The relation between the microscopic structure and the wood density of European beech (*Fagus sylvatica* L.)

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ABSTRACT: The aim of this study was to compare the structure of beech juvenile and mature wood in relation to wood density. The comparative analysis between juvenile and mature wood examined the diameter of vessels, the width and height of pith rays, and the number of vessels and pith rays per 1 mm^2. The results show that the average vessel diameter as well as the width and height of pith rays reach statistically lower values in juvenile wood than in mature wood. On the other hand, no significant difference between the two types of wood has been found in terms of the frequency of vessels per 1 mm^2. Having said that, the difference in the frequency of rays per 1 mm^2 between juvenile and mature wood is far from being negligible; juvenile wood has three times as many pith rays as mature wood. The density of juvenile wood is higher (ρ_{12} = 726.07 kg/m^3) than the density of mature wood (ρ_{12} = 701.50 kg/m^3).

Keywords: beech; juvenile wood; mature wood; vessels; rays; density

Juvenile wood occurs in both softwoods and hardwoods as a result of the normal physiological process. Juvenile wood is generally defined as a zone around the pith, where its characteristics and properties are subject to a gradual change. Juvenile wood is surrounded with mature wood. It is found to a greater extent in trees grown in plantations. Most studies were carried out on pine, Douglas fir and eucalyptus wood (Bhat et al. 1990; De Kort 1991; Kretschmann, Bendtsen 1992; Larson et al. 2001). Assessing juvenile wood in hardwoods is different compared with conifers since the juvenile zone in hardwoods is usually less distinct than in conifers (Zobel, Van Buijtenen 1989). Fibre length, cell wall thickness of fibres and vessel diameter increase rapidly in the first rings from the pith. The frequency of vessels per 1 mm^2 and microfibrillar angle of the S2 layer decrease from juvenile to mature wood. Juvenile wood is also characterized by poor physical properties such as low specific gravity, density in general, low strength and high shrinkage (Fukazawa 1984; Zobel, Sprague 1998; Barcík et al. 2006; Adamopoulos 2006).

The European beech (*Fagus sylvatica* L.) is one of the most important commercially used hardwood species both in the Czech Republic and in other countries in Central Europe. In 2005, its proportion amounted to 6.6% of the total area of the Bohemian and Moravian forests. The aim of this study was to compare the microscopic structure of juvenile and mature beech (*Fagus sylvatica* L.) wood in relation to wood density (moisture content 12%).

MATERIAL AND METHODS

To compare the microscopic structure of juvenile and mature wood in relation to wood density 30 trees of European beech (*Fagus sylvatica* L.) were chosen. The sample trees (83 years old) came from a locality near the village of Rajnochovice (Hostýnsko-Vsetín-

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Table 1. Descriptive statistics of vessel diameter, ray height and width

	Type of wood	N	Mean (μm)	Minimum (μm)	Maximum (μm)	Standard deviation (μm)	Coefficient of variation (%)
Vessel	JW	204	33.28	9.22	54.18	9.15	27.50
	MW	186	46.84	20.10	74.92	12.83	27.39
Height of ray	JW	488	173.68	31.09	971.32	118.64	68.31
	MW	171	324.06	64.85	1,578.29	228.01	70.36
Width of ray	JW	488	23.79	8.11	94.85	11.16	46.89
	MW	171	38.50	7.97	193.20	22.63	58.77

ské vrchy Highlands, the Czech Republic). A log (about 30 cm long) was taken out of each stem (at the height of 0.5 m).

Samples from three trees were taken to analyze the vessel diameter and the height and the width of rays in dependence on the position in the stem. The first set of samples was taken from the central part of the stem (5th tree-ring from the pith; juvenile wood) and the second set of samples was taken from the peripheral part of the stem (5th tree-ring from the cambium; mature wood). The samples were 15 × 15 mm diagonally and 20 mm long. Transverse, radial and tangential cuts were taken out of each wood sample. The cuts were 20 μm thick. They were dyed (with safranine), drained and inserted between the slides using Canadian balsam (Vavrčík, Gryc 2004). The images obtained from the permanent sections were assessed in the Lucia application. The vessel diameter was determined from two orthogonal measurements. The height of the ray was measured as the longest axial dimension; the width of the ray was measured as the horizontal dimension at the widest place.

Wood density was determined using standard test samples with the dimensions of 20 × 20 × 30 mm and 12% moisture content (ČSN 49 0108). The samples to determine the juvenile wood density were made out of the central part of the stem (wood up to 15th tree-ring). The samples of mature wood were taken from the peripheral parts adjacent to the cambium.

