Variation of wood density in Turkish hazel (*Corylus colurna* L.) grown in the Czech Republic

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ABSTRACT: The aim of this study was to investigate the wood density of Turkish hazel (*Corylus colurna* L.), an introduced species in the Czech Republic. Sample trees coming from a Czech site were tested for basic wood density and oven-dry density according to Czech National Standards. Four sections were taken from each tree to evaluate the variability of wood density along the stem height and along the stem radius. The mean values for the basic density and the oven-dry density were 544 kg·m^{-3} and 627 kg·m^{-3}, respectively. The results show that the highest density can be found in the bottom part of the tree, followed by a decline with the increasing height of the stem. For the radial direction from the pith to the bark, the pattern of density variability was more complex, reaching its highest value close to the cambium. Practically no correlation between annual ring width and density values was found out.

Keywords: *Corylus colurna* L.; wood; density; variability

Introduced species, in spite of legislative barriers and persistent resistance of some professional groups, are still a focus of forestry research in the Czech Republic. Non-native species often exceed domestic species in their production potential and other properties. A significant benefit, which often follows the introduction, is their greater ability to resist adverse conditions and various agents in comparison with native tree species. With respect to high volume production, Douglas fir (*Pseudotsuga menziesii* [Mirb.] Franco) and grand fir (*Abies grandis* [Dougl.] Lindl.) rank among the promising species, which exceed domestic tree species in this criterion (Beran 2006; Tauchman et al. 2010). The important soil-improving functions of these introduced tree species cannot be neglected (Podrázský et al. 2001; Podrázský, Remeš 2009). The awareness of the wood quality of introduced tree species growing in this country is insufficient, even though they often feature better wood properties compared to our related native tree species (Zeidler 2005). Surprisingly, despite considerable popularity in park and garden plantings, Turkish hazel (*Corylus colurna* L.) has remained outside the interest of the Czech forestry sector. In the countries of its original distribution it ranks among the commonly used commercial woody species (Němec et al. 2005). It is also an important source of tasty and nourishing nuts (Duke 2001). Turkish hazel is a tree which reaches a height of up to 20 m and rarely occurs in the form of a shrub. It is native to Southeast Europe, the Caucasus, Asia Minor, Iran and the Himalayas (Hejný, Slavík 2003). Heartwood is present mostly in older trees. Sapwood is wide, reddish, and the colour of heartwood is reddish-brown. The wood is characterized by the presence of aggregated rays (Kavina 1932). The occurrence of pith flecks (Němec et al. 2005) is also frequent. Turkish hazel belongs to a group of diffuse porous hardwoods by wood structure and vessel arrangement (Kavina 1932; Greguss 1959). The wood is described in the literature as medium-weight and moderately hard. It is well machined (Wagenführ 2004). The durability of the wood is quite low (Němec et al. 2005). The wood is mainly used for furniture making and for the production of decorative veneers (Kavina 1932). It is also popular for boulle making (Wagenführ 2004).

Wood density represents the weight of wood mass related to its unit volume. This is an essen-

Table 1. Description of sample trees of Turkish hazel

Sample tree	Diameter $d_{1,3}$ (cm)	Tree high (m)	High of first living branch (m)
1	23.5	15.5	7.5
2	29.0	17.3	5.3
3	27.5	18.4	8.7

tial feature of timber, as it significantly influences other wood properties (Zobel, Van Buitenen 1989). In particular, it closely correlates with the strength characteristics of wood (Sonderegger et al. 2008). The density is therefore widely used to estimate the strength characteristics of wood (Niemz 1993). The wood density value is greatly influenced by moisture content. For this reason, the oven-dry density of wood, with its uniqueness of determination, is used to compare results. In trade, where people work with fresh material, the basic wood density is used. This value describes the amount of wood mass in a volume of wood with a certain moisture. The volume of maximally swollen wood is normally used (Požgaj et al. 1997).

