Density of juvenile and mature wood of selected coniferous species

V. Gryc, H. Vavrčík, K. Horn

Faculty of Forestry and Wood Technology, Mendel University in Brno, Brno, Czech Republic

ABSTRACT: The objective of research was to determine the density of juvenile (JW) and mature wood (MW) of selected coniferous species growing in the Czech Republic. The research included the wood of Norway spruce (*Picea abies* (L.) Karst.), Scots pine (*Pinus sylvestris* L.) and European larch (*Larix decidua* Mill.). The juvenile wood density close to the pith was 410 kg·m^{-3} for spruce, 391 kg·m^{-3} for pine and 573 kg·m^{-3} for larch with 12% water content. Mature wood in the peripheral parts had the higher density in all species – spruce 516 kg·m^{-3}, pine 552 kg·m^{-3} and larch 652 kg·m^{-3}. The highest difference, the difference of 161 kg·m^{-3}, between juvenile and mature wood was found out in Scots pine. The large difference in the wood density of pine is caused by a considerable difference in the mean ring width of its juvenile and mature wood. Further, it was proved that wood density decreases with the increasing ring width while wood density increases with the increasing proportion of latewood.

Keywords: density; juvenile wood; larch; mature wood; Norway spruce; Scots pine

In the last decades, with the development of wood processing technology, logs of smaller diameters have been processed. This means that the end products always contain juvenile wood (JW). The structure and properties of this wood highly differ from those of mature wood (MW).

Juvenile wood is to be found mainly in the central part of the stem, and also in the peripheral and upper parts (Rendle 1959; Panshin, De Zeeuw 1980; Zobel, Sprague 1998). One of the first definitions was formulated by Rendle (1959), who said that juvenile wood is the secondary xylem formed during the early life of the tree. From the anatomical aspect, juvenile wood can be characterized by a gradual change of dimensions and corresponding changes in the form, structure and layout of cells in the growing rings. The range of juvenile wood is usually defined using the number of rings. However, there is no unified opinion concerning the number of rings of juvenile wood. Most authors refer to the first twenty rings as juvenile wood (10 rings – Cown 1992; 15 rings – Corson 1991; 22 rings – Mutz et al. 2004). On the other hand, Harris (1981) stated that juvenile wood can never be defined exactly as its properties depend on a high number of factors and their development in the radial direction can vary significantly. For instance, the process of tracheid lengthening can be completed, while the increase of wood density is only halfway. Yet it is mostly possible to differentiate a specific number of rings surrounding the pith which have the worse technological properties of juvenile wood. Loo et al. (1985) reported that the formation of the juvenile wood zone depends on the location, source of seeds, local climate, and also on the genetic basis of each tree.

Juvenile wood is usually characterized by density because it is easily determined and it also affects other wood properties. The density of JW is lower in comparison with MW (Zobel, Sprague 1998; Gryc et al. 2008). As Harris (1965) found out, the mature wood of *Pinus radiata* D. Don has the density of 430 kg·m^{-3}; its juvenile wood has only 330 kg·m^{-3}. Bunn (1981) examined a 25-years-old Scots pine (*Pinus sylvestris* L.) and he determined the density of 340 kg·m^{-3} near the pith but 450 kg·m^{-3} just under the bark. As he assumed, the mature wood had

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a thicker cell wall than JW but the diameters of tracheids of both woods were equal. The fact that the density changes along the stem radius with the lowest values around the pith also applies to spruce (Palovič, Kamenický 1961; Gryc et al. 2008).

The objective of the research was to compare the basic density of juvenile and mature wood of economically significant tree species growing in the area of the Czech Republic, viz Norway spruce (*Picea abies* [L.] Karst.), Scots pine (*Pinus sylvestris* L.) and European larch (*Larix decidua* Mill.).

MATERIAL AND METHODS

The material for the sample preparation was donated by the company Lesy města Náchoda s.r.o. (City Forests of Náchod). The samples of spruce (*Picea abies* [L.] Karst.) originated from the Vápenka forest section, Stárkov cadastral area, stand 22C12, age 115 years. Spruce (the main species) accounted for 85% of the tree species composition, while the interspersed species were pine 8%, larch 5% and fir 2%. The stand grows on an east-oriented slope. The forest is a production forest, management unit 411 (spruce management of exposed locations at middle altitudes), forest type 4K9 (acid beech wood).

