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EFFECT OF VARIABLE GROWTH CONDITIONS ON SELECTED ANATOMICAL PROPERTIES OF HUNGARIAN TURKEY OAK WOOD

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Abstract: *Quercus cerris (Turkey oak) has been categorised as a drought-tolerant species because it can survive with rainfall below 400 mm/year, and it usually develops deep and penetrating taproots. This characteristic suggests that Turkey oak is a survival candidate species to the future environment with the predicted climate scenarios in Hungary. Potentially, Turkey oak could support a sustainable supply of timber to the Hungarian wood industry in the future, as the aesthetic value is similar to that of noble oaks. The objectives of the study are to determine 1; the selected micro-level wood properties (wood tissue characteristics) and 2; the selected macro-level wood properties (tree-ring width, sapwood-heartwood ratio) for Turkey oak from two different sites. The heartwood portion for all trees constituted 67-82% of cross-diameter. The growth-ring width decreased from pith to bark. The annual rings in the sapwood had a width value range of 1000 to 1600 µm; in heartwood 1600 to 2500 µm; in juvenile wood 2400 to 3300 µm. Soil quality and stand composition had a significant effect on growth-ring width. Fibre length ranged from 800.03 to 1305.59 µm, whereas fibre-wall thickness varied between 11.73 and 18.51 µm, with soil quality and species composition having highly significant influence. The earlywood parts of the growth rings had a vessel diameter range of 274.62-401.54 µm, whereas the latewood portion ranged from 46.50 to 190.08 µm. Overall, stand composition was a major source of variation in the properties studied.*

Key words: *Turkey oak, tree ring width, sapwood-heartwood, fibre characteristics.*

1. Introduction

The global demand for wood will continue to grow larger despite the introduction of alternative competitive materials. Decades ago, the demand for wood was mainly attributed to the expected annual increment in human population which leads to more consumption of timber and wood

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products. Presently, the demand for timber in the construction industry is sustained because wood has proven to be energy efficient and provides low carbon buildings desired for today's urban environments. Gradually, it is being understood that the use of wood could help to address some of the current climate emergencies [25]. Currently, the traditionally known uses of wood and wood products (construction, indoor and outdoor furniture, pulp and paperproducts, fuelwood) are active. Meanwhile, scientific innovations have added other advanced wood utilisations such as for bioethanol production andnanotechnological applications [20, 21].

Wood is a renewable biomaterial produced from a single layer of meristematic cells called the vascular cambium [17, 22]. The functionality of the cambium is affected by factors including plant hormones, and climate variables such as temperature, precipitation, photoperiod, especially in the temperate and Mediterranean climatic zones. Generally, wood formation is an irreversible structural growth process [14]. It is influenced by genetics, age, edaphic conditions, silvicultural practices, and prevailing climate [22]. The complex wood formation process results in the formation of a unique internal structure, amongst others, useful for diagnostic purposes. The anatomical structure of every wood carries enormous amounts of information. It can uncover the conditions in which the tree has grown. Again, the internal structure of wood can be the base to forecast other propertiesof wood. For instance, fibre length and wall thickness influence the strength properties of wood; cell wall thickness and parenchyma content can influence wood natural durability in outdoor applications [6, 24].

Hungary is associated with three native oak species: *Quercus petraea* ((Mattuschka) Liebl.), *Q. cerris* (L.)*, and Q. robur* (L.). They are ecologically important because they thrive at different altitudes. Economically, oak forests are relevant to Hungary [2]. Turkey oak has been categorised as drought-tolerant because it can withstand annual rainfall below 400 mm and it usually develops deep and penetrating taproots [10, 23]. The aesthetic appearance of Turkey oak is likethat of noble oaks, making it a good substitute. These physiological and wood traits project Turkey oak as a potential contributor to the Hungarian wood industry in terms of raw material supply, amidst predicted climate warmings. This study focused on answering the question "Can soil quality and stand composition compromise the wood quality of Turkey oak in Vas County of Western-Hungary?". The specific objectives are to examine the effect of soil quality (poor and good) and stand composition (broadleaved-broadleaved mixed-species and pure-species stands) on 1; the characteristics of selected wood tissues (fibre, vessel) - 2; the annual growth-ring width, and 3; the sapwood-heartwood ratio.