Due to exposure to both external and internal factors, the density is subjected to considerable variability. Apart from the kind of tree species (Simpson, TenWolde 1999), the value of the density is affected in particular by annual ring width, by the proportion of latewood within the annual rings, and the position within a stem (Kollmann 1951; Bosshard 1974; Panshin, De Zeeuw 1980). The presence of juvenile wood has a significant influence on density fluctuations within the stem in the radial direction, from the pith to the bark (Gryc et al. 2008a).

Turkish hazel is a less common introduced tree species in the Czech Republic that has been neglected from the perspective of wood properties. This article is one of the first outputs of comprehensive research focused on the physical and mechanical properties of wood from Turkish hazel grown in the territory of the Czech Republic. The objective of this study was to investigate the basic wood density and the oven-dry density of Turkish hazel wood, as well as their vertical and horizontal variability within a stem. The impact of annual ring width on the wood density was also evaluated.

MATERIAL AND METHODS

Three representative trees of Turkish hazel were sampled to test wood density and other physical and mechanical properties of wood. The locality where the trees were sampled was situated in the north-western part of Prague district, Central Bohemia. The height of the locality is about 280 m a.s.l. The average annual precipitation is around 500 mm and average temperature about 9°C. Although the sample trees did not come from a forest stand but rather from a plantation, they were from an extensive group of trees with the closed canopy cover. For this reason the trees had straight stems, free of any branches to a relatively great height. Selection of the representative trees for evaluation of wood properties took into particular consideration, in addition to a straight stem, the absence of other

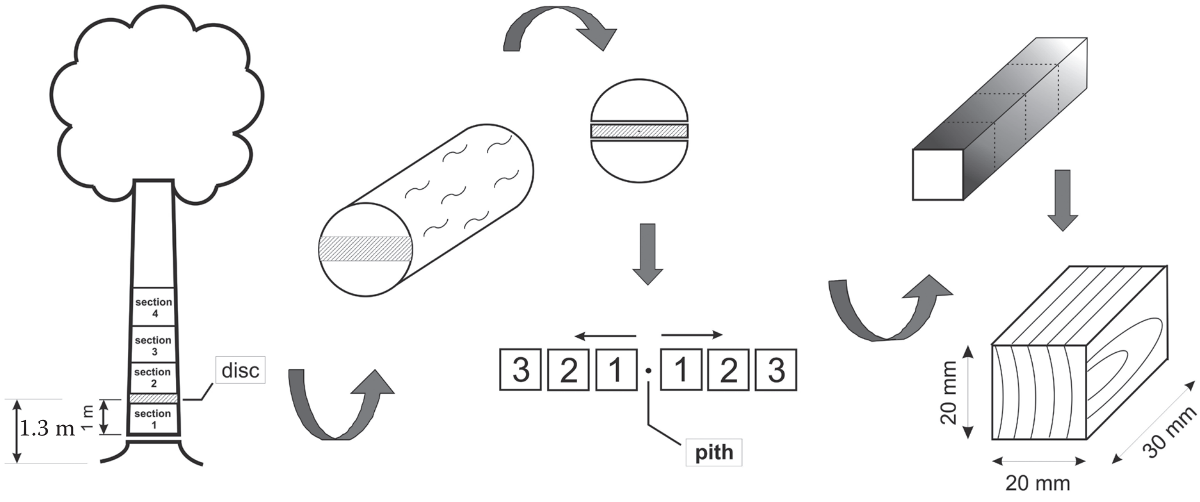

Fig. 1. Tree sampling and position of testing samples in the tree

growth irregularities and visible defects. Basic descriptions of the sample trees are given in Table 1.

The felled sample trees were cut into 4 sections, each 1 m long, in ascending order from the basal area up to the crown. Central boards were sawn from these sections and stored in a sheltered place to reduce moisture content. The remaining sections were further processed into boards used for the preparation of specimens for testing of selected mechanical properties.

Specimens 20 × 20 × 30 mm were made from the central board. The position of the testing sample from the aspect of the pith was in focus, in order to evaluate the variability of properties in the radial direction (Fig. 1). These specimens were used to determine density, shrinkage, hardness and compressive strength. All processes of the specimen preparation, selection and moisture content treatment as well as measurements were in accordance with the Czech National Standard CSN 49 0101.