RESULTS

The dimensions of vessels (diameter) and rays (height and width) of juvenile and mature wood were compared. The transverse and the tangential cuts of juvenile and mature wood are presented in Fig. 1. The difference in the wood structure is more than obvious. Fig. 2 shows the detail of a ray at the boundary of a tree-ring. The ray distends at the tree-ring boundary, the distension being more significant in mature wood.

The statistical examination rejected the zero hypothesis stating that the average values of vessel diameters, height and width of rays do not differ. The results show that there is a significant difference ($P \leq 0.01$) in vessel diameters and ray dimensions between juvenile and mature wood. The descriptive statistics of dimensions of anatomical elements is presented in Table 1.

Histograms of the vessel frequency layout in juvenile and mature wood are presented in Fig. 3. The layout of the values shows that the vessel diameter is larger and more balanced in mature wood. Juvenile wood has smaller vessel diameters and there are microvessels smaller than 20 μm. Rays are larger both in width and height in mature wood (Fig. 4). The difference in width between juvenile and mature wood is not as distinct as the difference in the height of rays. The height of rays can be up to twice bigger in mature wood (Table 1).

Table 2. Number of vessels and rays per 1 mm^2

	JW	MW
Number of vessels	204	186
Number of vessels/mm^2	83	69
Number of rays	488	171
Number of rays/mm^2	29	10

Table 3. Descriptive statistics of beech wood density

	JW	MW
Mean (kg/m^3)	726.07	701.49
Standard deviation (kg/m^3)	30.71	29.95
Minimum (kg/m^3)	674.72	641.31
Maximum (kg/m^3)	819.99	760.75
Coefficient of variation (%)	4.23	3.41
N	160	195

