Variation in the Tracheid Dimensions of Scots Pine (*Pinus sylvestris* L.) and Lodgepole Pine (*Pinus contorta* Dougl. var. *latifolia* Engelm) Trees Grown in Latvia

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Abstract

Wood anatomical properties of 27-year-old Scots pine (*Pinus sylvestris* L.) (n = 32) and lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm) (n = 19) sample trees grown in Latvia were investigated. Stem diameters, growth rings, and dimensions of 150 earlywood (EW) and 150 latewood (LW) tracheids per sample tree were measured. Lodgepole pine demonstrated significantly ($P < 0.05$) larger stem diameters (21%), wider growth rings (8%), and higher LW content (15%) than Scots pine. Tracheid dimensions such as lumen area and diameter, and mean tracheid diameter of EW were significantly higher in Scots pine, while tracheid wall thickness was higher in lodgepole pine. Lumen area and diameter of LW were significantly higher in lodgepole pine. Scots pine had tracheids with larger average lumen area (10%) and diameter (5%), radial diameter (8%) and tracheid diameter (3%), while lodgepole pine had thicker tracheid walls (6%) and longer fibres (10%). Tracheid wall thickness and average diameter of EW and LW cells increased from pith to cambium in both pine species. The number of tracheids was assumed to play more important role than tracheid size in the increment of the stems and growth rings of lodgepole pine.

Key words: Wood anatomy; Tracheid dimensions; Earlywood (EW); Latewood (LW); Lodgepole pine; Scots pine

Introduction

Wood fibre dimensions belong to the important pulp property parameters and determine, for example, the suitability of the pulp for the production of specific grades of paper or insulation boards. The dimensions of the fibres change to some extent during chemical delignification; however, fibre characteristics reflect the properties of the raw material (Reme and Helle 2002). The most important fibre dimensions are length, width, lumen diameter, and wall thickness. Tracheid length correlates with the tensile and tear strength of paper (Jackson 1988). Cell wall thickness and tracheid radial and tangential diameter affect paper properties such as light scattering, and tear and tensile indices (Havimo et al. 2009).

Differences in tracheid length, diameter, and cell wall thickness reflect the changes occurring in the cambium. The differentiation of tracheids implies their maturing process from birth at the cambial zone to death after the secondary wall formation, by which both water-conducting functions and mechanical properties are given to the tracheid (Fujita and Harada 2001, Schuetz et al. 2013). In softwood, consisting mainly of tracheids (approximately 90%), latewood (LW) can be distinguished from earlywood (EW) by smaller radial dimensions and thicker cell walls. EW usually has a lower density as compared to the LW and it is found that the wood properties are affected by EW-LW ratio (Pallardy 2008).

Wood traits are influenced by genetic properties (Kilpeläinen et al. 2010), environmental conditions, forest structure and silvicultural management (Ikonen et al. 2008). In its turn, the wood traits affect the suitability of wood as a raw material for mechanical wood processing and the quality of the end-products. However, it is probably difficult to achieve simultaneous desirable changes in growth, fibre and wood traits (better growth, thinner but longer fibres and higher density) due to the numerous negative genetic correlations, especially between growth traits and wood density (Fries 2012). Pronounced effect of such intensive stand treatments as thinning, fertilization or combination of both have been proven in numerous studies. For example, Cao et al. (2008) found that increasing intensity of thinning leads to lower mean wood density, tracheid length, and latewood proportion in harvested wood. Mäkinen et al. (2002) noted that fertilization resulted in reduced fibre length and cell wall thickness, but increased the fibre and lumen diameter in rings of the same age. The effect of fertilization and irrigation on the cell cross-sectional dimensions from pith to bark was studied also by Lundgren (2004). Ring width in Norway spruce (*Picea abies*) was positively influenced by treatment, and fertilization produced wood with thinner cell walls and somewhat larger cells. Analysis of material from large set of Scots pine (*Pinus sylvestris*) trials in Finland revealed, that increased increment rate, caused by any of different treatments or environmental conditions, resulted in similar types of changes in the wood and tracheid properties (Mäkinen and Hynynen 2012). The impact of tree-growing conditions can be effectively characterized by radial annual growth rate (Zhu et al. 2007a, b). It was found (Zhu et al. 2007b) that a tree plantation with a higher density (growth suppression) produced wood with less distinction in wood density, tracheid radial diameter, and wall thickness between EW and LW. The authors supposed that the uniformity can be beneficial for mechanical pulp production, because less distinction between EW and LW reduces the degree of cutting damage to EW fibres. To control the variation in tracheid cross-sectional dimensions, Havimo (2010) determined that the fractionation of delignified Scots pine tracheids into EW and LW classes had the highest theoretical efficiency and yielded the lowest variances in the raw material.