In this study the basic density and the oven-dry density were the wood properties of Turkish hazel that were tested. Czech National Standard CSN 49 0108 was used for the density determination. To achieve a state of absolutely dry wood, the specimens were placed in a kiln and dried at 103°C. Determining the moisture content of wood was in accordance with the Standard CSN 49 0103. To reach a maximum volume the specimens were soaked in distilled water until the moisture content was above the fibre saturation point.

To assess the impact of annual ring width on wood density variability in the radial direction, a disk was cut from each sample tree at breast height. After sanding, the discs were scanned at a resolution of 1,200 dpi. The annual ring width was measured using NIS Elements software. The disks were also used to estimate the age of the trees.

Table 2. Basic statistical description for the wood density of Turkish hazel

	Basic density	Oven-dry density
N	370	370
Standard deviation (kg·m^{-3})	26	31
Coefficient of variation (%)	4.8	4.9
Minimum (kg·m^{-3})	483	551
Maximum (kg·m^{-3})	619	714

All data were statistically processed in the STATISTICA 9 software. The statistical significance of differences among the trees, sections or sets of specimens according to a distance from the pith was evaluated using the ANOVA method. Regression analysis was employed to explain the density fluctuations depending on annual ring width and position within the stem. For all statistical analyses the same significance level, $\alpha = 0.05$, was used.

RESULTS

The basic wood density and the oven-dry density of the tested Turkish hazel trees were 544 kg·m^{-3} and 627 kg·m^{-3}, respectively. A more detailed statistical description of the density is given in Table 2.

It was possible to find differences among the particular sample trees. The basic density of the first sample tree differed significantly from the remaining trees. The difference of the first tree was also statistically confirmed for the oven-dry density.

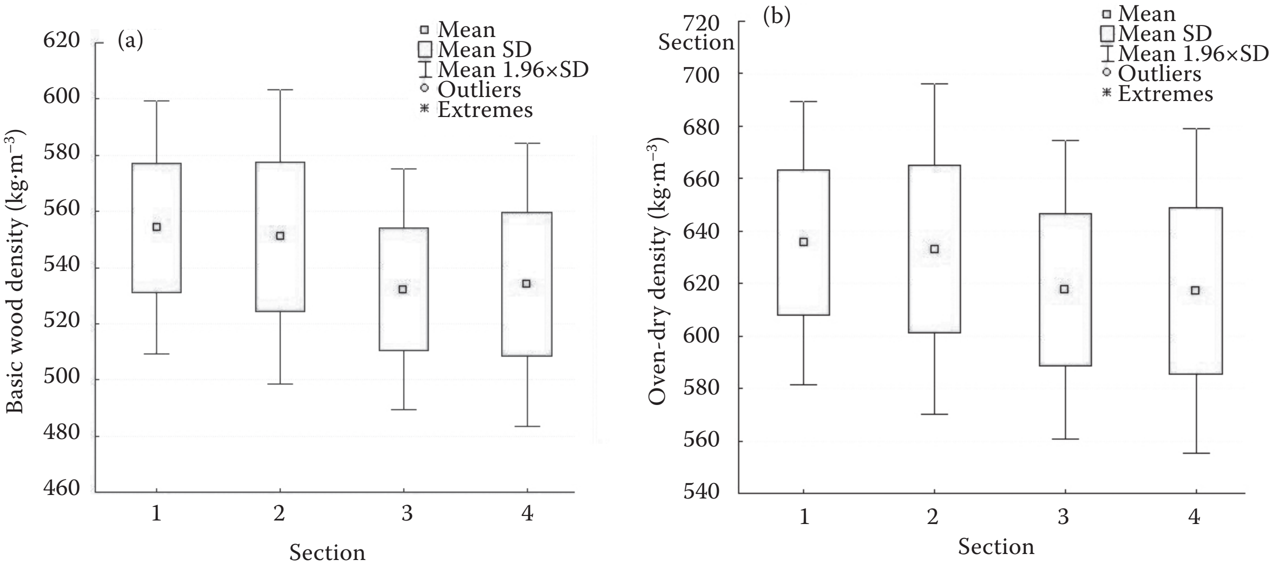

Fig. 2. Variation in the basic density and oven-dry density at various heights of the stem in Turkish hazel