JW MW

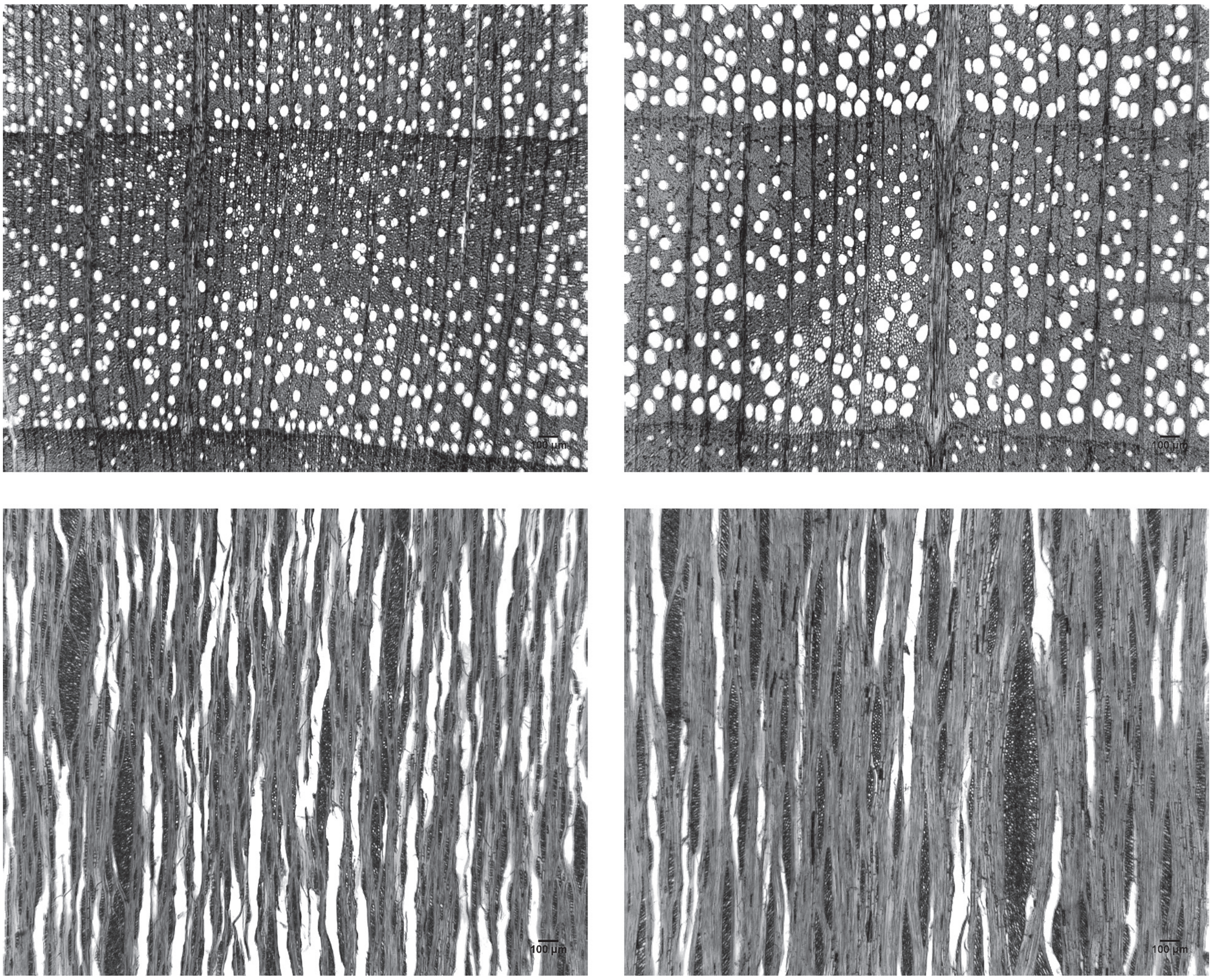

Fig. 1. Microscopic structure of juvenile and mature wood

The number of vessels and rays of all the analyzed images was recalculated per area. The results (Table 2) show that mature wood has a lower number of these units per area. The difference in the density of rays between JW and MW is highly considerable. The number of rays per 1 mm^2 is three times higher in juvenile wood – 29 rays/mm^2 in contrast with mature wood – 10 rays/mm^2. Mature wood has huge (multilevel) rays mainly, whereas narrow rays dominate in juvenile wood (see Fig. 1).

