COMPARISON OF THE PROPERTIES OF WOOD AND PULP FIBERS FROM LODGEPOLE PINE (*Pinus contorta*) AND SCOTS PINE (*Pinus sylvestris*)

Inese Sable, Uldis Grinfelds, Aris Jansons, Laura Vikele, Ilze Irbe, Anrijs Verovkins, and Arnis Treimanis*

In this study, the relationship between the properties of the wood and kraft pulp fibers as well as paper characteristics of 27-year-old trees, lodgepole pine *(Pinus contorta)* and Scots pine *(Pinus sylvestris),* was assessed. All trees had been grown in Latvia, within the same forest type, *Myrtillosa.* Wood density, year ring width, chemical composition and cross-sectional cell wall dimensions were measured. Fiber characteristics were determined, and handsheets were made for all samples from unbeaten kraft pulp. The results showed that the amount of latewood had a positive correlation with wood density for both species and with further positive impact on the paper burst index. Also, slight differences in cross-sectional dimensions were observed. Lodgepole pine provided paper with higher burst strength than Scots pine. Since the former is of higher density, less wood per volume is needed to produce a ton of pulp, and results showed a higher pulp yield in the case of lodgepole pine.

INTRODUCTION

The increasing demand for wood as a renewable material as well as the predicted climate change and its irregularities require the establishment of plantations of trees of species and provenances, previously unknown for a certain region. In Nordic countries, there is a growing interest in evaluating the properties and application of lodgepole pine *(Pinus contorta)*, which is a native of North America from Alaska to North California.

A review by Elfving et al. (2001) describes the introduction of lodgepole pine in Sweden. The large-scale introduction of this tree species in Sweden started in the 1970s. The planted area has reached about 600,000 ha, corresponding to nearly 3% of the forested land. The experience of silvicultural practices is described, along with the initial progress in tree breeding, although not much data on wood and fiber characteristics are given. It has been established that, during a 25-year period, lodgepole pine produces about 36% more wood than Scots pine (*Pinus sylvestris*). Nevertheless, according to Karlman (2001), severe restrictions in the planting program of lodgepole pine were made by the Swedish National Board of Forestry in 1987 and again in 1993 due to the extensive infection by pathogens. According to Nilsson et al. (2008), it is impossible to predict the future vegetation dynamics in the Swedish stands of lodgepole pine without considerable uncertainty. Other studies (Brown et al. 2006) suggest that non-native trees

form new vegetation assemblages that could lead to long-term changes in the community structure and succession.

Possible reasons for the superior growth rate of lodgepole pine as compared to Scots pine have been investigated by Norgren (1996). The species were grown in large pots with sand, till, or topsoil during 4 years, following sowing. It was shown that the faster relative growth rate in lodgepole pine seedlings is linked with a higher leaf (needles) area ratio, specific leaf area, and nitrogen use efficiency. A higher relative allocation to thin roots could also contribute to its superior productivity.

In a study performed at the Joensuu Research Unit of the Finnish Forest Research Institute METLA (Grekin 2006), Nordic Scots pine wood was benchmarked against the selected competing tree species in the segments of mechanical wood products (joinery, etc.). Also lodgepole pine was included in the list of competing species. Scots pine is concluded to be quite superior in the strength and stiffness properties, which are essential for joinery, interior, and furniture products. Lodgepole pine wood is used for lumber, mine timbers, railroad crossties, and poles. It is also increasingly used for framing, siding, flooring, etc. Moderately knotty wood is considered to set some restrictions on possible end uses.

Hunt et al. (2008) have reported the effect of processing on the physical properties of the fibrous material and flat fiberboard panels made from small-diameter lodgepole pine treetops processed with bark. Delimbed treetops were chipped and fiberized, digested with hot water and small amounts of chemicals, refined, and hot-pressed without using adhesive resins. Fiber quality was related to the mechanical properties of the panels. The strength properties of resin-free fiberboard surpassed the minimum standards for commercial hardboard. Small diameter lodgepole pine treetops were found to be well suited for the production of structural boards.