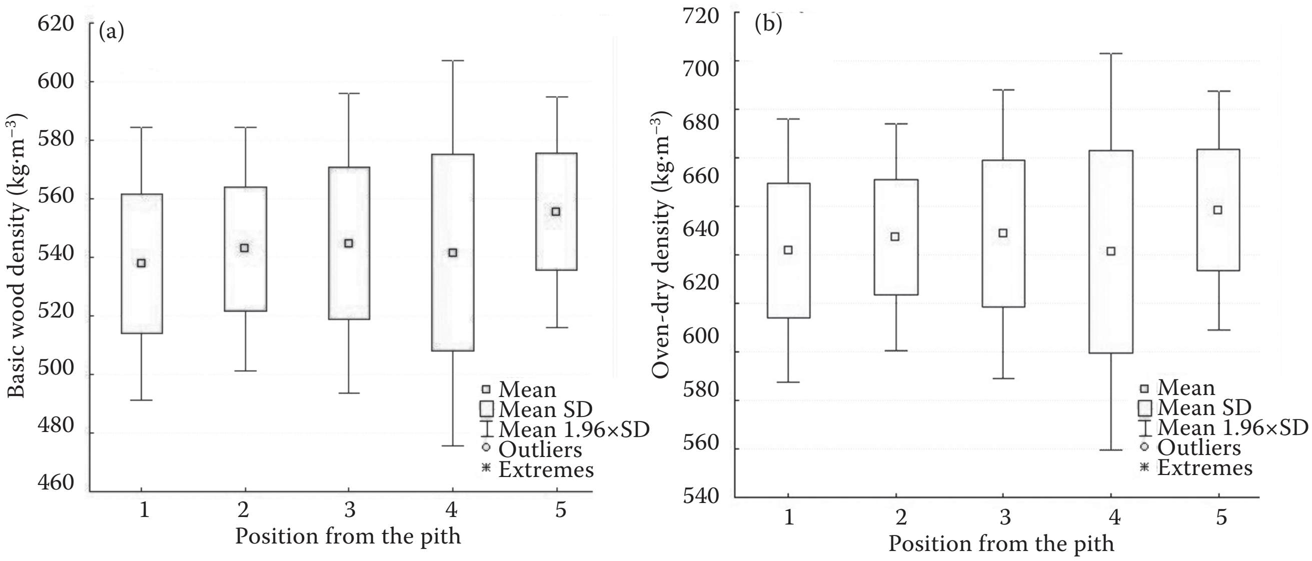

Fig. 3. Variation in the basic density and oven-dry density in the radial direction from the pith to the bark in the stem of Turkish hazel

The basic density of Turkish hazel was highest at the very bottom part of the stem and decreased with the increasing height of the tree. The same pattern for increasing height was observed for the oven-dry density (Fig. 2). The two bottom sections differed from the upper sections statistically in the case of both densities.

In the radial direction, from the pith outwards to the bark, the basic density rose initially. That increase was followed by a moderate decrease at 4/5 of the radius to be replaced again by an increase, reaching the highest value in the whole cross-section. Statistical tests confirmed a significant difference only between the first and the last zone. Distribution of the oven-dry density in the horizontal direction showed a very similar pattern (Fig. 3). The next-to-last zone featured a drop in the growth trend, and the highest value of the oven-dry density was found at the zone close to the bark. Statistically only the last zone differed from the previous zone.

Nonlinear regression models were used to fit the acquired data and predict variability of basic density and oven-dry density depending on the position in the stem (Fig. 4). The models indicate a decrease in density towards the crown and in the direction from the bark to the pith for both the basic density and the oven-dry density.