JW MW

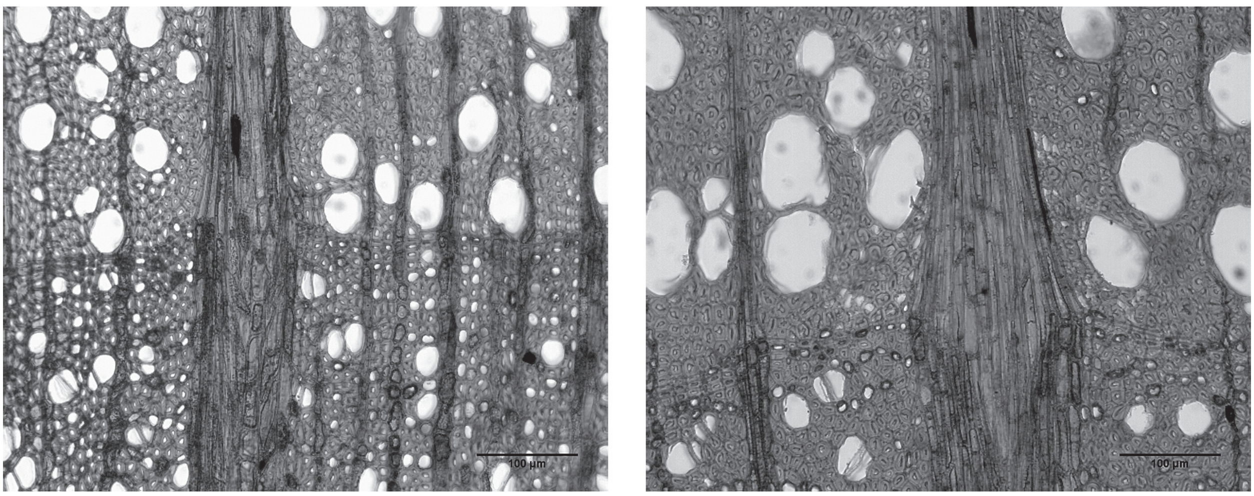

Fig. 2. Detail of distended ray along the ring boundary

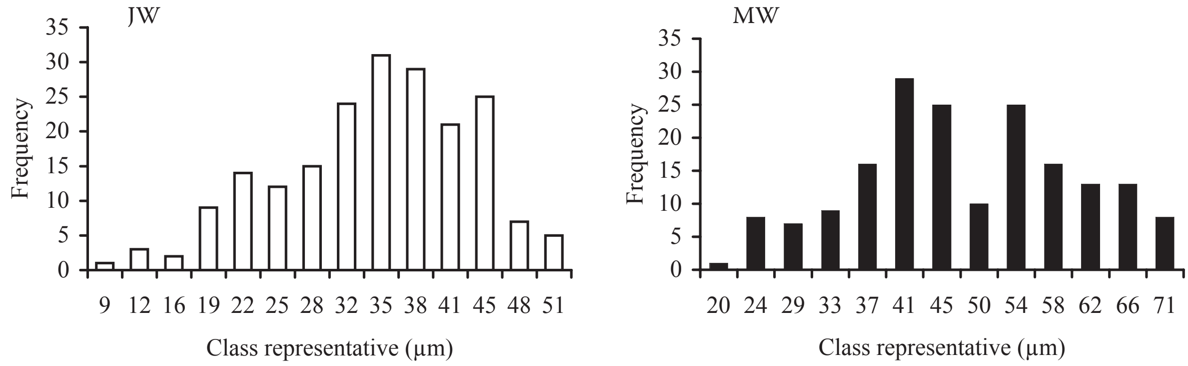

Fig. 3. Histogram of vessel diameters

The standardized test samples were used to determine the density of juvenile and mature wood. The results show that the juvenile wood density is slightly higher. The difference between juvenile and mature wood is 24.5 kg/m^3 in favour of juvenile wood. The average density of beech wood is 713.78 kg/m^3 with 12% moisture content. The descriptive statistics of wood density are presented in Table 3.

DISCUSSION AND CONCLUSIONS

Wood is a significant renewable raw material and many industrial fields, including forestry and timber industry, are dependent on it. In contrast to other industrial raw materials, it has a big advantage – it is renewable. It has a very variable structure and properties in comparison with other materials. The wood structure and the consequent properties are determined during the tree growth (Gryc, Horáček 2004). European beech (*Fagus sylvatica* L.) is one of the most important deciduous economic tree species not only in the Czech Republic but also in other countries of Central Europe.

Differences between juvenile and mature wood are well known in the conifers but much less work has been done on deciduous trees (Laming et al.