There are not many published studies, aiming at investigating the pulping behavior of lodgepole pine and the properties of pulp fibers. McGovern (1951) evaluated several types of green-cut and insect-killed lodgepole pine from Montana, US. Also a sample of dead wood from predominantly green stands was examined by physical and chemical tests. Except for somewhat lower holocellulose and alpha-cellulose contents, dead wood did not differ appreciably from green wood in chemical composition. Lignin content was in the order of 25.1% to 27.9%. The samples of green wood were satisfactorily pulped over a range of sulfate pulping conditions. The screened yield of the pulps obtained was between 45.8% and 47.4%; higher values were determined for green wood. Green and sound dead woods showed good pulp strength characteristics.

Hatton and Gee (1993) have determined the yield and quality of unbleached kraft pulps from 12 second-growth lodgepole pine trees from British Columbia and Alberta. From each tree, three samples were taken, namely, juvenile wood and mature wood from butt-end, and top wood. Mean values of pulp yield for each 12-sample set of juvenile wood, mature wood, and top wood components were 45.0, 47.5 and 46.9%, respectively, which reflected wood chemistry differences. Values of fiber coarseness were found to be in a rather broad range from 135 to 281 µm. The fibers from juvenile wood and top wood kraft pulps were consistently less coarse than those from the corresponding mature wood pulps. The weighted average fiber length values were established to be 2.41, 2.49, and 3.14 mm for juvenile wood, top wood, and mature wood samples, respectively. Tensile

index was established in the range of 53 to 60 N.m/g, and burst index values were between 3.4 and 4.3 kPa.m^2/g for unbeaten kraft pulp fiber handsheets. The authors concluded that short rotation lodgepole pine provided an excellent potential to produce kraft pulp to meet specific customer needs.

Dalpke et al. (2008) have published a Working Paper on kraft and thermomechanical pulping of mature wood spruce-lodgepole pine-subalpine fir (SPF) chip mixtures, which were shifting to a higher lodgepole pine ratio due to mountain pine beetle infestation. The laboratory experiments showed that a likely decrease in kraft pulp yield and strength properties might happen.

Measurements of red pine, Douglas-fir, and lodgepole pine wood density and anatomical properties of wood disks were conducted by Zhu et al. (2007) using "SilviScan" equipment and an imaging technique. Two lodgepole pine samples were investigated, one grown under normal conditions (24 years old) and the other (128 years old) that experienced growth suppression over its entire lifetime, both from an unmanaged natural forest. The average ring widths for the two disks were 3.0 (normal) and 0.5 mm (suppressed), respectively. The authors found that no clear distinction was apparent in tracheid radial diameter, wall thickness, and wood density between earlywood and latewood for the suppressed tree samples. The results presented in the study indicated also that annual growth ring width can be a unifying parameter to characterize the effect of tree growth rate on fiber properties.

The objective of this study was to obtain additional data on the physical properties and chemical composition of the wood of lodgepole pine trees as compared to those of Scots pine. Further, kraft pulping was performed, and the yield and strength properties of the relevant pulp fibers were examined. All the trees were grown in Baltic Countries, Latvia, and the study is the first one conducted on the lodgepole pine wood and fiber properties of the trees planted here in 1985.

EXPERIMENTAL

Sample Procurement

Samples were collected during 2009 and 2010 in 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). Initial spacing was 1 x 2 m; no thinning had been carried out prior to the collection of sample trees. Altogether 93 Scots pine sample trees, representing the progenies of 5 seed orchards, were selected. Lodgepole pine (*Pinus contorta*) was represented by 26 sample trees from 3 provenances from Canada: Pink Mountain (latitude 57°00', longitude 122°15'-45'), Fort Nelson (latitude 58°38', longitude122°41'), and Summit Lake (latitude 54°24', longitude 122°37'). Wood samples were chosen based on randomized number methods. Approximately 2 cm thick wood discs were made and treated with No. 150 sandpaper to determine the latewood content, year ring width and content of sapwood at the height of 1.3 m. The discs were dried at room temperature and scanned with a "Canon 4400" device using calibrated "Leica ImagePro6" software.

Wood Properties Determination

All tree samples were debarked and processed according to the scheme shown in Fig. 1. Tree age was detected at the 0.0 m height of the tree; wood density samples were made from the stem part at the height of 0.5 to 1.0 m; microscopy and all wood chemical analyses and kraft cooking were made from the stem wood at the height of 1.0 to 1.3 m.