In Nordic countries, the introduction of lodgepole pine (*Pinus contorta*), a native species of North America's West coast from Alaska to North California, has been carried out since the 1950's. It is established that, during a 25-year period, lodgepole pine produces by 36% more wood than Scots pine (Elfving et al. 2001). Currently, there is a growing interest in the establishment of plantations of lodgepole pine. The experience of silvicultural practices of this species in Swedish conditions is described along with the initial progress in tree breeding (Fries 1986) although not much data on wood and fibre characteristics are available in the literature. The establishment of lodgepole pine provenance trials in Latvia, using the material from Canada and also selections from trees growing in Sweden, has been carried out since the 1980's. Comprehensive analysis of the trials has been started recently (Jansons et al. 2012), indicating a similar superiority in productivity in comparison to Scots pine as it was found also in Sweden.

A previous study (Sable et al. 2012) on 27-year-old lodgepole pines and Scots pines was performed to compare physical, chemical and kraft pulping properties. Results demonstrated that the lodgepole pine wood had higher density (9%), lower lignin (2.6%) and content of extractives (11.5%) than Scots pine. Besides, the lodgepole pine pulp was obtained at a higher yield by ~1% and possessed slightly higher strength properties concerning burst index. The present study aimed to compare wood anatomical properties of lodgepole pine and native Scots pine in hemi boreal zone, south from the boreal region of Sweden, where lodgepole pine is well studied and cultivated on a commercial scale. Results of the study would provide important part of the understanding of future prospect to use this species on wider scale in Latvia and region with similar soil and climatic conditions. Therefore it is crucial to gain understanding not only about differences among both pine species, that share similar environmental requirements, but also study provenance level differences of the introduced lodgepole pine.

To characterize both pine species and determine the most suitable end use of lodgepole pine wood, growth rings, tracheid dimensions in EW and LW as well as tracheid dimensions from pith towards cambium were examined.

Materials and methods

Sample trees

27-year-old sample trees were collected during 2009 and 2010 at an experimental site in the central part of Latvia (latitude 56°41', longitude 24°27'). Plant production for the experiments was started in 1983; planting was carried out in 1985 on dry, sandy soil (*Myrtillosa* forest type according to classification developed by Bušs (1976) and used in Latvia). Initial spacing was 1 x 2 m; no thinning had been carried out prior to the collection of sample trees. Altogether 32 Scots pine (*Pinus sylvestris* L.) sample trees, representing the progenies of 4 seed orchards, marked as KVE (Kvepene), IST (Istra), RAI (Raiskums) and ZVI (Zvirgzde), were selected. On average, eight sample trees from each seed orchard were chosen. Lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm) was represented by 19 sample trees from 3 provenances in Canada, British Columbia: Pink Mountain (latitude 57°00', longitude 122°15'-45') (marked as No. 1, 2, 4), Fort Nelson (latitude 58°38', longitude122°41') (marked as No. 7, 9), and Summit Lake (latitude 54°24', longitude 122°37') (marked as No. 13, 15). On average, six sample trees from each provenance were selected. Dominant and co-dominant trees were randomly selected from the most represented diameter group of particular provenance.

Sample discs

2 cm thick discs were cut off at a 1.3 m height of all sample trees and treated by No. 150 sandpaper. The discs were dried at room temperature and scanned by "Canon 4400" using calibrated "Leica ImagePro plus 6.0" software. Stem diameter, annual ring width, and LW content were determined.

Tracheid micromorphology

2 cm wide radial strip was cut off from each sample disc in the direction from pith to bark. The strip with an average of 23 annual rings was divided into three equal blocks. The wood blocks were saturated with distilled water prior to sectioning. Thin cross sections (15–20 µm) were obtained from each block and captured with a video camera "Leica DFC490" attached to a light microscope "Leica DMLB". Cross-sectional dimensions of individual tracheids were measured by calibrated image analysis software "Image-Pro Plus 6.3" (Media Cybernetics, Inc.). Under measuring conditions at 400x magnification, the spatial calibration system corresponded to 0.1 µm/ pixel.