The samples of pine (*Pinus sylvestris* L.) also originated from the Vápenka forest section, but from the Dolní Vernéřovice cadastral area, stand 19B10, aged 98. The tree species composition in this location consists of spruce 99% and beech 1%. Pine is only an interspersed species. The stand grows on a south-oriented slope. The forest is a production forest, management unit 531 (spruce management of acid locations at higher altitudes), forest type 5K1 (acid fir-beech wood). Again, spruce which forms scarce groups of trees at the site was affected by decay; moreover, there were groups of soil-improving and soil-strengthening tree species.

The samples of larch (*Larix decidua* Mill.) originated from the Montace forest section, Trubějov cadastral area, stand 1C8, aged 80. The tree species composition is dominated by spruce as the main species (75%), followed by sessile oak (admixed species 15%), larch (4%) together with birch (5%) and pine (1%) as interspersed species. The stand grows on a southwest-oriented slope. Again, this was a production forest, management unit 431 (spruce management of acid locations at middle altitudes), forest type 4K1 (acid beech wood).

Five logs from co-dominant trees were taken in each of the locations – 50 cm in length from the height of 1.3 m. The selected sampled trees were not affected by any kind of decay and there was no pith eccentricity that would bring about the presence of reaction compression wood.

A 6 cm thick central plank with the pith in the axis was made using an electric chainsaw from the central part of the logs and then samples of 2 × 2 × 3 cm were produced in compliance with valid norms for the determination of density. The samples were taken in the zone close to the central part of the stem (JW) and in the zones of external rings close to the cambium (MW). Only samples with special orthotropic shape were selected. 25 samples of juvenile wood and 25 samples of mature wood were thus produced from each log. The samples were numbered for correct identification during the measurement.

Wood density was determined at a moisture content of 0% and 12% (ČSN 49 0108). For that reason the samples were first conditioned (MC = 12%) and then dried in a laboratory drying kiln at the temperature of 103 ± 2°C. To find out the influence of ring width on density we measured the average ring width and the percentage of latewood in the cross-section of the samples (Rybníček et al. 2009).

RESULTS

Spruce

We found out that juvenile wood always has the lower density than mature wood (Table 1). This applies to all logs. The mean density of spruce juvenile wood at a moisture content of 0% is 387.7 kg·m^{-3}, mature wood with the same moisture content has the density of 488.1 kg·m^{-3}. The difference of 100.4 kg·m^{-3} is significant. The difference between the mean values of density at a moisture content of 12% is 105.5 kg·m^{-3}, i.e. it is almost the same as the difference at zero moisture content. Density values at different moisture contents vary by about 25 kg·m^{-3} in favour of wood with 12% moisture content. The difference is caused by the absorbed air moisture. Statistical analysis (*F*-test and *t*-test) shows a statistically significant difference between medium values of JW and MW at 0% moisture content (α = 0.05). Very low values of the coefficients of variation show that the variability of density is very low (absence of extreme values).

Pine

The data in Table 1 shows that also in this case juvenile wood has the lower density than mature

Table 1. Descriptive statistics of the density for juvenile (JW) and mature wood (MW) in Spruce, Pine and larch