Stem height 0.0 – 0.5 m   Stem height 0.5 – 1.0 m   Stem height 1.0 – 1.3 m
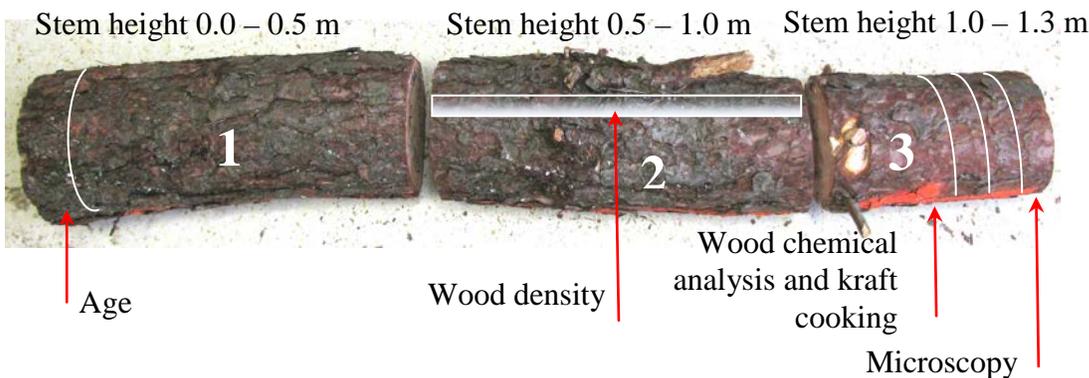
Figure 1. Division of the pine tree stem into parts to determine tree age and other parameters

Wood Density

Wood density was measured according to the DIN 52:182 standard after conditioning in a normal climate (23 ± 1°C and relative humidity $50 \pm 2\%$), according to DIN 50014-20/65-1.

Chemical Composition of Wood

All samples were ground in a Wiley mill to pass through a 0.6 mm screen. The ground wood particles were then Soxhlet extracted with acetone for 8 h to quantify the extractable components gravimetrically after rotary vacuum-evaporation, and expressed as a percentage of the original weight of the wood sample. The extracted lignocellulosic material was then air-dried and analyzed for cellulose and lignin contents as follows. For Kürschner cellulose content determination, 2 g of the sample of extracted wood was used. It was transferred to a 250 mL reaction vessel, and 150 mL of the mixture was added containing 30 mL of concentrated nitric acid and 120 mL of ethanol. Wood samples were heated in a water bath at 92°C for about 20 min; then the solution was exchanged by a new one. The procedure was repeated 7 times, and finally the fibers were washed with warm deionized water. The dry substance was weighed to determine Kürschner cellulose gravimetrically.

Lignin content was determined by the acetyl–bromide method using UV spectroscopy according to Iiyama and Wallis (1988; 1990), Lin and Dence (1992), and Hatfield et al. (1999). The method is based on the small weight of the wood screened sawdust sample treated with 25% of acetyl bromide in a glacial acetic acid solution. Perchloric acid was used as a catalyst for the acetylation reaction. Absorption was measured at 280 nm, and absorption coefficient was adopted to be equal to 20.0 L/(g cm). The content of lignin in wood was calculated by the equation,

$$w(\%) = \frac{A \cdot V \cdot 100\%}{a \cdot b \cdot m \cdot 1000} \tag{1}$$

where A is the absorption at 280 nm; V is the volume of the mixture (mL); m is the weight of the sample (g); a is absorption coefficient, 20.0 L/(g cm); and b is the thickness of the cuvette, cm.

Kraft Pulping

About 200 g of wood chips was cooked in a 2 L laboratory digester at 170°C. The white liquor contained 57.4 g/L active alkali as NaOH, the sulfidity was 29.8 %, and the liquor to wood ratio was 4.5 L/kg. Before cooking, the digester was left overnight at room temperature to impregnate wood chips with chemicals. Then the autoclave was placed into the heating unit, the temperature was increased from room temperature to 170°C in 104 min, and the mixture was cooked for 75 min. After the cooking procedure, the autoclave was immediately placed in a water-ice bath to terminate the delignification reactions. The kraft pulp fibers obtained were carefully washed with warm water until the neutral reaction of washing waters. The pulp was washed until the filtrate was colorless. The delignified fibers were treated in a standard PTA disintegrator for 30,000 revolutions, then filtered and collected on a Büchner funnel and dried for 3 days at room temperature to determine the total kraft pulp yield.

