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STEM QUALITY OF *QUERCUS CERRIS* TREES FROM KOSOVO FOR THE SAWMILLING INDUSTRY

Quercus cerris is an important species in the forests of Kosovo with a potential high economic value, although there is little information on the stem quality for the saw-milling industry. This study brings data on wood properties, particularly on heartwood, sapwood and bark development within Q. cerris trees grown in two sites in Kosovo, where mature trees were felled, and discs taken at different stem height levels.

The average radial growth rate was 1.21 and 1.76 mm yr^{-1} for both sites. Heartwood decreased from the tree base upwards with a proportion of 53% and 43% until 5 m of height in the two sites. The radial width of sapwood was higher at the stem base (on average 44 mm) and afterwards approximately constant at 32 mm. The taper was low at an average 3.3 mm m^{-1} between 3.3 and 7.3 m of height. Bark represented on average 16.4% of the total stem cross-section and contained a substantial proportion of rhytidome (51% of the total bark area proportion at stem base and 41% at 9.3 m).

Q. cerris in Kosovo showed good potential as a timber species for the supply of stem wood to the saw-milling industry, allowing good yields of heartwood-only sawn wood components. The bark should also be considered for complementary valorization.

Keywords: *Quercus cerris*, heartwood, sapwood, bark, ring width, growth rate, taper

Introduction

Quercus cerris, the Turkey oak, is native to the southern, central and southeastern part of Europe, extending into southwestern Asia [Danielewicz et al. 2014]. It is a large, fast-growing deciduous tree, tolerating a range of soil

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types and is able to quickly colonize open areas. It can withstand air pollution, is relatively tolerant to drought and has an attractive appearance, thereby often being planted as an ornamental in urban areas [Preston et al. 2002; Sterry 2007].

The Turkey oak may represent an important forest resource in its natural habitat regions or in areas where it was introduced [de Rigo et al. 2006]. It is useful for reforestation, erosion control and soil conservation [Mert et al. 2016] as well as a potential cork provider [Sen et al. 2011; Sen et al. 2016].

Regarding the timber value of the species, the wood has been used mainly for low-value applications, such as firewood and railway sleepers, and has not been considered for more demanding applications e.g. carpentry, due to its low dimensional stability and low durability, mainly of the sapwood [Giordano 1981] and difficulties with gluing [Lavisci et al. 1991]. The colour differences between the dark heartwood and the light sapwood and their irregular margins also contribute to the under-valuation of the species, but some studies were recently made to improve the wood properties and to homogenize surface colour by using heat and steaming treatments [Tolvaj and Molnart 2006; Todaro 2012; Todaro et al. 2012; Todaro et al. 2013]. Other properties of Turkey oak wood were also investigated, e.g. density and moisture [Monaco et al. 2011] and bending strength [Karastergiou et al. 2005].

Overall, there is little information on the Turkey oak wood, namely regarding the species stem quality for the saw-milling industry, e.g. the within--tree development of heartwood and ring width. In general, heartwood has a higher natural durability and aesthetic value and is therefore preferred for wood products [Pereira et al. 2003]. The development of heartwood and the sapwood was not characterized for *Q. cerris*. This information is of interest for stem quality evaluation for use in saw-milling for the production of wood components [Sousa et al. 2013].

This study brings data on heartwood and sapwood development within *Q. cerris* trees grown in two sites in Kosovo, in view of increasing the value of its exploitation as a timber species for the saw-milling industry. It also includes an analysis of bark content anticipating its possible valorization under a full resource use approach.

In Kosovo, forests cover 481 000 ha, representing 44.7% of the total area of the country, and are dominated by broadleaved trees, covering up to 93 % of the total forest area [Tomter at al. 2013]. The growing stock includes mainly *Fagus* and *Quercus* spp that account for 46% and 23% of the volume respectively. *Q. cerris* is the major oak species with 4.28 billion m^3, followed by *Q. petrea* with 3.67 billion m^3 and other oak species with 1.29 billion m^3. The national forest inventory from 2002 estimated the annual allowable cut at around 900 000 m^3/year gross, of which 55% is fuelwood [Mitchell 2009]. However, in the past decade, the annual allowable cut calculated and legally available for harvesting through the current system of forest management planning was under 200 000

m^3/year [Harou and Hajredini 2009]. Due to the country's recent history, exact statistical data on timber harvesting is still scarce and difficult to obtain.