Lumen area, lumen mean diameter, tracheid radial and tangential diameters as well as cell wall thickness (radial and tangential/ 2) were measured in 150 LW and 150 EW cells of each radial strip (Figure 1). Only characteristic EW and LW cells near the pronounced border between both growth rings were randomly selected. Totally, 300 tracheids were measured per each sample tree.

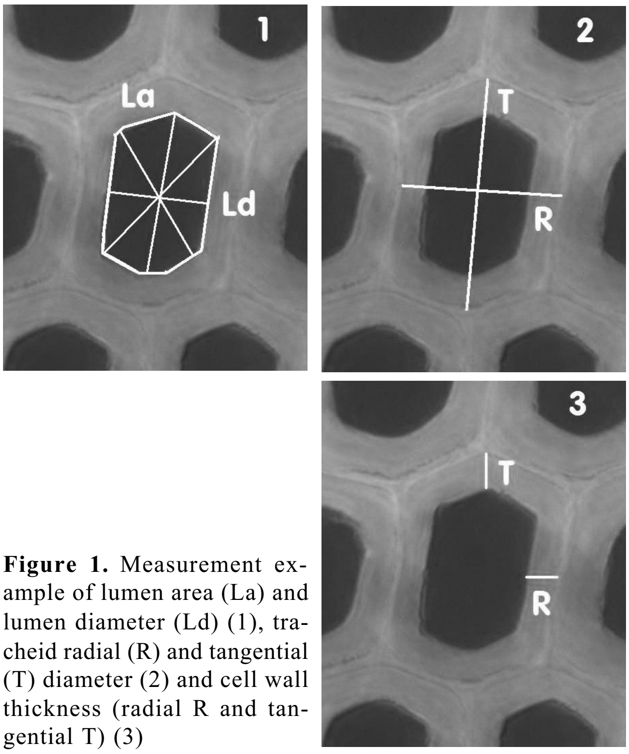

Figure 1. Measurement example of lumen area (La) and lumen diameter (Ld) (1), tracheid radial (R) and tangential (T) diameter (2) and cell wall thickness (radial R and tangential T) (3)

To obtain results of average tracheid dimensions in each sample disc, the average arithmetical values of three blocks were re-calculated as average weighted values, by taking into account the specific weight of each block in a disc and its influence to the whole tree properties (Figure 2). Considering the wood disc shape and the location of each block in it, the following equations were used:

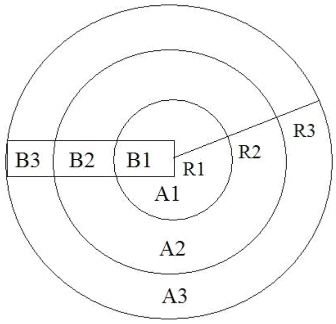

Figure 2. Location of wood blocks in a sample disc. A1, A2, A3 – area of circle, R1, R2, R3 – radius of circle, B1, B2, B3 – blocks

$$\begin{cases} A_3 = \pi(R_1+R_2+R_3)^2 - \pi(R_1+R_2)^2 \\ A_2 = \pi(R_1+R_2)^2 - \pi R_1^{\,2} \\ A_1 = \pi R_1^{\,2} \\ \pi(R_1+R_2+R_3)^2 = 100\% \end{cases}$$

$$\begin{cases} 9\pi R^2 = 100\% \\ A_3 = \pi 9R^2 - \pi 4R^2 = 5\pi R^2 \\ A_2 = 4\pi R^2 - \pi R^2 = 3\pi R^2 \\ A_1 = \pi R^2 \end{cases}$$

$$\begin{cases} A_1 = \frac{1}{9}\times 100\% = 11{,}11\% \\ A_2 = \frac{1}{3}\times 100\% = 33{,}33\% \\ A_3 = \frac{5}{9}\times 100\% = 55{,}56\% \end{cases}$$