2. Methodology

2.1. Materials

Wood samples of unknown genotype were randomly collected from four locations (Figure 1) in Vas County in Hungary. The materials were transported to the University of Sopron for further processing into experimental sample sizes. Some descriptions of the materials and sitesare provided in Table 1. The ages of the trees were determined by a careful count of the annual rings, after smooth sanding of the transverse surface of 5 cm thick wood discs taken from the breast-height level of each tree.

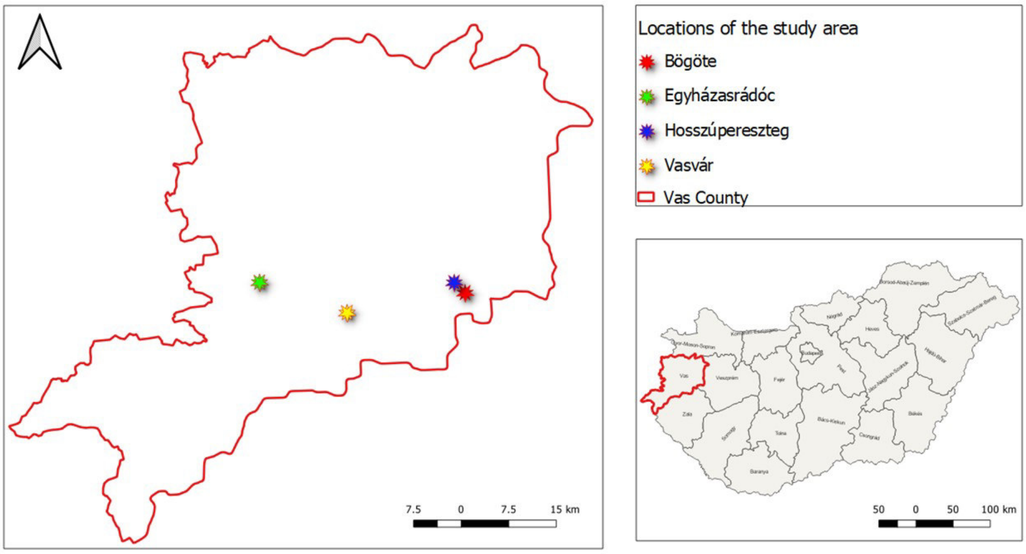

Fig. 1. *A map showing four study locations in Vas County in Hungary*

Description of study locations and materials Table 1

Location	Soil quality	Stand composition	Diameter (DBH) [cm]	Age [years]	Brief soil description
Bögöte	Good	Mixed-species	46	87	Rusty brown forest sandy soil. 60-100 cm deep
Bögöte	Good	Mixed-species	50	78	
Egyházasrádóc	Poor	Mixed-species	54	87	Brown forest loamy soil with slack water. 40-60 cm deep
Egyházasrádóc	Poor	Mixed-species	31	76	
Egyházasrádóc	Poor	Mixed-species	42	87	
Hosszúpereszteg	Good	Pure-species	54	129	Rusty brown forest sandy soil. 100 cm deep
Hosszúpereszteg	Good	Pure-species	54	123	
Vasvár	Poor	Pure-species	15	69	Rusty brown forest loamy soil. 60-100 cm deep
Vasvár	Poor	Pure-species	27	70	
Vasvár	Poor	Pure-species	23	68	
Vasvár	Poor	Pure-species	20	67	
Vasvár	Poor	Pure-species	18	69	

Abbreviations: DBH – diameter at breast height

The mixed species are broadleaved-broadleaved species of Sessile oak, Hornbean, Robinia, and European Ash.

The soil quality classification is dependent on a database developed for Hungarian land valuation [28].