The development of a wood products industry is recognized as an important component for enhancing the economic growth of Kosovo. Today the wood industry only uses roundwood for producing lumber in sawmills (over one hundred mills located over the country) and for firewood. A production increase of sawn products from beech and oak is possible given the potential supply surplus, but will require an effective availability of quality logs [Bajraktari et al. 2014] as well as a sustainable production of fuelwood [Bouriaud et al. 2014].

The overall objective is to enrich the raw-material supply to the wood industry and to improve the economic and technological performance of *Q. cerris* trees for quality timber products.

The main objective is the assessment of the stem quality of *Q. cerris* trees, through the study of tree growth and ring width, heartwood and sapwood variation, bark development and taper.

Materials and methods

The data regarding the location and tree are displayed in table 1.

The study was based on 10 mature trees of *Quercus cerris* L. sampled from two stands in Blinaja and Duboçak, in Kosovo. Both stands were harvested to produce logs for the saw-milling industry.

Table 1. Data regarding location and trees

	Site KB	Site KD
Coordinates	42°30'31" – 42°30'38" N and 20°59'06" – 20°59'152" E, at 650-697 m of altitude	42°51'20" – 42°51'23" N and 20°43'50" – 20°44'02" E, at 817-885 m of altitude
Climate	moderate continental climate and continental climate	
Annual average air temperature	11.3°C (-1.7°C – 21.4°C)	10.4°C (-1.5°C – 20.7°C)
Average annual precipitation	609.8 mm	604.8 mm
DBH (average)	243.9 mm	214.3 mm
Total tree height (m)	17.8 m	11.1 m

Results and discussion

The sampled *Q. cerris* trees were representative of the wood supply to the saw--milling industry in Kosovo. The stem showed distinct tree rings that were visible to the naked eye. The wood is ring porous (fig. 1) with wide pores in the earlywood in comparison to the small pores in latewood, that allowed distinct ring boundaries and easy ring counting and measurement. The heartwood was clearly singled out from the sapwood by a darker brown color. In the bark, it was possible to make the distinction between the phloem and the rhytidome in the cross-section; the rhytidome showed large longitudinal running fissures (fig. 1).

Fig. 1. Part of a stem cross-section of *Quercus cerris* Lam. showing the colour differences between heartwood and sapwood, the visible annual rings and the bark with distinction between phloem (to the inside) and rhytidome (to the outside)

Tree growth and ring width

The within-tree variation of radial growth is exemplified in figure 2 for both sites, by plotting the cumulative radial dimensions measured along the stem as a function of tree height.

The radial growth in the trees measured at breast height from the two sites is shown in figure 3 as the mean ring width from pith to bark. The cambial ages attained on average was 66 and 80 years at breast height respectively in KB and KD. Overall, there was a radial variation of ring width with a steady decrease along the first 15 rings and afterwards maintaining a rather constant mean value in spite of the inter-annual fluctuations.

Table 2 displays data for both sites, on mean annual ring width, mean annual ring for the initial growth in the first 20 years from pith, and mean annual ring for the mature growth in the 45 to 65 years of cambial age.

In both sites, the mature growth rate was similar, but the initial growth was considerably higher at KB than at KD.

The radial variation of the annual growth rate found here for *Q. cerris* was similar to previous reports for the same species: a growth rate of 2.2-2.9 mm in the first 15 years and 1.5-1.7 mm afterwards until 25 years [Manetti 2002]. For

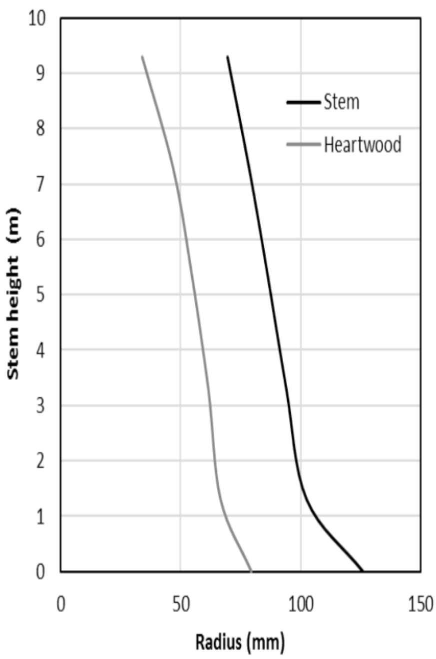

Fig. 2. Radial dimensional variation at different height levels along the stem for the *Quercus cerris* trees from KD