$$\bar{x} = \frac{11\times B_1 + 33\times B_2 + 56\times B_3}{100} \qquad (1)$$

where $\bar{x}$ = average weighted value, A_1, A_2, A_3 = area of circle, R_1, R_2, R_3 = radius of circle, š – constant 3.14..., B_1, B_2, B_3 = blocks from areas A_1, A_2, A_3. The LW content in calculations was taken into account to obtain the final average weighted values:

$$\frac{(TdEW \times (100 - LW\%)) + (TdLW \times LW\%)}{100} \qquad (2)$$

where TdEW and TdLW = average weighted value of specific EW or LW tracheid dimension (lumen area, lumen mean diameter, tracheid radial and tangential diameters, cell wall thickness) calculated in equation (1), LW% = latewood percentage in a sample disc.

Tracheid dimensions towards cambium were measured in the growth rings 1-23 of 27-year-old Scots pine and lodgepole pine stems. The wood blocks B_1, B_2, B_3 contained growth rings 1-8, 9-16 and 17-23, respectively.

Kraft pulping

Delignified fibres were obtained by the Kraft pulping procedure in a 2-L laboratory digester at 170 °C; white liquor contained 57.4 g/L active alkali as NaOH, sulfidity was 29.8%, and the liquor to wood ratio was 4.5:1. After the cooking procedure, delignified fibres were washed with water and treated in a standard PTA disintegrator for 30 000 revolutions, then filtered and collected on a Büchner funnel. Pulp fibre samples were dried overnight at 50 °C, and the moisture content was measured to determine fibre weight for dimensions measurement. Accurately weighed samples were then re-suspended in 20 mL of de-ionized distilled water, and the length of about 10 000 - 20 000 fibres from each tree was measured using Lorentzen & Wettre "Fiber-Tester".

Statistical analysis

Statistical software (SPSS 17.0) was used for estimating descriptive statistics. Analysis of variance (ANOVA) was used to detect the influence of the studied factors such as tree species, provenance, EW or LW, and the distance from the pith on tracheid parameters. The level of significance *p* d” 0.05 was applied in all cases.

Results

Stems diameters and annual rings

Figure 3 shows that lodgepole pine grew faster than Scots pine and reached larger final diameter of the stem even within the same growing conditions and age. The average diameter of lodgepole pine stems at 1.3 m height was 130 mm, while that of Scots pine was only 107 mm ($p < 0.05$). It reflects the general results of analysis of productivity differences among pine species across a number of sites.

The average width of annual rings was significantly larger in lodgepole pine as compared with that in Scots pine, 2.98 mm and 2.76 mm, respectively (Figure 4). The width of annual rings in lodgepole pine was more variable than that in Scots pine ranging from 2.20 to 4.04 mm. The correlation between stem diameter and annual ring width in lodgepole pine was stronger ($r > 0.8$; $p < 0.05$) than in Scots pine ($r < 0.8$; $p < 0.05$). LW content in lodgepole pine was higher (44.9%) than in Scots pine (39.2%).

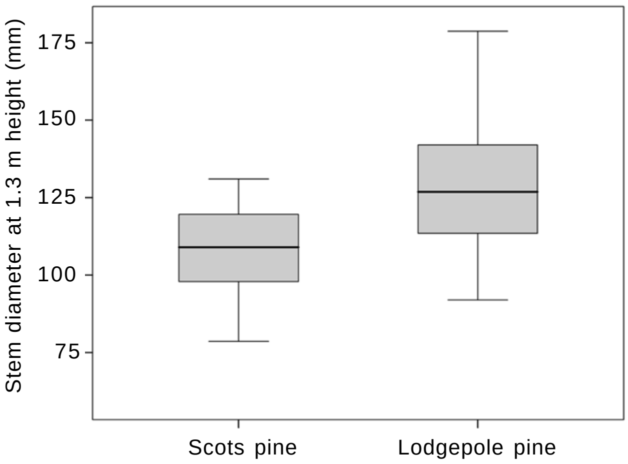

Figure 3. Stem diameter values of 27-year-old Scots pine and lodgepole pine trees