2.2. Determination of Wood Tissue Dimensions

Wood samples were collected from both the sapwood and heartwood portion of each tree to absorb any variability within. The samples were macerated using protocols adopted in earlier studies [12].The samples were kept in labeled vials containing a solution of 1:1 glacial acetic acid and hydrogen peroxide and placed in a water-bath at 65°C. Complete maceration was achieved after 72 hours. The macerates were thoroughly cleaned with distilled water and allowed to rest for 24 hours. The fibres and vessels (Figure 2) were observed and measured using an advance microscope (Nikon Eclipse 80i, Nikon, Japan) with ProScan III software (Prior Scientific Limited, United Kingdom). Only straight and unbroken tissues (fibres and vessels) were measured.

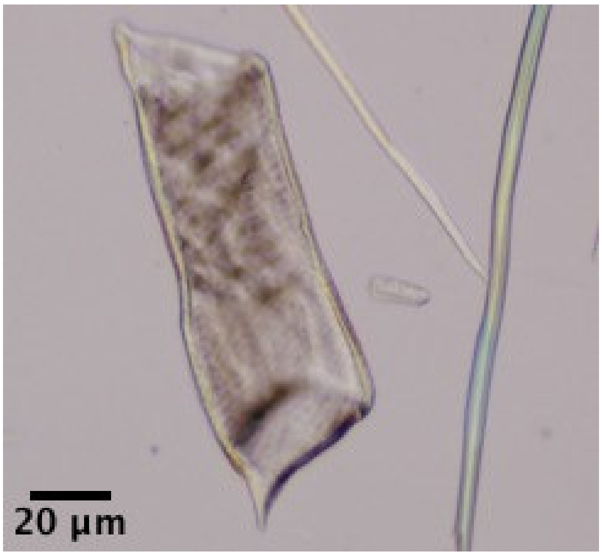

Fig. 2. *Vessel cell and portions of fibres*

2.3. Sapwood-Heartwood Proportion and Tree-Ring Width

The sampled discs had the typical distinct heartwood and sapwood portions, and their boundaries were not ambiguous. Four cross-diameter measurements were taken on each disc with a simple measuring tape (Figure 3). The heartwood portion was measured, and the sapwood portion deduced subsequently. Their proportions were expressed as a percentage of the mean cross-diameter.

Awood strip of about 3 cm width (Figure 4) was cut from bark to bark through the pith. The transverse surface of the wood strip was smoothened using a sand belt with grit size of up to 600. The clean and smooth surfaces of the strips were scanned using a flatbed scanner (CanonScan LiDE 110, Canon, Japan). The images were processed for annual growth-ring width measurement using the ImageJ software (National Institute of Health, United States of America) [1].

Fig. 3. *A disc of Turkey oak with a typical distinction between heartwood and sapwood*

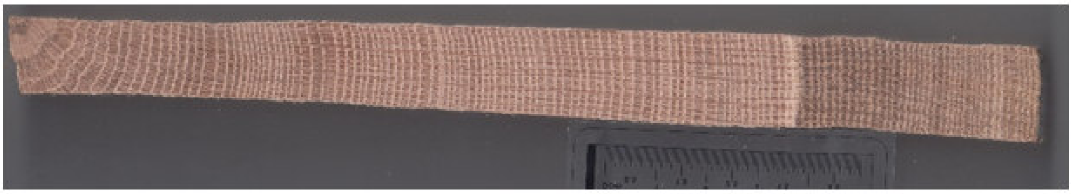

Fig. 4. *A wood strip (bark to pith) sanded to show annual growth rings*

The data was organized in Excel (version Office 365, Microsoft, United States of America) software and analysed in the R statistical package (The R Foundation, United States of America) [27]. An analysis of variance was done following Tukey Honest Significant Difference at 95% confidence level.