Klason lignin content was determined according to the TAPPI Standard T 222 om-98.

Fiber Properties

The kraft pulp fiber samples were dried overnight at 50°C, and the moisture content was measured to determine fiber weight for dimensions and coarseness measurements. Accurately weighed samples were then re-suspended in 20 mL of de-ionized distilled water, and fiber properties (length, width, form, coarseness and fines) were determined on a Lorentzen & Wettre "FiberTester".

Pulp Strength Properties

Standard handsheets were made according to ISO 5269/2 standards by a PTA "Rapid-Köthen" handsheets paper machine. Handsheets were prepared at the grammage 75 g/m^2 to determine tensile and burst strength indices (ISO 1924-1 and ISO 2758, respectively).

Specific wood consumption (SWC) in m^3/t was calculated as follows,

$$SWC = \frac{1}{Y \cdot d} \cdot 10^5 \tag{2}$$

where Y is kraft pulp yield (%), and d is wood density (kg/m^3).

Tracheid Micromorphology

Sample discs were taken at the 1.3 m height of each tree. A 2 cm wide radial strip was cut from each disc and divided into three blocks of equal size. Before sectioning,

wood blocks were saturated with distilled water. Thin cross sections (15 to 20 µm) were prepared from each block and captured with a video camera "Leica DFC490" attached to a light microscope "Leica DMLB". Cell parameters were measured by use of calibrated image analysis software "Image-Pro Plus".

Cell wall thickness and mean lumen diameter were measured in 150 latewood and 150 earlywood cells of each sample disc (Fig. 2). Mörk's index (Mörk 1928) was calculated as the double wall thickness to lumen width ratio for earlywood and latewood cells.
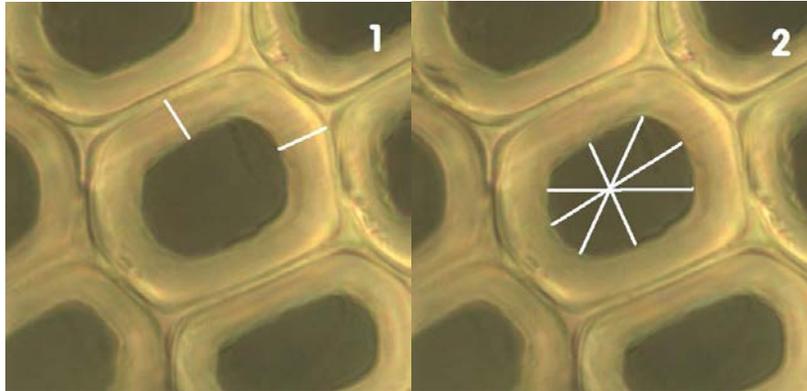
Figure 2. Measurements of cell wall thickness (1) and mean lumen diameter (2)

Statistical Analysis

Data collected were subjected to analysis of variance (ANOVA, $P < 0.05$) for each species, separately using appropriate statistical software (SPSS). Error bars in all graphs refer to 95% just significant confidence intervals.

RESULTS AND DISCUSSION

Tree Growth Dynamics

The growth dynamics of the investigated samples are reflected in Fig. 3. All trees had the same age. In this graph, the cumulated year ring area is plotted, which shows the process of the increase of the stem diameter.

It can be seen that the lodgepole pine grew faster than the Scots pine and, on average, it reached larger final diameter of the stem even within the same growing conditions. This has been verified by the final diameter of stems at a 1.3 m height, which expanded from 64 mm to 179 mm (Fig. 4). Considering the fact of the lodgepole pine's fast growth, one may decide to plant it instead of Scots pine to raise economical profit.