Tree	Statistical variable	MC 0%		MC 12%	
		JW	MW	JW	MW
Spruce					
	mean (kg·m^{-3})	385.48	491.61	407.76	519.79
1	standard deviation (kg·m^{-3})	33.08	29.71	34.86	32.04
	coefficient of variation (%)	8.58	6.04	8.55	6.16
	mean (kg·m^{-3})	371.40	410.387	393.03	433.77
2	standard deviation (kg·m^{-3})	37.45	11.27	39.42	11.61
	coefficient of variation (%)	10.08	2.75	10.03	2.68
	mean (kg·m^{-3})	377.78	506.85	399.96	535.44
3	standard deviation (kg·m^{-3})	22.15	15.59	22.39	16.3
	coefficient of variation (%)	5.86	3.08	5.60	3.05
	mean (kg·m^{-3})	385.10	489.26	406.04	516.21
4	standard deviation (kg·m^{-3})	18.00	19.78	19.79	20.47
	coefficient of variation (%)	4.67	4.04	4.87	3.97
	mean (kg·m^{-3})	418.66	542.25	443.78	572.93
5	standard deviation (kg·m^{-3})	24.09	12.78	25.78	93.49
	coefficient of variation (%)	5.75	2.36	5.81	16.32
	mean (kg·m^{-3})	387.69	488.07	410.12	515.63
Σ	standard deviation (kg·m^{-3})	26.95	17.83	28.45	34.78
	coefficient of variation (%)	6.95	3.65	6.94	6.75
Pine					
	mean (kg·m^{-3})	390.42	544.60	413.26	575.46
1	standard deviation (kg·m^{-3})	38.26	11.36	15.45	11.86
	coefficient of variation (%)	9.80	2.09	3.74	2.06
	mean (kg·m^{-3})	372.01	461.92	393.20	488.29
2	standard deviation (kg·m^{-3})	16.26	24.11	48.38	24.91
	coefficient of variation (%)	4.37	5.22	12.31	5.10
	mean (kg·m^{-3})	378.11	545.93	393.93	576.27
3	standard deviation (kg·m^{-3})	23.27	27.11	19.10	27.56
	coefficient of variation (%)	6.15	4.96	4.78	4.78
	mean (kg·m^{-3})	358.76	545.49	379.21	576.89
4	standard deviation (kg·m^{-3})	15.99	61.70	12.67	61.35
	coefficient of variation (%)	4.46	11.31	3.34	10.64
	mean (kg·m^{-3})	349.77	513.13	369.11	542.54
5	standard deviation (kg·m^{-3})	14.72	14.14	39.68	14.47
	coefficient of variation (%)	4.21	2.76	10.75	2.67
	mean (kg·m^{-3})	369.81	522.22	390.94	551.89
Σ	standard deviation (kg·m^{-3})	21.70	27.68	27.06	28.03
	coefficient of variation (%)	5.87	5.30	6.92	5.08

Table 1. to be continued

Tree	Statistical variable	MC 0%		MC 12%	
		JW	MW	JW	MW
Larch					
	mean (kg·m^{-3})	492.48	577.48	520.86	610.81
1	standard deviation (kg·m^{-3})	34.58	17.61	37.77	17.73
	coefficient of variation (%)	7.02	3.05	7.25	2.90
	mean (kg·m^{-3})	530.61	575.12	560.30	607.11
2	standard deviation (kg·m^{-3})	33.05	29.94	33.46	30.05
	coefficient of variation (%)	6.23	5.21	5.97	4.95
	mean (kg·m^{-3})	544.95	627.55	572.54	663.15
3	standard deviation (kg·m^{-3})	66.26	23.89	69.87	22.60
	coefficient of variation (%)	12.16	3.81	12.20	3.41
	mean (kg·m^{-3})	614.96	671.41	649.27	709.86
4	standard deviation (kg·m^{-3})	45.71	21.66	45.95	60.37
	coefficient of variation (%)	7.43	3.23	7.08	8.50
	mean (kg·m^{-3})	531.51	633.42	561.93	669.69
5	standard deviation (kg·m^{-3})	24.31	27.35	23.50	27.42
	coefficient of variation (%)	4.57	4.32	4.18	4.09
	mean (kg·m^{-3})	542.90	617.00	572.98	652.13
Σ	standard deviation (kg·m^{-3})	40.78	24.09	42.11	31.63
	coefficient of variation (%)	7.51	3.90	7.35	4.85

wood. The mean density of JW at 0% moisture content is 369.8 kg·m^{-3}, for MW it is 522 kg·m^{-3}. The difference equals 152 kg·m^{-3}, which is considerably more than in spruce. At 12% moisture content the difference is slightly higher, 161 kg·m^{-3}. The higher values of density at 12% moisture content are caused by bound water that is stored in the cell walls of anatomical elements. The difference between the densities at 0% moisture content and at 12% moisture content is 21 kg·m^{-3} in JW and 30 kg·m^{-3} in MW. Statistical evaluation consisting of *F*-test and *t*-test revealed statistically significant differences between medium values of the density of pine juvenile and mature wood at a moisture content of 0% (α = 0.05). Very low values of the coefficients of variation show the compactness of the density with the absence of extreme values.

Larch

We found out that juvenile wood of larch also has the lower density than mature wood (Table 1). The mean value of JW density at a moisture content of 0% is 542.9 kg·m^{-3}, the mean value of MW density is 617 kg·m^{-3}. The difference is 74 kg·m^{-3}, which is a relatively low value in comparison with spruce and pine. The difference in the density values at a moisture content of 0% and 12% has been explained above. This difference is 30 kg·m^{-3} on average for JW and 35 kg·m^{-3} on average for MW. Statistical analysis (*F*-test, *t*-test) proves a statistically significant difference between the medium values of JW and MW density at zero moisture content (α = 0.05). Low values of the coefficients of variation show again that the variability of density values is small.