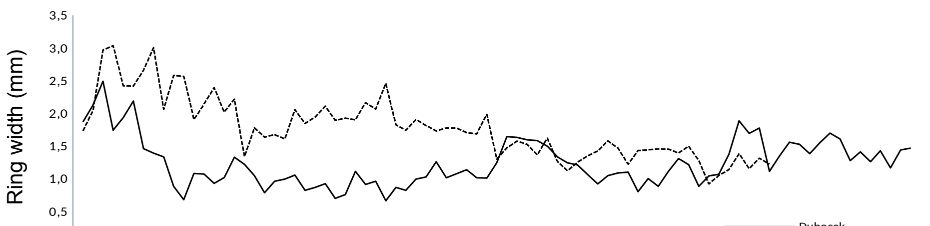

Fig. 3. Variation of average tree ring width with cambial age at 1.3 m of height of *Quercus cerris* trees at the two sites

45-58-year-old *Q. cerris* trees sampled in Italy, the mean annual radius increment was 2.3 mm [Corona et al. 1995]. The values are also similar to those reported for other oaks: Corcuera et al. [2006] found a radial ring width decrease of approximately 1.6 mm to 0.5 mm for a cambial age of 35-41 years in *Q. pyrenaica*; Sousa et al. [2013] reported a decrease in ring width from 2.8--1.2 mm to 1.5-1.0 mm for cambial ages of 30-40 years for *Q. faginea* while widths between 1.5 mm and 1.9 mm were reported for *Q. petraea* and *Q. robur*

[Zhang et al. 1993; Degron and Nepveu 1996]. Tree ring width in *Q. suber* also showed a decrease in cambial age with an average of 3.3 mm in the beginning of cambial activity to an average of 1.1 mm at 26 years of age [Leal et al. 2008].

Table 2. Tree growth variables for *Quercus cerris* trees (mean ± standard deviation) from two sites KB and KD in Kosovo measured at 1.3 m height: RW - mean annual ring width; IRW - mean annual ring for the initial growth in the first 20 years from pith; MRW – mean annual ring for the mature growth in the 45 to 65 years of cambial age

	Annual growth rate (mm yr^{-1})
	Site KB
RW	1.76 (0.57)
IRW	2.22 (0.62)
MRW	1.34 (0.28)

In spite of the radial variations of ring width found in the sampled *Q. cerris* trees, the overall variations were of small magnitude and therefore the stem showed considerable homogeneity. This indicates that the within-tree variation of properties will not be detrimental to the product value.

Heartwood and sapwood variation

Heartwood was present in all the trees until the maximal sampling height of 9.3 m. The vertical development of heartwood (fig. 4) was similar in all the trees, decreasing from the tree base upwards, with the heartwood profile following closely that of the stemwood.

The variation of the heartwood diameter was highly significant in relation to site and height level ($P < 0.001$), but not to their interaction. The heartwood diameter was related to tree diameter at any height level (fig. 4); in fact, the diameter of heartwood in *Q. cerris* was strongly correlated with the stem diameter ($R^2 = 0.83$ and 0.88 in KB and KD, $p < 0.0001$). This result shows the possibility of modelling heartwood dimensions in *Q. cerris* standing trees by the measurement of tree diameter.

The correlation of the heartwood diameter with tree diameter has been reported for several species, e.g. *Acacia melanoxylon* [Knapic et al. 2006], *Eucalyptus globulus* [Gominho and Pereira 2000; Gominho and Pereira 2005], *Pinus pinaster* [Pinto et al. 2004] and *P. canariensis* [Climent et al. 2003].

The proportion of heartwood in the total stemwood cross-section remained stable in the lower part of the stem until about 5 m of tree height, after which it decreased to the upper height levels (table 3).