Scots pine appeared to be more regular in its growth (Fig. 4), which is demonstrated by a smaller distribution of the stem diameter. By contrast, the diameter of the investigated samples of lodgepole pine was more variable but also larger.
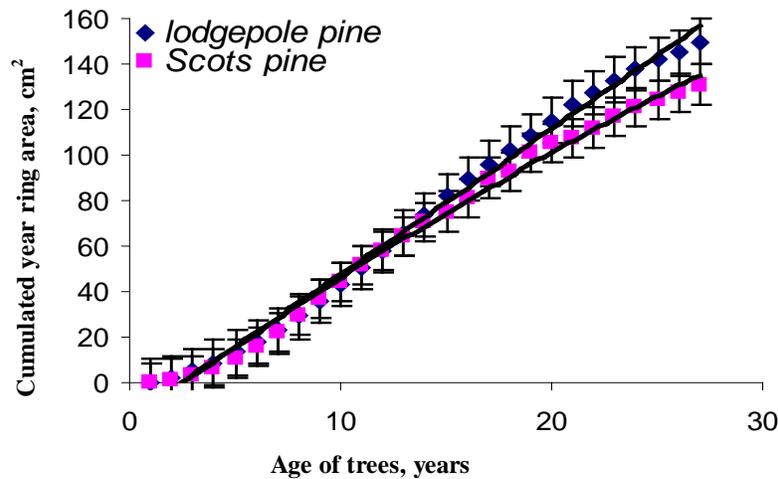
Figure 3. Cumulated year ring area of Scots pine and lodgepole pine, grown in the same region and conditions
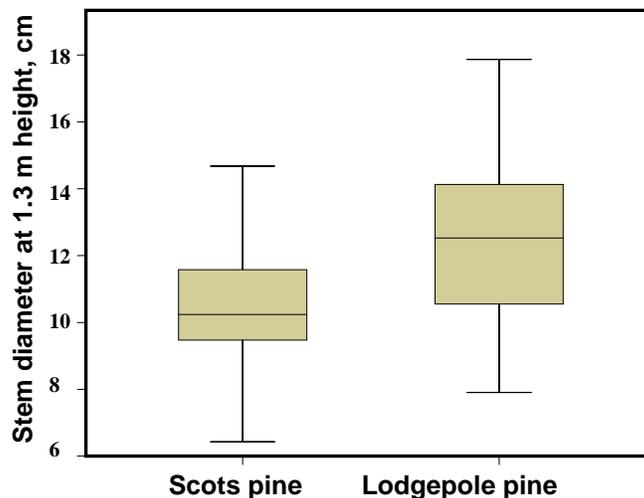
Figure 4. Final stem diameter values for 27-year-old Scots pine and lodgepole pine trees

Physical Properties and Chemical Composition

Scots pine and lodgepole pine wood density values were well separated, with a significance of less than 0.05 (Fig. 5). The fact that both boxes did not intercept the same interval of wood density testified that the two species had a different wood density.

As shown in Figure 5, the amount of latewood differed between the two species; latewood content in the lodgepole pine wood was between 36% and 43% as compared to 36-39% for Scots pine wood. Possibly the proportion of latewood and earlywood is the reason that lodgepole pine wood from trees of initial growth stands exhibited a higher wood density, the mean value being 487 kg/m^3 as compared to 445 kg/m^3 for Scots pine wood. This is in contrast to the Swedish observations for older trees stands (Skogforsk 1999).
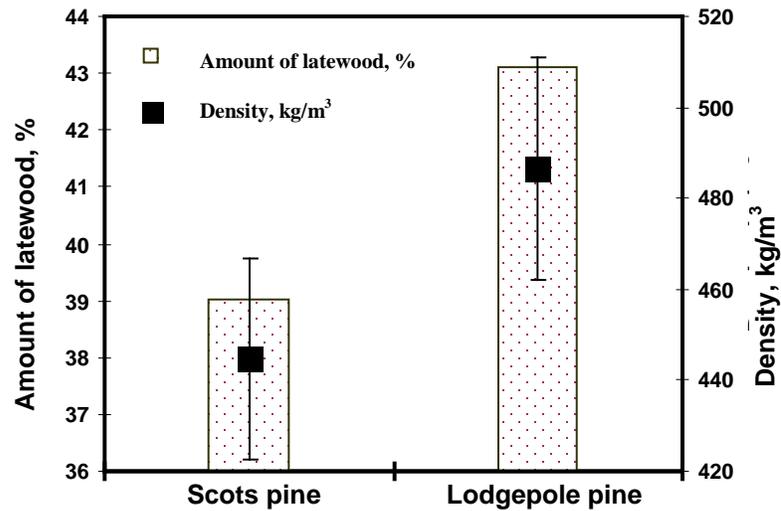
Figure 5. Amount of latewood and wood density for Scots pine
and lodgepole pine, grown in the same region and conditions

As Scots pine wood appeared to be less dense than lodgepole pine wood, this might have an impact on the production of pulp. In the same volume of the digester, pulp manufacturers are able to cook more lodgepole pine chips and therefore, at the same yield of cooking, they may obtain more pulp in weight per m^3 of a digester. Also slight differences in the cross sectional dimensions of cells were found between species (Table 1).