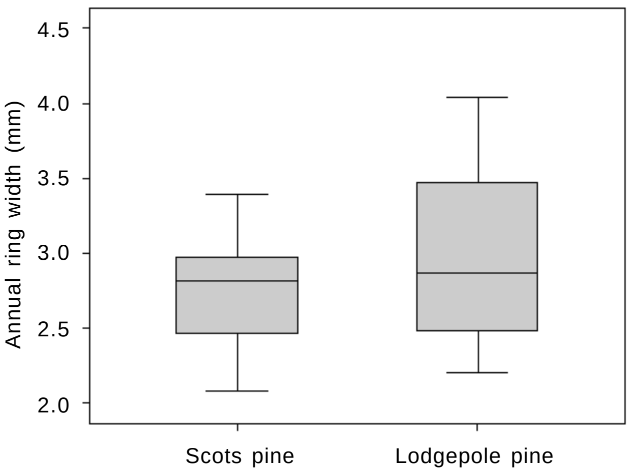

Figure 4. Width of annual rings of 27-year-old Scots pine and lodgepole pine trees

Tracheid dimensions

Cross-sectional dimensions of EW and LW tracheids are given in Table 1.

All measured EW parameters (lumen area and diameter, tracheid diameter and cell wall thickness) significantly differed ($p < 0.05$) between Scots pine and lodgepole pine species. Tracheid dimensions of EW were higher for Scots pine with the exception of the cell wall thickness and tangential diameter of tracheid, which were higher in lodgepole pine. Tracheid parameters of LW demonstrated different trends in both species. Lumen area and diameter as well as tangential diameter of LW tracheids were significantly higher in lodgepole pine ($p < 0.05$), while mean tracheid diameter and wall thickness did not vary between both species ($p > 0.05$). The fibre length varied between Scots pine and lodgepole pine trees, 2.1 mm and 2.3 mm, respectively (Table 1).

Table 1. Average tracheid dimensions of 27-years old Scots pine (*P. sylvestris*) (n = 32) and lodgepole pine (*P. contorta*) (n = 19) trees. Measurments of 150 EW and 150 LW tracheids are presented for each sample tree. Average (EW and LW) values represent measurements of 300 tracheids per tree. EW, earlywood; LW, latewood; SD, standard deviation; *P*-value, statistical significance

Structural characteristics	Wood species	EW	SD	*P*–value	LW	SD	*P*–value	Average (EW and LW)	SD	*P*–value
Lumen area (μm^2)	*P. sylvestris*	870.4	101.0	0.001	215.5	34.3	0.001	613.4	79.5	0.000
	P. contorta	816.6	94.7		237.2	41.8		555.3	65.3	
Lumen diameter (µm)	*P. sylvestris*	32.6	1.9	0.002	16.0	1.4	0.003	26.1	1.8	0.000
	P. contorta	31.6	1.9		16.8	1.5		24.9	1.5	
Tangential diameter of the tracheid (µm)	*P. sylvestris*	34.7	1.6	0.000	29.3	1.8	0.022	32.6	1.4	0.033
	P. contorta	35.8	1.9		30.5	3.5		33.4	2.6	
Radial diameter of the tracheid (µm)	*P. sylvestris*	37.7	2.8	0.000	24.7	1.3	0.155	32.6	2.2	0.000
	P. contorta	35.0	2.7		24.3	1.8		30.1	1.8	
Mean diameter of the tracheid (µm)	*P. sylvestris*	36.2	1.8	0.007	27.0	1.2	0.183	32.6	1.6	0.005
	P. contorta	35.4	1.7		27.4	2.3		31.7	1.9	
Thickness of the cell wall (µm)	*P. sylvestris*	2.4	0.3	0.001	5.6	0.7	0.110	3.6	0.4	0.025
	P. contorta	2.6	0.3		5.4	0.8		3.8	0.4	
Fibre length (mm)	*P. sylvestris*	-	-	-	-	-	-	2.1	0.2	0.000
	P. contorta	-	-	-	-	-	-	2.3	0.2	

Significant differences were observed also in tracheid average dimensions (EW and LW) for both species (Table 1). Scots pine had tracheids with larger average lumen area (10%) and diameter (5%), radial diameter (8%) and tracheid diameter (3%) than lodgepole pine. In its turn, lodgepole pine tracheids possessed thicker cell walls (6%) and longer fibres (10%).

The correlation between fibre length and cell wall thickness in lodgepole pine and Scots pine was weak (r < -0.5 and 0.5) and not significant ($P > 0.05$). The correlation between the tracheid diameter and wall thickness in lodgepole pine stems was moderate ($r < 0.8$) and significant ($P < 0.05$), while the same tracheid parameters in Scots pine correlated weakly and were insignificant.