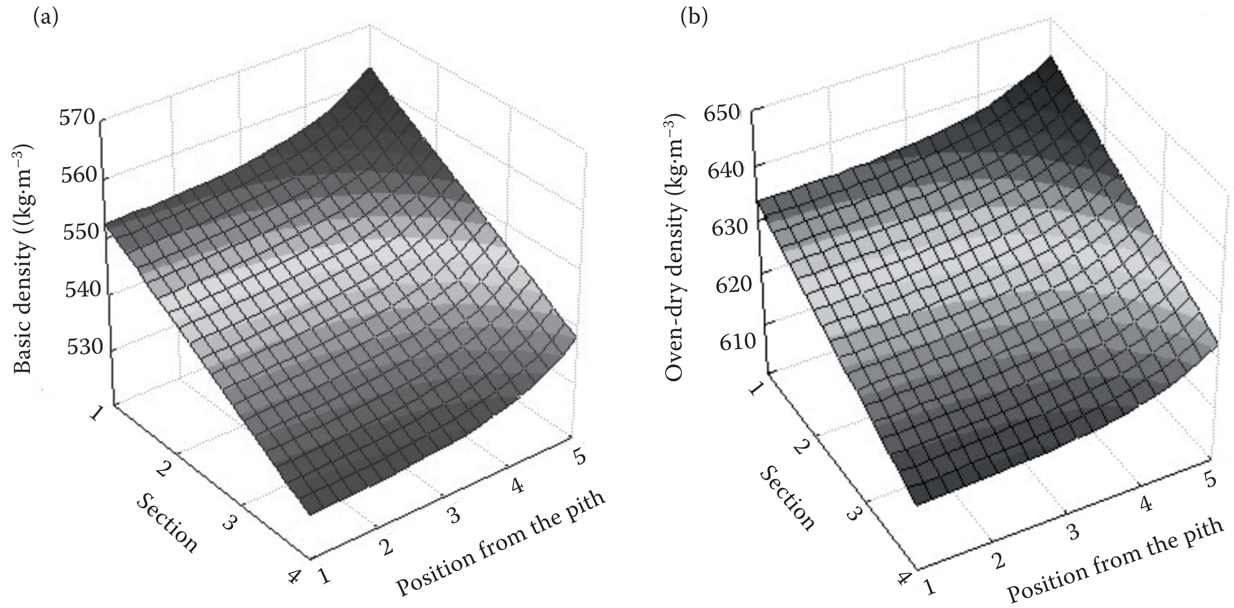

Fig. 4. Regression models for predicting the basic density (a) and oven-dry density (b) depending on the position within the stem

Table 3. Equations and coefficients of determination for regression models

	Equation	R^2
Basic density	$z = 560.5 - 8.23x + 0.071 \exp(y)$	0.14
Oven-dry density	$z = 640.3 - 6.92x + 0.067 \exp(y)$	0.08

Although the presented models are statistically significant, the coefficients of determination are quite low. The equations and the coefficients of determination are presented in Table 3.

The number of annual rings at breast height varied from 34 (sample tree 1) to 38 (sample tree 2) and to 41 (sample tree 3). In any case, we cannot speak about the felling maturity of sample trees. Average annual ring width for the evaluated trees was 3.2 mm. The average annual ring width was very similar on the level of individual sample trees, while a statistical test did not confirm any significant differences. The width of the annual rings increases from the pith to the middle of the radius, and then this trend is followed by a decrease (Fig. 5). This pattern of annual ring width distribution is similar for all sample trees.

Table 4. Comparison of the oven-dry density of Turkish hazel and selected native commercial species

Tree species	Oven-dry density (kg·m^{-3})
Turkish hazel	627
European birch*	610
Norway maple*	620
Sessile oak*	650
European beech*	680

*Lexa et al. (1952)

The density value has a very low correlation with annual ring width in the Turkish hazel wood. The linear regression model explained only a negligible part of density fluctuation. The coefficients of determination obtained for the basic density and the oven-dry density were only 0.05 and 0.06, respectively.