Table 1. Cell Cross Sectional Dimensions for Scots Pine and Lodgepole Pine Wood

Characteristics	Species				
	Scots pine (n=32)		Lodgepole pine (n=19)		
		STD		STD	Significance
Earlywood cell wall thickness, μm	1.4	0.2	1.5	0.2	0.009
Latewood cell wall thickness, μm	3.3	0.4	3.2	0.5	0.169
Mean cell wall thickness, μm	2.2	0.3	2.3	0.3	0.024
Earlywood lumen diameter, μm	19.4	1.2	18.8	1.1	0.014
Latewood lumen diameter, μm	9.5	0.8	10.0	0.9	0.012
Mean lumen diameter, μm	15.5	1.1	14.8	0.9	0.000
Mörk's index, earlywood	0.15	0.02	0.16	0.02	0.000
Mörk's index, latewood	0.70	0.13	0.65	0.11	0.004
Mörk's index, mean	0.28	0.05	0.31	0.03	0.001

Lodgepole pine had thicker cell wall and smaller lumen diameter in earlywood and larger lumen diameter in latewood in comparison to the Scots pine wood cells. In general, the observed lodgepole pine tracheid anatomical properties were in good agreement with the data available in the literature (Zhu et al. 2007), which were obtained by the "SilviScan" technique.

As can be seen from Table 2, lodgepole pine and Scots pine woods represented the same amount of cellulose and ash content but had slightly varied results in the amount of lignin and extractives. Hemicelluloses content was not determined, but it can be calculated that their content in lodgepole pine wood was slightly higher.

Table 2. Chemical Composition for Scots Pine and Lodgepole Pine Wood

Characteristics	Species				
	Scots pine (n=93)		*Lodgepole pine* (n=26)		
	Mean	STD	Mean	STD	Significance
Cellulose content, %	49.0	1.2	49.0	1.2	0.938
Lignin content, %	27.1	0.9	26.4	0. 7	0.000
Ash content, %	0.3	0.03	0.3	0.04	0.589
Extractives content, %	2.9	0.8	2.6	0.9	0.018

The content of lignin and extractives was found to differ significantly between the species ($p < 0.05$). Hence, it can be said that lodgepole pine wood contained less lignin than Scots pine, with 27.1% for Scots pine and 26.4% for lodgepole pine. It can be concluded that lodgepole pine wood pulp can be easier to delignify or it needs less chemicals for this process than in the case of Scots pine. The reduced extractives content for lodgepole pine also promises an easier pulping process.

Pulp Fibers' and Handsheet Properties

Table 3 shows that more wood was consumed to produce the same amount of pulp in the case of Scots pine, compared to lodgepole pine. It was mentioned that wood density for lodgepole pine was higher than that for Scots pine. Assuming that digesters are filled by volume, pulping of lodgepole pine wood will be more profitable for the manufacturers, who will obtain more pulp in weight.

Table 3. Pulp Yield Values and Specific Wood Consumption (SWC) for Both Species Represented as Calculated Mean Values Obtained in Kraft Pulping

Characteristics	Species				
	Scots pine (n=90)		Lodgepole pine (n=24)		
	Mean	STD	Mean	STD	Significance
Pulp yield, %	45.9	2.1	46.9	1.7	0.002
Lignin content, %	4.4	0.2	4.5	0.3	0.582
Specific wood consumption, m^3/t	4.7	0.5	4.4	0.3	0.000

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Table 4 and 5 give information on the properties of kraft pulp fibers and the amount of fines in the unbeaten pulp at the degree of freeness of 12 to 14°SR.