Distance from pith to cambium

Lumen area and lumen diameter in Scots pine and lodgepole pine EW significantly increased ($P < 0.05$) from pith to cambium (Figures 5, 6). The lumen area and diameter of LW in Scots pine tended to decrease while lodgepole pine lumens increased towards cambium.

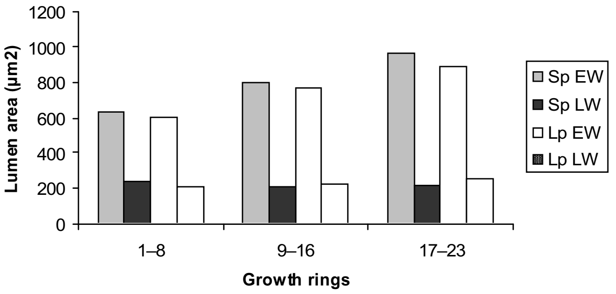

Figure 5. Lumen area vs. growth rings in 27-year-old Scots pine (Sp) and lodgepole pine (Lp) EW and LW from pith to cambium

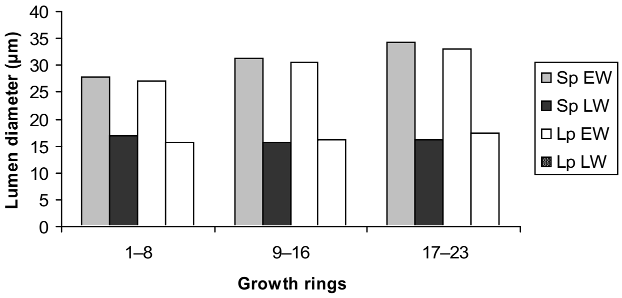

Figure 6. Lumen diameter vs. growth rings in 27-year-old Scots pine (Sp) and lodgepole pine (Lp) EW and LW from pith to cambium

Cell wall thickness increased towards cambium both in the EW and LW of Scots pine and lodgepole pine (Figure 7).

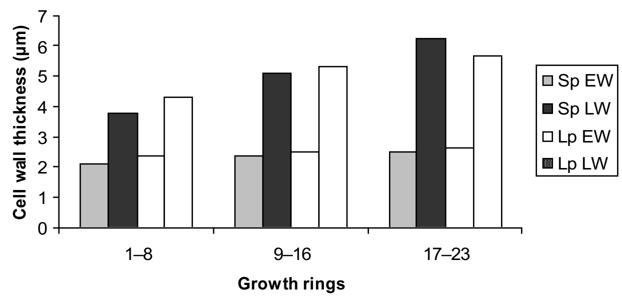

Figure 7. Cell wall thickness vs. growth rings in 27-year-old Scots pine (Sp) and lodgepole pine (Lp) EW and LW from pith to cambium

The most pronounced increment ($p < 0.05$) of cell wall thickness was observed in LW tracheids of Scots pine.

The diameter of EW and LW tracheids significantly increased towards cambium in Scots pine and lodgepole pines trees (Figure 8).

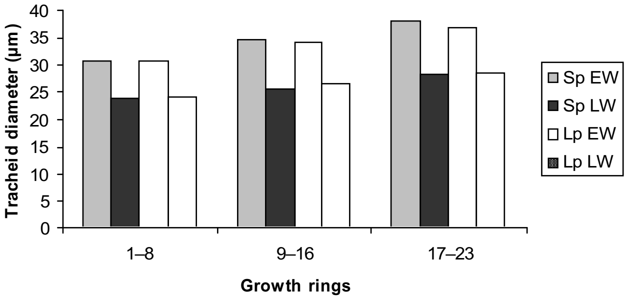

Figure 8. Tracheid diameter vs. growth rings in 27-year-old Scots pine (Sp) and lodgepole pine (Lp) EW and LW from pith to cambium

Relationship between provenances and tracheid parameters

The average results of EW and LW tracheid parameters in Scots pine and lodgepole pine are shown in Table 2.