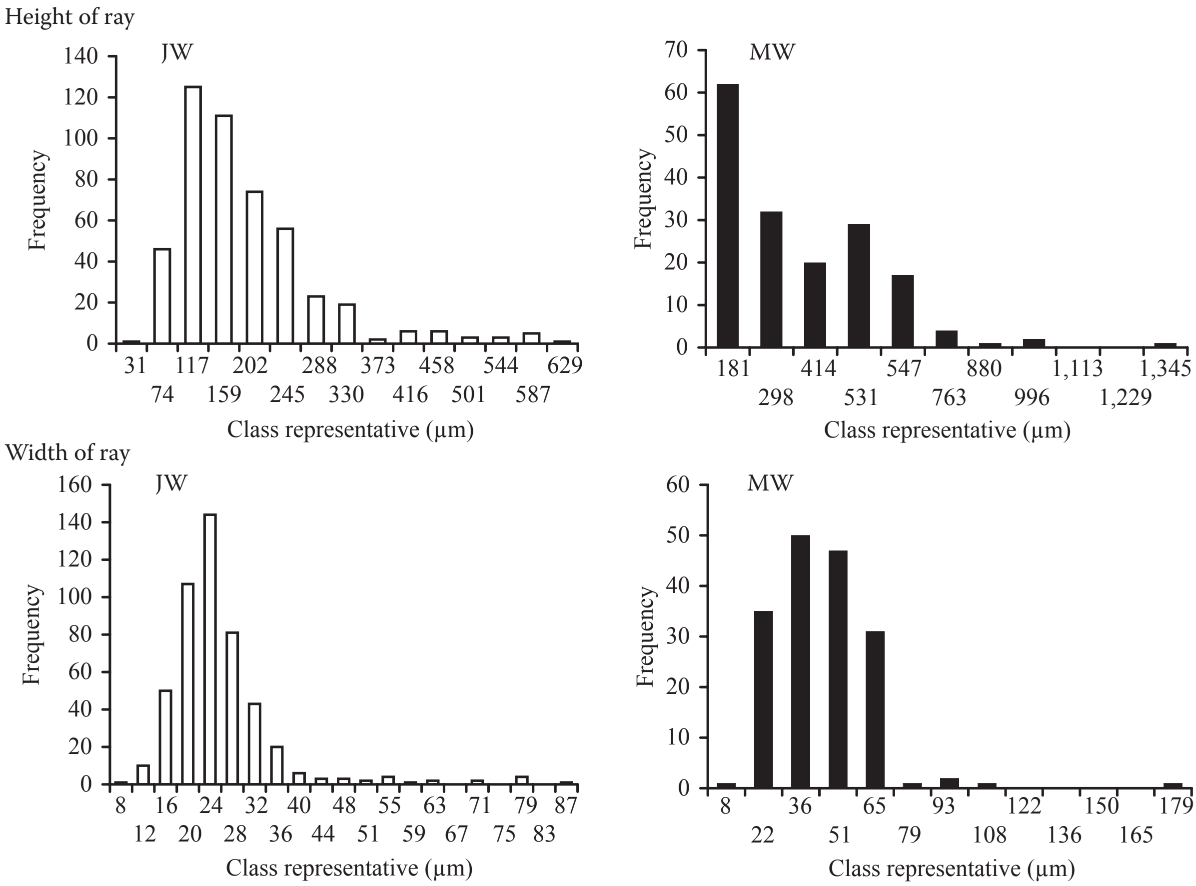

Fig. 4. Histogram of ray heights and widths

1971). The juvenile wood of deciduous tree species was observed to have shorter libriform fibres which have a smaller width of the cell wall (Koltzenburg 1966; Zobel, Sprague 1998; Adamopoulos 2006). Vessels, as an anatomic element with the conductive function, are of a smaller diameter, vessel segments are shorter and at the same time there are more of them in juvenile wood (Barcík et al. 2006; Adamopoulos 2006). The presented study of the juvenile wood of European beech has also confirmed that there is a higher number of vessels per area unit and the vessels are of a smaller diameter than in mature wood. Wagenführ (2000) reported the vessel diameter to be from 8 to 85 µm in the beech, the average value being 45 µm. The results presented in Table 1 are within the same range. The lower values (8–45 µm) correspond to juvenile wood, the average up to the maximum values correspond to mature wood. The lower frequency of vessels in mature wood is compensated by their larger diameter. This study has not concentrated on the total area of vessel lumens per area unit. Therefore, we cannot either reject or confirm the conclusions of Barcík et al. (2006), who found out a smaller area of vessels per area unit in the juvenile wood of *Populus tremula* than in the mature wood. If we calculate the total area of vessel lumens using the number of vessels per area unit and their diameters, we obtain the same results as Barcík et al. (2006), i.e. the larger area of vessel lumens in mature wood. The larger area of vessel lumens is necessary to supply water to a larger crown of a tree. This trend is the same for rays. There is only a third of the number of vessels per 1 mm^2 in mature wood but their dimensions, especially the length, are bigger.

Wood density depends on the wood structure. The wood density of coniferous and deciduous tree species with ring-porous structure is very variable along the stem radius, which is mainly caused by the decreasing tree-ring width and the decreasing percentage of late wood (in deciduous tree species with ring-porous structure) or by the increasing percentage of late wood in the tree-ring of conifers (Kollmann 1951). Only a moderate relationship between age and specific gravity exists in many of the diffuse-porous hardwoods, especially in most eucalypti and poplars, even though some hardwoods have a pattern of specific gravity where the highest values are near the pith and the lowest near the bark. The differences in juvenile and mature wood density are often smaller than for conifers (Zobel, Sprague 1998). A small difference was found in the wood density of the juvenile and mature wood of European beech. The low variability of wood density of deciduous tree species can be explained by small differences between the structures of early and late wood within one tree-ring. The average wood density of beech we have found out (713.78 kg/m^3) is not significantly different from the measurements presented earlier (Kollmann 1951; Cividini 1969; Wagenführ 2000).

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Vztah mezi mikroskopickou strukturou a hustotou dřeva u buku lesního (*Fagus sylvatica* L.)

ABSTRAKT: Cílem práce bylo srovnat stavbu juvenilního a zralého dřeva buku ve vztahu k hustotě dřeva (vlhkost dřeva 12 %). Pro srovnání stavby juvenilního a zralého dřeva byl hodnocen průměr cév, výška a šířka dřeňových paprsků, počet cév a dřeňových paprsků na 1 mm^2. Z výsledků vyplývá, že průměr cév, výška a šířka dřeňového paprsku mají v juvenilním dřevě menší rozměry než v případě dřeva zralého. Z hlediska četnosti cév na jednotku plochy není výrazný rozdíl mezi juvenilním a zralým dřevem. U hustoty dřeňových paprsků na jednotku plochy je rozdíl výrazný; juvenilní dřevo má třikrát větší počet dřeňových paprsků. Juvenilní dřevo má vyšší hustotu (ρ_{12} = 726,07 kg/m^3) než dřevo zralé (ρ_{12} = 701,50 kg/m^3).

Klíčová slova: buk; juvenilní dřevo; zralé dřevo; céva; dřeňové paprsky; hustota

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