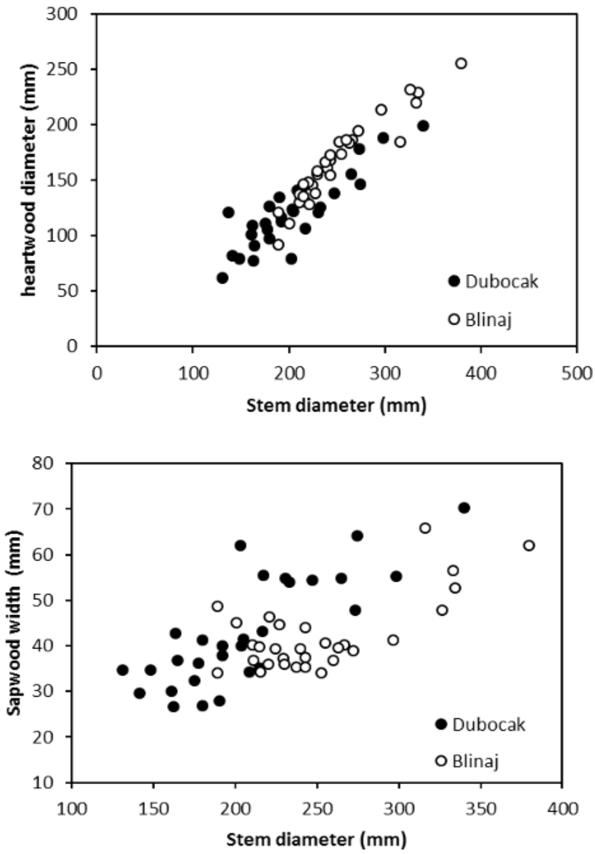

Fig. 4. Variation of heartwood radius and sapwood radial width with *Quercus cerris* tree diameters at different height levels at two sites (KB and KD) in Kosovo

Table 3. Variation along the tree height of *Quercus cerris* trees at two sites (KB and KD): total stemwood cross-sectional area (cm^2), heartwood proportion and sapwood width. Mean (standard deviation)

Height level	Site KB			Site KD		
	Cross-section wood area (cm^2)	Heartwood proportion (% of wood area)	Sapwood width (mm)	Cross-section wood area (cm^2)	Heartwood proportion (% of wood area)	Sapwood width (mm)
Base	756.9 (122.7)	52.5 (5.9)	42.5 (5.4)	511.3 (181.6)	40.7 (8.6)	46.3 (13.3)
1.3 m	469.9 (75.1)	57.2 (5.7)	29.7 (3.6)	333.8 (86.5)	43.2 (7.8)	35.6 (8.7)
3.3 m	407.2 (59.5)	54.4 (6.6)	29.7 (3.9)	281.2 (77.2)	43.9 (9.8)	32.2 (9.6)
5.3 m	371.4 (65.8)	51.2 (6.9)	30.9 (4.6)	234.0 (73.9)	41.1 (11.8)	31.6 (10.2)
7.3 m	333.3 (66.6)	48.1 (7.7)	31.3 (4.4)	196.9 (66.2)	37.0 (11.5)	34.4 (10.1)
9.3 m	285.9 (61.4)	43.6 (9.3)	32.7 (5.1)	155.9 (64.5)	25.6 (11.9)	35.1 (11.2)

There was a difference between the sites in the average heartwood proportion with the trees from KB showing more heartwood than the trees from KD: the average proportion until 5 m of height was 53% and 43% respectively.

The radial width of sapwood was higher at the stem base, where it represented on average 44 mm (table 3) and afterwards was approximately constant at 32 mm. There were no significant differences in sapwood development between the trees of both sites (fig. 4) but the analysis of variance showed that site ($P = 0.005$) and height level ($P < 0.001$) were significant factors of variation, but not their interaction.

The within-tree axial variations of heartwood and sapwood are in agreement with previous results for most species [Hillis 1987] e.g. for *Q. faginea* [Sousa et al. 2013]. The results also corroborate the theoretical background that, heartwood formation is a cumulative process that increases during tree growth, as required by the physiological conditions of the species, to maintain an approximately constant sapwood width [Bamber 1976]. In the case of the sampled *Q. cerris* trees, the sapwood area (at 1.3 m) averaged 199.30 cm^2 in KB, and 191.86 cm^2 in KD (table 3) while the average sapwood width of 3-4 cm is similar to values reported for other oaks e.g. *Q. faginea* (2-5 cm) [Sousa et al. 2013], *Q. petraea* (2 cm) [Granier et al. 1994] and *Q. robur* (3 cm) [Čermák et al. 1991]. The relatively small radial dimension of the sapwood of *Q. cerris* trees allow the production of sawn wood components that are mostly constituted by the more valuable heartwood.

Bark development

Bark represented on average 16.4% of the total overbark stem cross-section, with slightly higher values for the trees of KD in relation to KB (table 4). The mean bark proportion decreased from the base to the dbh level; it remained constant until the upper sampled level in KB representing 14% of the total area, while in KD it increased along the tree from 16% at bh to 20% at 9.3 m. Within the tree, the bark thickness was highest at the stem base (14.4 mm and 13.2 mm in KB and KD respectively) (table 4).

The analysis of the variance of bark thickness showed the significant influence of stem height level ($P = 0.451$) but not of site or their interaction. The analysis for bark proportion showed that the site ($P < 0.001$), stem height level ($P = 0.005$) and their interaction ($P = 0.020$) were significant factors of variation. This can be explained by the fact that there is a difference in age between the two sites.