Table 2. Average tracheid dimensions (earlywood and latewood) of Scots pine and lodgepole pine provenances. SD, standard deviation

Provenance	Abbreviation and number of trees (n)	Lumen area (µm^2)	SD	Lumen diameter (µm)	SD	Mean diameter of the tracheid (µm)	SD	Cell wall thickness (µm)	SD	Fibre length (mm)	SD
Scots pine:											
Istra	IST (9)	639.7	80.3	26.7	1.8	32.7	1.3	3.4	0.4	2.1	0.1
Kvepene	KVE (8)	602.7	66.5	25.9	1.5	32.5	1.4	3.7	0.4	2.0	0.2
Raiskums	RAI (6)	660.1	78.9	27.0	1.4	33.7	2.1	3.9	0.5	2.3	0.2
Zvirgzde	ZVI (9)	565.5	62.6	25.0	1.7	31.8	1.0	3.8	0.3	2.1	0.2
Lodgepole pine:											
Pink Mountain	1, 2, 4 (6)	555.4	73.0	24.8	1.5	31.5	1.2	3.8	0.2	2.1	0.2
Fort Nelson	7, 9 (5)	562.8	74.2	25.2	1.8	31.2	1.8	3.4	0.2	2.3	0.1
Summit Lake	13, 15 (8)	550.6	55.2	24.8	1.4	32.2	2.2	4.1	0.5	2.4	0.1

Only significant differences ($P < 0.05$) among the provenances are described further. The largest lumen area and lumen diameter were observed in the Scots pine provenances IST and RAI. The Scots pine provenance RAI had the largest diameter of tracheids (33.7 µm). The thickest cell walls were observed in the Summit Lake provenance (4.1 µm), while IST and Fort Nelson demonstrated the lowest values in this parameter, i.e. 3.4 µm. The longest fibres (2.4 mm) were displayed by the Summit Lake provenance, but the shortest ones by the KVE provenance.

Discussion

It is evident that a larger diameter of lodgepole pine stems was affected by the formation of wider annual rings (Figures 3, 4). Consequently, the LW content was higher by 15% in lodgepole pine stems. Ivkovich et al. (2002) proposed that the differences in the heritability of tracheid characteristics that determine ring width may come from different regulatory processes. Cell number production can be strongly influenced by favourable environmental conditions, but cell size is strongly controlled by hormonal activity and phenology, while cell wall thickness is assumed to depend mostly on the availability of photosynthates.

In our study, both pine species were grown at the same experimental site and exposed to equal environmental conditions. The increment of stem diameter and growth rings was influenced by the development of individual tracheids. There could be two reasons for the formation of wider rings in lodgepole pine, namely, the production of a higher tracheid number or larger tracheids. In the present study, the tracheid dimensions were measured to determine their role in the enlargement of the growth rings and stem diameter.

The greatest differences between EW and LW tracheids for both pine species were observed in lumen area and diameter, cell wall thickness and radial tracheid diameter (Table 1). It is in agreement with the earlier study by Havimo et al. (2009) that the cell cross-sectional dimensions of 140-year-old Scots pine considerably varied in cell wall thickness (2.0 µm for EW and 3.7 µm for LW) and radial tracheid width (33.9 µm for EW and 24.9 µm for LW). It was also found (Havimo 2010) that the variation in cell wall thickness and radial diameter of Scots pine and Norway spruce tracheids mainly originated from the differences between EW and LW, whereas the variation in tangential diameter mainly originated from the differences between mature and juvenile wood.

Overall, 27-year-old lodgepole pine significantly differed from Scots pine by the formation of larger stem diameters, wider annual rings, and tracheids with smaller average diameter, thicker cell walls and longer fibres. Consequently, the larger stem diameters and ring widths of lodgepole pine could not be related to the tracheid diameters (Table 1). In its turn, Scots pines formed stems with smaller diameters and narrower rings but larger tracheids. The earlier study of white spruce (Ivkovich et al. 2002) showed that, both phenotypically and genetically, ring width was determined by the number of tracheids and, to a lesser extent, by their mean size. On average, rings with larger cells did not have significantly thicker cell walls. This caused ring width to be negatively correlated with the mean ratio of wall thickness to tracheid size, i.e. cell density (Ivkovich et al. 2002).