The influence of ring width and latewood proportion on density

The largest proportion of latewood is to be found in spruce. This applies both to JW and MW. Generally spoken, the values of latewood proportion are comparable, being around 30% for JW and around 46% for MW. The difference between JW and MW in larch is the smallest in contrast with spruce and pine.

Table 2. Descriptive statistics of ring width and latewood proportion for juvenile (JW) and mature wood (MW) in studied species

Statistical variable		Norway spruce		Scots pine		Larch	
		JW	MW	JW	MW	JW	MW
Ring width (mm)	mean (mm)	3.54	1.49	5.23	1.05	4.89	2.42
	standard deviation (mm)	0.88	0.41	0.90	0.26	2.15	0.62
	coefficient of variation (mm)	24.91	27.52	17.24	23.05	43.92	25.74
Proportion of late wood (%)	mean (%)	36.68	51.90	28.84	46.82	31.79	40.22
	standard deviation (%)	5.54	13.40	9.20	12.81	9.05	7.59
	coefficient of variation (%)	15.09	25.81	31.90	27.37	28.47	18.86

It means that larch wood is the most homogeneous from the aspect of the latewood proportion in a ring.

Moreover, Table 2 shows that pine has the greatest mean ring width for JW (5.23 mm) and the smallest for MW (1.05 mm). This makes it the most inhomogeneous wood in the examined sample from the aspect of ring width. On the other hand, the smallest difference between the mean values of ring width for MW and JW is to be found in spruce (2.05 mm).

Fig. 1 illustrates the dependence of wood density (MC = 12%) on the mean ring width. The graph contains the data for all three species and also for both MW and JW. It shows that wood density decreases with the increasing ring width. The lowest correlation coefficient was found in larch wood (R^2 = 0.33). A considerably higher dependence between ring width and wood density was found in spruce (R^2 = 0.6). As for pine, we can see two groups of data – the one group, higher values correspond to mature wood, the other group represents juvenile wood. In agreement with this, the correlation coefficient of pine was the highest, 0.82.

Fig. 2 shows the influence of the latewood proportion on wood density at 12% moisture content. It is obvious in all three species that wood density increases with the increasing latewood proportion. The slopes of lines for spruce and pine are very similar. Larch also has a rising line but its slope is not so steep and the correlation between the examined variables is very low (R^2 = 0.14). The functions which describe the relations among the studied variables are presented in Table 3.

DISCUSSION

The latest trends in forestry require shorter rotation periods and more complex utilization of

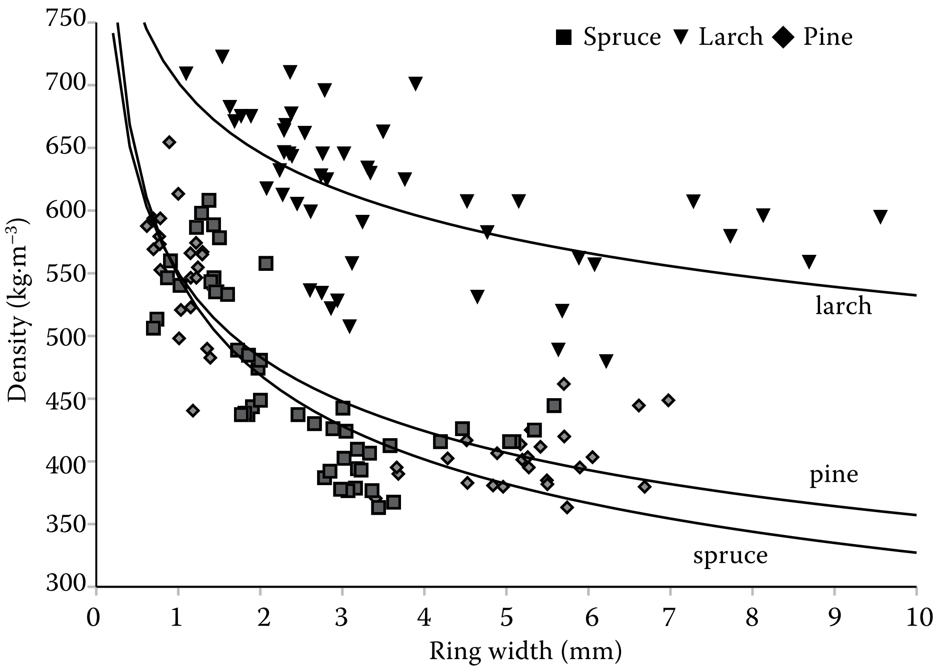

Fig. 1. Influence of ring width on the density of wood (MC 12%)