DISCUSSION

Korkut et al. (2008) reported a value of 699 kg·m^{-3} for the oven-dry density of Turkish hazel. The tested trees came from Turkish sites and therefore represented the wood density of this species in native areas. The wood density reached in the Czech Republic is lower. It is necessary to stress that sample trees in the Turkish research were grown in mountain areas, on steep slopes, and that the site conditions were totally different compared to the experiment presented in this article. Moreover, it could be supposed that those mature trees contained a different proportion of juvenile wood compared to the quite young tested trees from the Czech area. Further testing material from different sites would be necessary to assess the influence of site and age on the density value.

A surprisingly low value of variability was obtained for the tested Turkish hazel wood. The coefficients of variation for the basic density and the

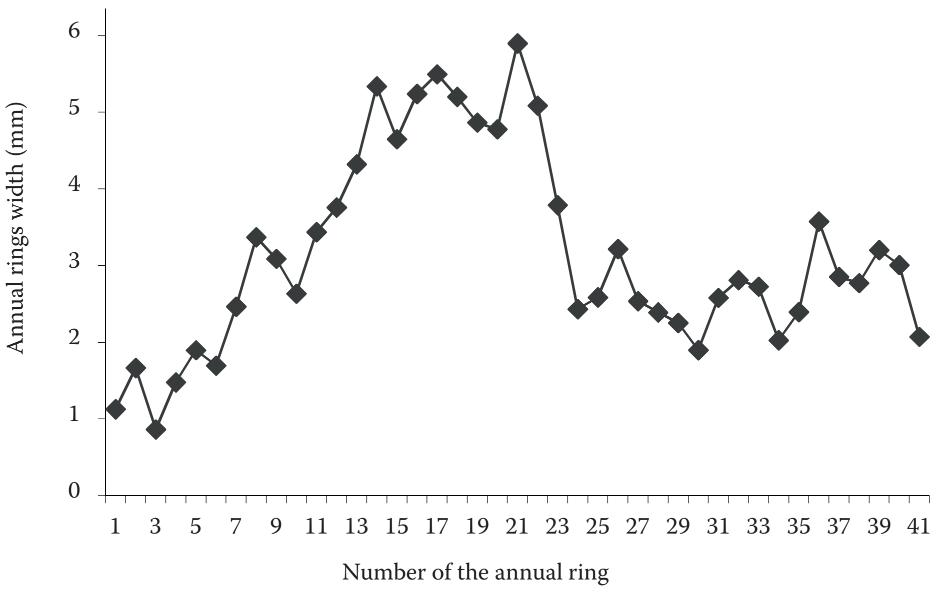

Fig. 5. Annual rings width (pith to bark direction)

oven-dry density were 4.8% and 4.9%, respectively. A common value for the coefficient of variation for wood density is about 10% (Novák 1970; Simpson, TenWolde 1999). In the case of the tested trees, the coefficient value is reduced by half.

Wood density is widely used as quite a reliable indicator of other important wood properties. From that aspect, the evaluated Turkish hazel wood could resemble Czech native species such as European birch, Norway maple, and sessile oak. Not even does European beech substantially exceed the tested Turkish hazel wood in terms of wood density (Table 4).

In hardwoods the variability of wood density in the radial direction is closely connected with anatomical structure, especially with the proportion of vessels and fibres and their cell wall thickness. In the group of diffuse porous species, it is difficult to find any explicit trend in this direction compared to softwoods or ring porous hardwoods (Panshin, De Zeeuw 1980). The study of Kord et al. (2010) reported a pattern of increasing wood density from the pith to the bark for *Populus euramericana.* On the other hand, Gryc et al. (2008b) found a downward trend in that direction for European beech. In the case of willow, no impact of the horizontal position in a stem on the wood density value was confirmed (Sennerby-Forsse 1989). The complexity and ambiguity surrounding the issue of wood density variability in the radial direction in diffuse porous hardwoods was demonstrated by Kärki (2001) for European aspen, and by Bhat and Karkkainen (1981) for birch. The wood density of those species grew, decreased or was constant in the radial direction depending on the vertical position in those species.