At the delignification degree achieved, physical properties appeared to vary little between the two species, as demonstrated in Table 4. Using boxplot (Figs. 6 and 7), it can be said that the fiber width and amount of fines were slightly differentiable for the two species. In conclusion, no discernible influence of physical properties was observed.
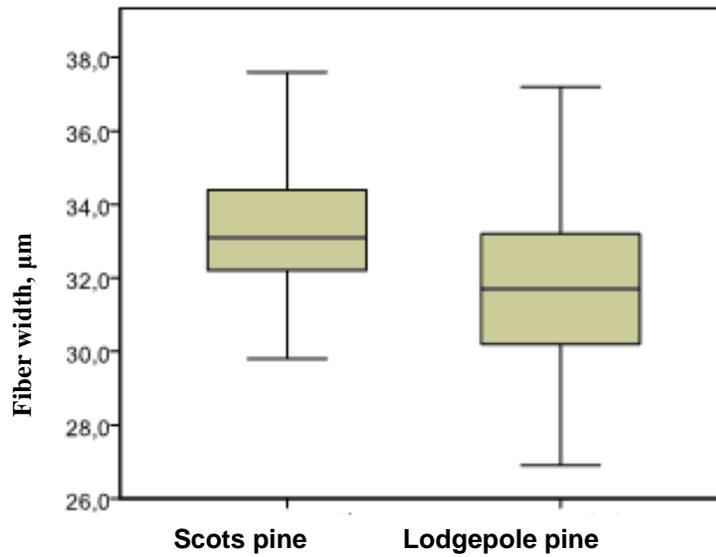
Figure 6. Fiber width for Scots pine and lodgepole pine kraft pulp samples
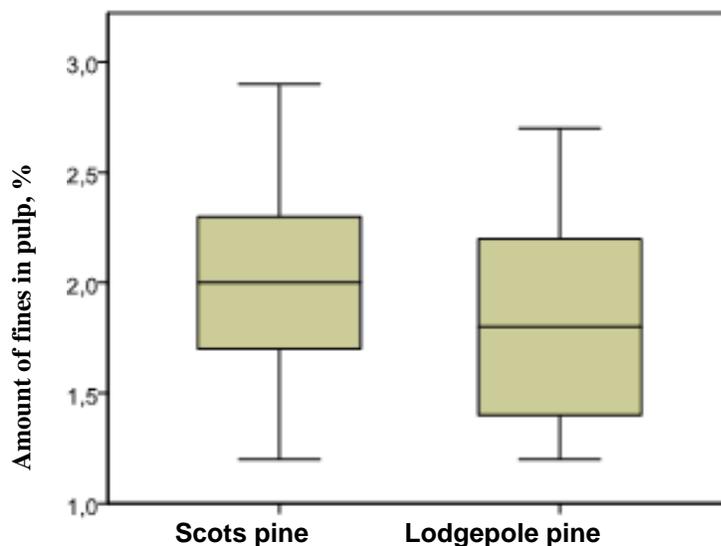
Figure 7. Amount of fines in unbeaten kraft pulp of lodgepole pine and Scots pine