The bark structure showed that the rhytidome proportion was highest at the stem base where it represented on average 51% of the total bark area (table 4). Rhytidome proportion decreased for the upper tree levels; at 9.3 m, it represented on average 41% of the total bark area.

Table 4. Variation along the tree height of *Quercus cerris* trees at two sites (KB and KD) of bark proportion, thickness, and rhytidome content. Mean ± standard deviation

Height level	Site KB			Site KD		
	Bark (% of total stem area)	Bark thickness (mm)	Rhytidome (% of bark)	Bark (% of total stem area)	Bark thickness (mm)	Rhytidome (% of bark)
Base	16.8 (3.0)	14.4 (2.2)	53.5 (3.2)	18.2 (2.4)	13.2 (2.6)	49.4 (6.0)
1.3 m	14.4 (1.0)	10.0 (1.8)	52.8 (4.2)	16.3 (1.2)	9.6 (0.8)	46.6 (5.1)
3.3 m	14.1 (0.9)	8.9 (1.1)	47.8 (3.9)	16.9 (1.1)	9.0 (0.8)	45.6 (5.9)
5.3 m	14.1 (0.4)	8.6 (1.0)	43.5 (5.9)	18.1 (1.5)	8.9 (0.6)	46.0 (8.4)
7.3 m	14.4 (0.4)	8.2 (0.9)	41.1 (4.4)	18.8 (1.6)	8.5 (1.1)	43.9 (5.7)
9.3 m	14.6 (1.0)	7.9 (1.2)	40.6 (5.4)	20.1 (1.1)	8.0 (1.3)	41.7 (2.7)

The analysis of variance of the proportion of rhytidome in the bark showed a highly significant effect of stem height level ($P < 0,001$) and a significant effect of site ($P = 0.366$) and their interaction ($P = 0.346$).

Bark development in trees is a cumulative process and the formation of rhytidome is age dependent. This explains the fact that the bark thickness was highest at the stem base and contained the highest proportion of rhytidome.

Taper

Stemwood taper and heartwood taper for the different logs are summarized in table 5.

Table 5. Stemwood and heartwood taper, in mm/m, between different stem height levels (mean ± standard deviation) of *Quercus cerris* trees in two locations (KB and KD) in Kosovo

Height level	Stemwood taper (mm/m)		Heartwood taper (mm/m)
	Site KB	Site KD	Site KB
Base-1.3 m	25.1 (2.3)	18.0 (8.4)	15.1 (2.8)
1.3-3.3 m	4.2 (0.7)	4.2 (1.2)	4.2 (0.5)
3.3-5.3 m	2.6 (1.3)	4.2 (2.2)	3.2 (0.9)
5.3-7.3 m	2.9 (1.3)	3.6 (0.5)	3.1 (0.8)
7.3-9.3 m	3.0 (1.7)	4.5 (0.8)	3.7 (0.7)

Taper was highest for the butt log especially from the base to 1.3 m height and higher for the trees in KB than in KD (25 vs. 18 $mm \cdot m^{-1}$). The central logs showed a very small taper e.g. from 3.3 to 7.3 m, taper averaged 2.8 and

3.9 mm·m^{-1} respectively in KB and KD. The heartwood showed similar taper values, namely for the tree base (table 5).

Overall the stems had a small conicity and very low taper values which stresses the stem quality of *Q. cerris* for sawn wood components with a potential low material loss from stem edges. The values compare favourably in relation to e.g. *Q. suber* stems with an average of 24 mm·m^{-1} taper [Knapic et al. 2011; Bembenek et al. 2013]. Moreover, lower taper may facilitate mechanized harvesting of hardwoods. In the case of better trunk quality (lower taper), we can expect higher accuracy of bucking and lower damage to the outer layer of roundwood [Bembenek et al. 2015].

Conclusions

Q. cerris trees grown in Kosovo showed good potential as a timber species for the supply of stemwood to the saw-milling industry. The growth rates were like those of other oaks and the stems showed an overall low radial heterogeneity of ring width as well as a very low taper.

The *Q. cerris* trees contained a substantial proportion of heartwood and the sapwood width was, on average 4 cm with small axial variation, therefore, allowing potentially good yields of heartwood-only sawn wood components. The bark content was high, especially in the lower part of the stem where it included a high proportion of rhytidome and should therefore be considered for complementary valorization.

The wood of *Q. cerris* showed suitable characteristics for the production of lumber in sawmills, hence contributing to a possible further enhancement of the wood products industry in Kosovo.

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