Similarly to the horizontal variability, it is difficult to generalize the course of vertical variability within a stem in diffuse porous hardwoods (Panshin, De Zeeuw 1980). Zobel and Van Buitenen (1989) found out a decrease in wood density with increasing stem height for some species with the diffuse porous wood structure. A decrease in the wood density value with increasing tree height was also observed as an axial variation pattern in *Populus euramericana* (Kord et al. 2010). In European aspen the wood density also decreased at first, but the value started to rise from the middle part of the tree (Kärki 2001). Nevertheless, the ambiguity of this issue was reported by other authors. Birch wood density rose up to the crown, followed by a drop in the upper part (Sennerby-Forsse 1989), and no trend was found even for the vertical variability in eucalyptus (Rao et al. 2002).

Bouriaud et al. (2004) reported a negligible impact of annual ring width on the wood density value. Niemz (1993) stated that in general there did not exist a relationship between these two variables in diffuse porous hardwoods.

CONCLUSION

The results of this research confirmed that Turkish hazel should not be regarded as an inferior tree species from the perspective of wood quality. If we perceive wood density as one of the most important wood quality indicators, then Turkish hazel represents a suitable alternative to some of our native commercial species, especially maple, birch and to some extent even beech. Although the tested trees were not mature in terms of harvesting, the results do not differ significantly from indigenous areas. Despite the very low coefficient of determination, it is possible to find some trends in the model describing the within-stem variability of wood density. The highest value of wood density could be found in the basal part of the stem, and this value decreased in the direction towards the crown. In the horizontal direction the trend of wood density variation is more intricate. Nevertheless, even in the radial direction it is possible to trace an increase in the wood density value in the direction from the pith to the bark. The annual ring width cannot be used as a criterion for wood density estimation, as hardly and correlation between wood density and ring width was found. The tree species composition in Central Europe is relatively poor. Moreover, wood from those species is mostly light in colour with an often plain and therefore less attractive grain. From that aspect, Turkish hazel wood could lead to market enrichment, and the wood processing industry would benefit from its timber.

References

Beran F. (2006): Některé poznatky z hodnocení mezinárodního provenienčního pokusu s jedlí obrovskou – *Abies grandis* (Douglas) Lindl. [Some results from evaluation of the international provenance experiment with Grand fir - *Abies grandis* (Douglas) Lindl. – in the Czech Republic area.] In: Neuhöferová P. (ed.): Douglaska a jedle obrovská – opomíjení gigantic. [Douglas Fir and Grand Fir – Neglected Giants.] Prague, 12.–13. October 2006. Prague, Czech University of Life Sciences: 17–28.

Bhat K.M., Karkkainen M. (1981): Wood anatomy and physical properties of wood and bark in *Betula tortuosa* Ledeb. Silva Fennica, ***15***: 148–155.

Bosshard H.H. (1974): Holzkunde. Band 2. Basel, Stuttgart, Birkhäuser Verlag: 312.

Bouriaud O., Breda N., Le Moguedec G., Nepveu G. (2004): Modelling variability of wood density in beech as affected by ring age, radial growth and climate. Trees, ***18***: 264–276.

Duke J.A. (2001): Handbook of Nuts. Boca Raton, CRC Press: 343.

Greguss P. (1959): Holzanatomie der Europäischen Laubhölzer und Sträucher. Budapest, Akadémiai Kiadó: 335.

Gryc V., Vavrčík H., Rybníček M., Přemyslovská E. (2008a): The relation between the microscopic structure and the wood density of European beech (*Fagus sylvatica* L.). Journal of Forest Science, ***54:*** 170–175.

Gryc V., Vavrčík H., Gomola Š. (2008b): Selected properties of European beech (*Fagus sylvatica* L.). Journal of Forest Science, ***54***: 418–425.

Hejný S., Slavík B. (2003): Květena České republiky 2. [Flora of the Czech Republic 2.] Praha, Academia: 540.

Kärki T. (2001): Variation of wood density and shrinkage in European aspen (*Populus tremula*). Holz als Roh- und Werkstoff, ***59***: 79–84.

Kavina K. (1932): Anatomie dřeva. [Wood Anatomy.] Praha, Ministerstvo zemědělství Československé republiky: 296.

Kollmann F. (1951): Technologie des Holzes und Holzwerkstoffe 1. Berlin, Springer-Verlag: 1050.