Table 4. Pulp Fiber Properties for Both Species

Characteristics	Species				
	Scots pine (n=87)		Lodgepole pine (n=24)		
	Mean	STD	Mean	STD	Significance
Fiber length, mm	2.15	0.24	2.23	0.20	0.037
Fiber width, µm	33.1	1.9	31.7	2.2	0.000
Shape factor, %	93.2	1.0	93.4	0.9	0.222
Amount of fines in pulp, %	2.1	0.4	1.8	0.5	0.003
Coarseness, mg/m	173	32.7	164	28.0	0.123
Fiber L/D ratio	64.8	6.7	70.4	6.2	0.000
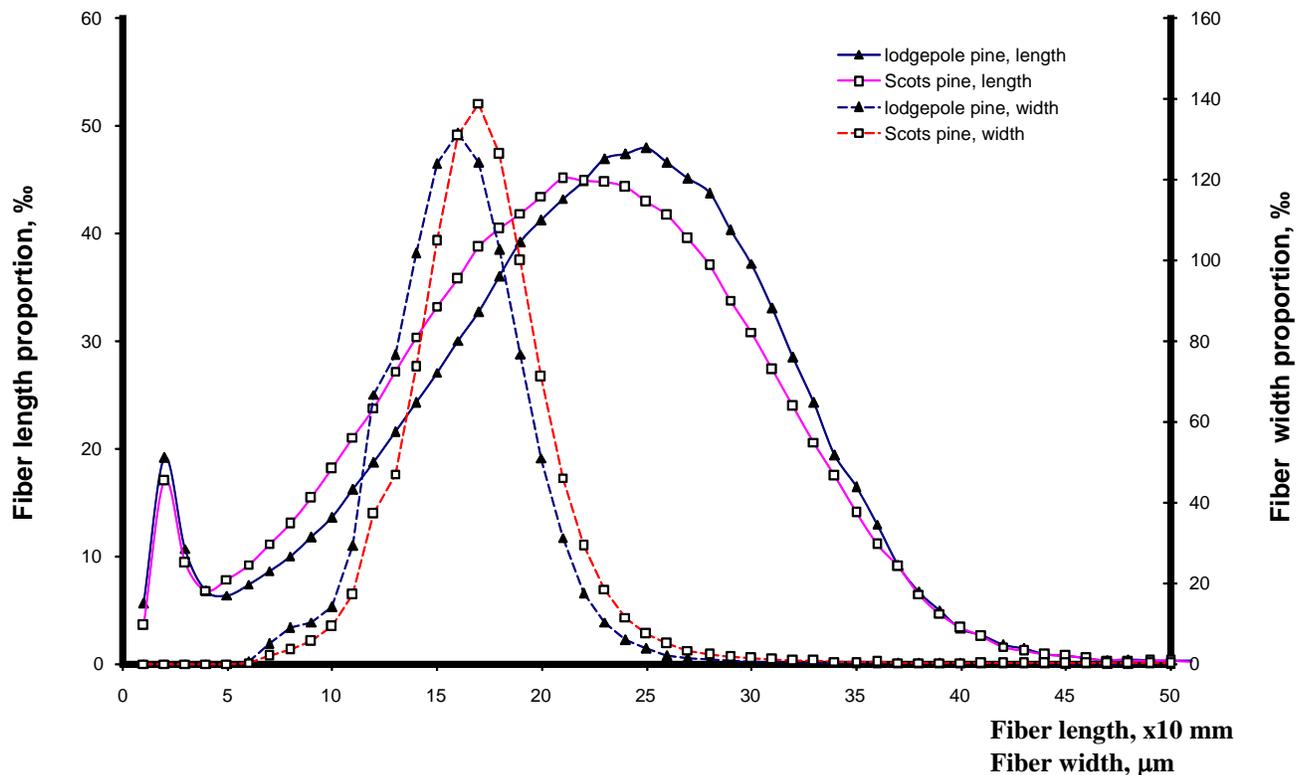
Figure 8. Weight average distribution of fiber length and width for lodgepole and Scots pine

Lodgepole pine fibers were longer and narrower than Scots pine fibers, as shown in Figure 8. This means that lodgepole fibers were more flexible and provided better fiber bonding strength than Scots pine fibers. This also influenced the mechanical properties of handsheets, mainly burst strength.

In regards to the pulp handsheet strength properties, breaking length and tensile index did not change with species, and stretch and burst indices were slightly higher for lodgepole pine (Table 5).

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Table 5. Strength Properties of Handsheets for Both Species

Characteristics	Species				Significance
	Scots pine (n=19)		Lodgepole pine (n=8)		
	Mean	STD	Mean	STD	
Burst index, kPa.m²/g	1.57	0.02	1.82	0.27	0.000
Stretch, %	1.1	0.2	1.5	0.4	0.000
Breaking length, km	3.4	0.4	3.5	0.4	0.435
Tensile index, Nm/g	33.5	3.5	34.3	4.2	0.449

The results shown mean that, for the same process conditions (pulping and papermaking), lodgepole pine pulp will provide to some extent higher strength papers (better stretch and better burst index), for example, for packaging papers. However, there was no considerable difference between both species in terms of breaking length and tensile index values to prefer one over the other.

CONCLUSIONS

1. When comparing the lodgepole pine and Scots pine trees at the age of 27 years, the former had a higher growth rate under the same breeding conditions in Latvia.
2. Lodgepole pine wood showed higher density values, evidently due to the higher content of latewood. Also slight differences in cross-sectional dimensions of cells were found between species. Lodgepole pine had thicker cell wall and smaller lumen diameter in early wood and larger lumen diameter in latewood in comparison to the Scots pine wood cells.
3. In regards to the chemical composition of the wood, a higher content of lignin and extractives was observed for Scots pine wood.
4. Lodgepole pine pulp was obtained at a higher yield by ca. 1% and possessed slightly higher strength properties in terms of burst index.

ACKNOWLEDGMENTS

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