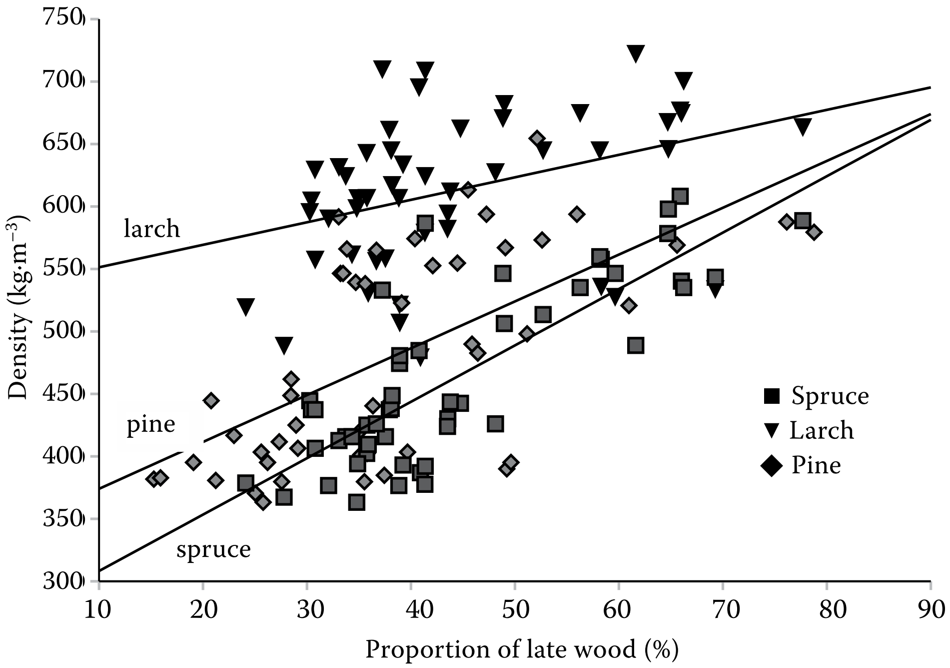

Fig. 2. Influence of the latewood proportion on the density of wood (MC 12%)

wood. From this aspect, it is desirable that wood of smaller diameter will be used. This kind of wood predominantly contains juvenile wood, which has a different structure from that of mature wood. As wood density is one of the basic wood properties, it has been paid attention to in this paper.

In general, wood density of conifers is the lowest in the JW zone, i.e. the nearest to the pith. Then the density increases, at first rapidly, then more slowly, and it is nearly constant in the MW zone. When conifers pass to the old age (100 years and more), the density starts decreasing. This tendency of density decrease at the old age has been proved for many tree species. It is typical of trees which were growing mainly in production forest (Pearson, Ross 1984; Zobel, Sprague 1998). According to Makovická Paulínyová (2007) the density of spruce (*Picea abies* [L.] Karst.) stem at breast height of a tree ranged between 350 and 550 kg·m^{-3}. In their research they carried out continuous measurements of wood density along the radius. Our research did not examine the variability of density along the radius; it only compared the density between the central parts and the peripheral parts of the stem.

The density of the central parts of spruce stem was lower than the density of its peripheral parts in all logs. It should be emphasized that the spruce trees were not growing at their typical growth site and results from natural growth stands could be different. The difference between JW and MW of spruce was around 100 kg·m^{-3}. This finding confirms the results of all the mentioned literary sources: the density in the centre of the stem is low while it is higher in the peripheral parts. The low density of JW can be caused by several factors. From the macroscopic aspect, everything is affected by the ring width. JW rings are located in the centre of the stem, they are broad with a small proportion of latewood. The difference between the ring widths of spruce JW and MW in our research was 2.05 mm. The ring width and the latewood proportion influ-

Table 3. The resulting functions of wood density (MC = 12%) dependence on ring width and proportion of latewood