Kord B., Kialashaki A., Kord B. (2010): The within-tree variation in wood density and shrinkage, and their relationship in *Populus euramericana*. Turkish Journal of Agriculture and Forestry, ***34***: 121–126.

Korkut D.S., Korkut S., Bekar I., Budakçi M., Dilik T., Cakicier N. (2008): The effects of heat treatment on the physical properties and surface roughness of Turkish hazel (*Corylus colurna* L.) wood. International Journal of Molecular Sciences, ***9***: 1772–1783.

Lexa J., Nečesaný V., Paclt J., Tesařová M., Štofko J. (1952): Technológia dreva I. – Mechanické a fyzikálne vlastnosti dreva. [Wood Technology I. – Mechanical and Physical Properties of Wood.] Bratislava, Práca: 436.

Němec J., Jandáček V., Hurda B. (2005): Dřevo – historický lexikon. [Wood – Historical Lexicon.] Praha, Grada: 78.

Niemz P. (1993): Physik des Holzes und der Holzwerkstoffe. Weinbrenner, DRW-Verlag: 243.

Novák V. (1970): Dřevařská technická příručka. [Wood Handbook.] Praha, SNTL: 748.

Panshin A.J., De Zeeuw C. (1980): Textbook of Wood Technology. New York, McGraw-Hill: 722.

Podrázský V., Remeš J. (2009): Soil-forming effect of Grand fir (*Abies grandis* [Dougl. ex D. Don] Lindl.). Journal of Forest Science, ***55***: 533–539.

Podrázský V., Remeš J., Liao C.Y. (2001): Vliv douglasky tisolisté (*Psedotsuga menziesii* [Mirbel] Franco) na stav humusových forem lesních půd – srovnání se smrkem ztepilým. [Effect of Douglas fir (*Pseudotsuga menziesii* [Mirbel] Franco) on the humus form state of forest soils – comparison with Norway spruce.] Zprávy lesnického výzkumu, ***46***: 86–89.

Požgaj A., Chovanec D., Kurjatko S., Babiak M. (1997): Štruktúra a vlastnosti dreva. [Wood Structure and Properties.] Bratislava, Príroda: 485.

Rao R.V., Shashikala S., Sreevani P., Kothiyal V., Sarma C.R., Lal P. (2002): Within tree variation in anatomical properties of some clones of *Eucalyptus tereticornis* Sm. Wood Science and Technology, ***36***: 271–285.

Sennerby-Forsse L. (1989): Wood structure and quality in natural stands of *Salix caprea* L. and *Salix pentandra* L. Studia Forestalia Suecica, ***182***: 1–17.

Simpson W., TenWolde A. (1999): Physical Properties and Moisture Relations of Wood, Wood Handbook – Wood as an Engineering Material. Madison, US Department of Agriculture, Forest Service: 463.

Sonderegger W., Mandallaz D., Niemz P. (2008): An investigation of the influence of selected factors on the properties of spruce wood. Wood Science and Technology, ***42***: 281–298.

Tauchman P., Hart V., Remeš J. (2010): Srovnání produkce porostu douglasky tisolisté (*Pseudotsuga menziesii* [Mirbel] Franco) s porostem smrku ztepilého (*Picea abies* [L.] Karst.) a stanovištně původním smíšeným porostem středního věku na území ŠLP v Kostelci nad Černými lesy. [Comparison of production of *Pseudotsuga menziesii* [Mirbel] Franco stand with *Picea abies* (L.) Karst. stand and original mixed broadleaved stand of middle age in the territory of School Training Enterprise Kostelec nad Černými lesy.] Zprávy lesnického výzkumu, ***55***: 187–193.

Wagenführ R. (2004): Bildlexikon Holz. Leipzig, Fachbuchverlag: 370.

Zeidler A. (2005): Valuable Tree Species in Forest Stands of the Czech Republic – Black Cherry. Zeszyty Naukove, ***419***: 471–478.

Zobel B.J., Van Buitenen J.P. (1989): Wood Variation, Its Causes and Control. Berlin, Springer-Verlag: 363.

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