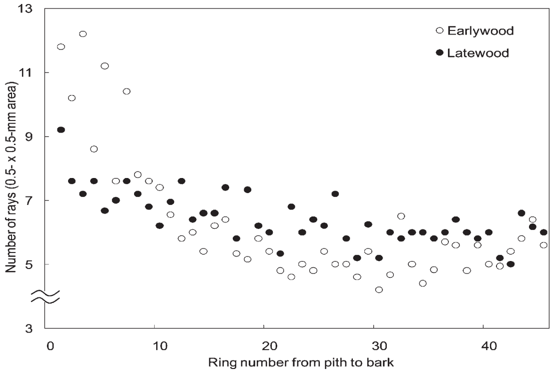

Figure 7. Variation of ray numbers from pith to bark in *Pinus koraiensis*.

In this study, the tendency of radial variation of ray numbers in a stem showed good agreement with the results of Fujiwara and Nakayama (1978), Lev-Yadun (1998), and Rahman et al (2005). Lev-Yadun (1998) examined the variation of ray numbers within a stem of *Pinus halepensis* and *Pinus pinea* and found a gradual decrease in rays from the pith outward. He reported that the ray number was greatest near the pith, which was 70 in a 0.5×0.5 mm area, and then decreased to about 40 in the outer rings. Fujiwara and Nakayama (1978) reported that the number of rays in a stem of

Cryptomeria japonica were greatest near the pith and then decreased rapidly to ring 10 and became constant. Immamura (1978) examined the frequency of ray numbers between normal and abnormal wood of *Cryptomeria japonica* and showed that the number of rays in normal wood was smaller than that in abnormal wood. Rahman et al (2005) also showed that ray number in teak became constant at about ring 10 from the pith.

Comparison of the Number of Fusiform to Uniseriate Rays

The ratio of the number of fusiform to uniseriate rays is presented in Table 1. The ratio ranged from a minimum of 1:45 in *Pinus koraiensis* and from 1:53 in *Larix kaempferi*. Therefore, fusiform rays can be found more easily in *Pinus koraiensis* as compared with *Larix kaempferi*.

Panshin and Zeeuw (1980) reported that the ratio of fusiform to uniseriate rays ranged from 1:25 in *Pseudotsuga*, 1:40 – 45 in *Picea*, and 1:60+ in *Larix*. It is also possible that the ratio of the number of fusiform to uniseriate rays could be used for identifying species.

CONCLUSIONS

The height and number of uniseriate and fusiform rays within a stem of *Pinus koraiensis* and *Larix kaempferi* changed with age. The height of uniseriate and fusiform rays was lowest near the pith, increased with age to about ring 10 – 20, and then became constant toward the bark. The average height of uniseriate rays in *Pinus koraiensis* was less than that in *Larix kaempferi*. There was no significant difference in the fusiform ray height between the species. The height of fusiform rays was greater than that of uniseriate rays: about 3.2 times in *Pinus koraiensis* and 2.3 times in *Larix kaempferi*. The number of uniseriate rays was at a maximum near the pith, decreased to about ring 10 – 20, and was nearly constant for the following rings. The number of uniseriate and fusiform rays in *Pinus koraiensis* were fewer than that of *Larix kaempferi*. The ratio of number of fusiform rays to uniseriate rays was 1:45 in *Pinus koraiensis* and 1:53 in *Larix kaempferi*.

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