	Species	Function	Coefficients of determination	Coefficients *a*	Coefficients *b*
Ring width (mm)	Norway spruce	$y = ax^{-0.22}$	0.60	547.28	
	Scots pine	$y = ax^{-0.19}$	0.82	550.28	
	Larch	$y = ax^{-0.12}$	0.33	702.13	
Portion of late wood (%)	Norway spruce	$y = a + bx$	0.65	263.11	4.51
	Scots pine	$y = a + bx$	0.40	336.58	3.75
	Larch	$y = a + bx$	0.14	533.34	1.8

ence the resulting wood density (see Figs. 1 and 2). It was ascertained that density decreases with the increasing ring width, while density increases with the increasing latewood proportion. In spruce both dependences are of medium degree. To sum up, the main factor at a macroscopic level is a large ring width with a small latewood proportion. From the microscopic aspect, we can state that the cell walls of early and latewood tracheids of juvenile wood are thin in comparison with the cell walls of mature wood. The most significant difference is in the latewood of JW and MW as in MW it is formed by thick-walled tracheids with the narrow lumen. It means that the influence of the microscopic structure on wood density is not negligible.

The differences in JW density among the particular logs were very small, which was probably caused by the fact that the young trees had relatively the same conditions at the beginning of their growth, enough light and space for each individual. However, the differences in MW density among the spruce logs were considerably larger. The reason could be a greater diversification of growth conditions in the later stages of stand growth, especially as concerns the light and space competition of crowns and root systems. As the trees grow larger, the stand becomes denser and the competition increases. The suppressed trees grow more slowly and form mature wood with narrower rings with a higher proportion of latewood, which is then reflected in the higher density of wood.

The wood density of most species of pine (*Pinus* sp.) depends on the location (Zobel, Talbert 1984). Bunn (1981) researched a 25-years-old Scots pine (*Pinus sylvestris* L.): the density of wood close to the pith was 340 kg·m^{-3}, the density of wood immediately below the bark was 450 kg·m^{-3}. Čunderlík et al. (2005) found out the density of 430 kg·m^{-3} in Scots pine around the pith. It follows from this data that our result of 390 kg·m^{-3} is within the range reported in literature for the density of pine juvenile wood.

Like in spruce, the density in the centre of pine stems was also lower than in its peripheral parts in all logs. The difference we established was 150 kg·m^{-3}, which is a higher value in comparison with both spruce and larch. It is caused by larger differences in the ring width of pine JW and MW in contrast to spruce and larch (Table 4). Juvenile wood of pine has wide rings with a small proportion of latewood and its mature wood has very narrow rings with a higher proportion of latewood, which results in the larger difference in density than in spruce where the differences in the ring width and latewood proportion are not so significant.

The influence of the ring width and latewood proportion in the case of pine was the same as in the case of spruce. The density of JW and MW agrees with the values presented in literature (Bunn 1981; Čunderlík et al. 2005).

The differences in density of JW and MW among individual logs are approximately the same. It means that the pine does not suffer from changes in growth in dependence on growth conditions related to the stand age to such an extent as spruce. Probably, the competition of pine roots is not as keen as in spruce due to the shape of root system. According to Zobel and Talbert (1984) the density mainly depends on the location, not so much on the genetic basis. Thus the differences in the values of density of individual logs could be caused by fluctuations in the quality of the location within a stand.

The third studied tree species – European larch (*Larix decidua* Mill.) demonstrated the same trends as the other two species. In all logs, the density of JW is lower than the density of MW. The difference is 80 kg·m^{-3}, which is clearly the smallest difference in comparison with spruce and pine. Regarding the wood density, larch produces the most homogeneous material. The small difference between JW and MW density is caused by a small difference in the proportion of latewood. The difference in the latewood proportion of a ring between JW and MW is only 8%, in spruce it is 15% and in pine it is the highest, 18%.

The differences in JW and MW density among individual logs are approximately the same. It means that larch is not affected by changes in growth in dependence on growth conditions related to the stand age to such an extent as spruce. The differences among density values of individual logs are perhaps caused by different growth conditions of individual trees, the main factor affecting the growth of larch being probably the amount of light. Larch is a heliophilous species with great height increment (Úradníček et al. 2001).

Wood in its essence is a highly inhomogeneous material. Juvenile wood is a part of each stem and it is necessary to be aware of this fact. The lower density of juvenile wood, the easier way of its processing and the consequent lower energy demands can be an advantage for the use of this material by some wood-processing technologies (e.g. production of paper, agglomerated materials, wooden crates).

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Corresponding author:
Ing. Vladimír Gryc, Ph.D., Mendel University in Brno, Faculty of Forestry and Wood Technology, Department of Wood Science, Zemědělská 3, 613 00 Brno, Czech Republic
e-mail: gryc@mendelu.cz