Among-species comparison in our trials can be influenced by the narrow initial spacing – species is an important factor determining natural mortality and Scots pine, in contrast to lodgepole pine, is light demanding and characterized by rather high self-thinning rate (Elfving 2010). Despite notable difference in survival (number of remaining trees per ha) between pine species, lodgepole pine produced slightly larger radial increment and resulting stem diameter than Scots pine. Results of our study do not provide information on how the differences in wood properties among pine species could change in trials with different stand density or thinning regime.

It can be seen (Figures 4-7) that tracheid parameters increased from pith to bark in both pine species with only exception of lumen parameters of Scots pine LW which decreased towards cambium. The study (Reme and Helle 2002) of an 84-year-old Scots pine confirmed a rapid increase in the cell wall thickness in the first 20 growth rings, then it seemed to pass through the peak around the growth ring 40, and at the end there was a slight decrease in wall thickness. Similar results were obtained by Lundgren (2004) in the study of Norway spruce by the SilviScan technique. An increment of the radial and tangential cell diameter from pith to bark was observed in about 20 growth rings. Reme and Helle (2002) demonstrated that the perimeter of pine tracheids in the adult Scots pine rapidly increased for the first 20 growth rings, and then continued to increase at a constant rate.

The Summit Lake provenance demonstrated higher wood density, LW content, cellulose content and Kraft pulp yield as compared to other investigated lodgepole pine provenances, namely, Pink Mountain and Fort Nelson (data not shown). Taking into account these results and superior tracheid dimensions of Summit Lake such as thicker cell walls and longer fibres (Table 2), Summit Lake trees could be effectively used for specific end products.

Conclusions

Lodgepole pine demonstrated higher growth rate, greater latewood content, tracheids with smaller average diameter, thicker cell walls and longer fibres than native Scots pine.

The number of tracheids was assumed to play more important role than tracheid diameter in the increment of the stems and growth rings of lodgepole pine.

The longer fibres of lodgepole pines could be attributed to the faster growth and larger stem diameters at this age.

Tracheid dimensions in both pine species tended to increase by the distance from pith to the cambium.

Lodgepole pine wood, grown in Latvia, can be considered as a suitable raw material for pulp production and other specific applications.

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РАЗЛИЧИЯ МЕЖДУ РАЗМЕРАМИ ТРАХЕИД ДЕРЕВЬЕВ СОСНЫ ОБЫКНОВЕННОЙ (*Pinus sylvestris* L.) И СОСНЫ СКРУЧЕННОЙ ШИРОКОХВОЙНОЙ (*Pinus contorta* Dougl. var. *latifolia* Engelm), ВЫРОСШИХ В ЛАТВИИ

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Резюме

Изучены анатомические свойства образцов 27-летних деревьев сосны обыкновенной (*Pinus sylvestris* L.) (n = 32) и сосны скрученной широкохвойной (*Pinus contorta* Dougl. var. *latifolia* Engelm) (n = 19), выросших в Латвии. Измерены диаметр ствола, годичные кольца, а также размеры 150 трахеид ранней древесины и 150 трахеид поздней древесины для каждого дерева. Показано, что сосна скрученная широкохвойная имеет значительно ($P < 0.05$) больший диаметр ствола (21%), более широкие годичные кольца (8%) и более высокое содержание поздней древесины (15%), чем сосна обыкновенная. Такие размеры трахеид, как площадь и диаметр полостей клеток, а также средний диаметр трахеид ранней древесины значительно больше у сосны обыкновенной, а толщина стенок трахеид больше у сосны скрученной широкохвойной. Площадь и диаметр полостей клеток поздней древесины значительно больше у сосны скрученной широкохвойной. Средний размер площади (10%) и диаметра (5%) полостей клеток, а также радиальный диаметр (8%) и диаметр трахеид (3%) больше у сосны обыкновенной, а толщина стенок трахеид (6%) и длина волокон (10%) больше у сосны скрученной широкохвойной. Толщина стенок трахеид и средний диаметр клеток ранней и поздней древесины возрастали по направлению от сердцевины к камбию у обеих пород сосны. Предполагается, что для прироста ствола и годичных колец сосны скрученной широкохвойной, количество трахеид играет более важную роль, чем размер трахеид.

Ключевые слова: размеры трахеид, анатомия древесины, ранняя древесина, поздняя древесина, сосна скрученная широкохвойная, сосна обыкновенная.