3. Results

3.1. Fibre Characteristics

The results on fibre characteristics, presented in the following figures and tables, are comparable amongthe studied trees. Figures 5 and 6 present the mean values indicating the singular influence of soil quality and stand composition on fibre length and fibre double wall thickness, respectively. These two traits were under focus because of their known influence on other strength properties. In solely considering soil quality, the mean values for fibre length for Turkey oak wood from good and poor soil were 1096.69±291 μm and 1179.59±201 μm, respectively. The fibre double wall thickness values were 13.7±5.24μm and 16.67±4.98 μm, respectively. Regarding stand composition, the fibre lengths for mixed- and pure-species planting were 1273.6±192 μm and 975.89±223 μm, whereas the corresponding wall thickness values were 17.29±5 μm and 12.92±4 μm, respectively. The average fibre diameters for good and poor soil categories were

23.84±4 μm and 25.39±10 μm, whereas the fibre lumen widths were 10.14±6 μm and 8.72±6 μm, respectively. For the stand composition category of mixed and pure stands, the fibre diameters were 26.92±10 μm and 22.21±3 μm, whereas the fibre lumen widths were 9.63±5 μm and 9.28±6 μm, respectively.

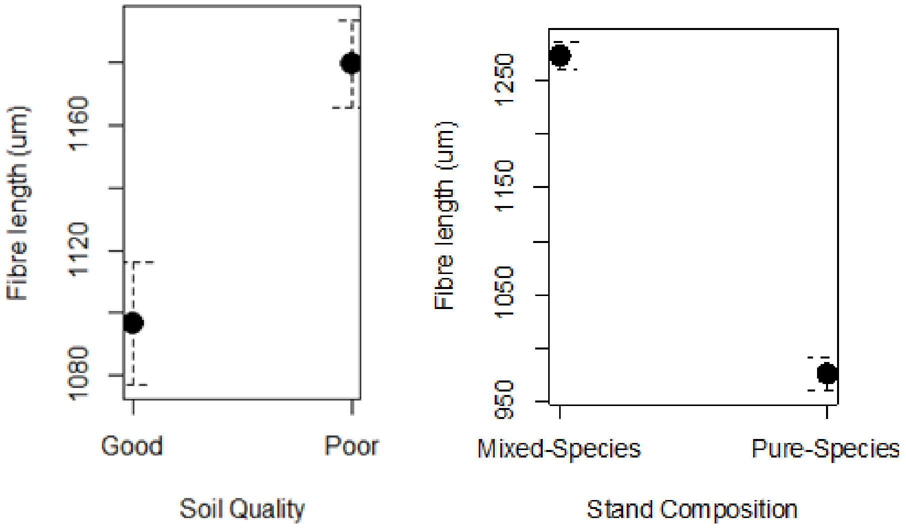

Fig. 5. *Mean value of fibre length for Turkey oak grown on good and poor soil, and as a pure and mixed-species stand; the error bars are the standard error of the mean*

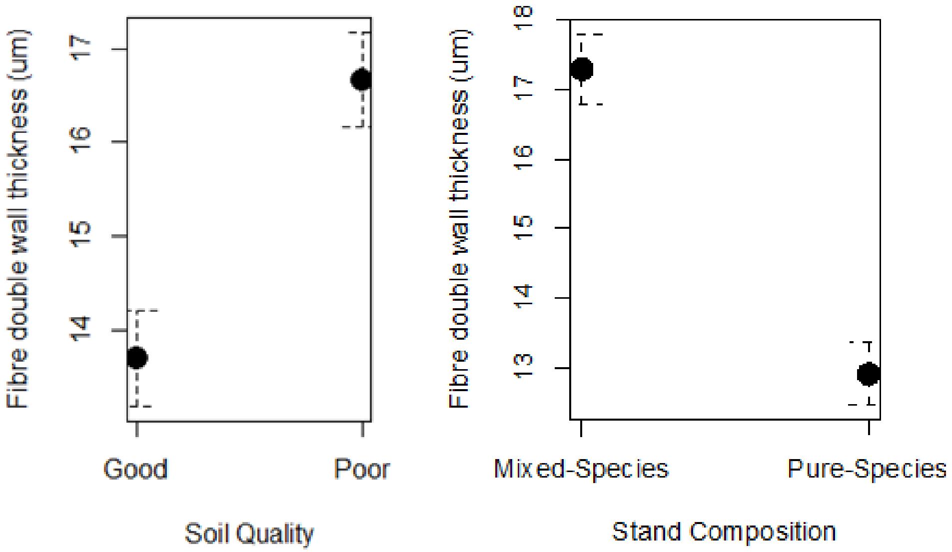

Fig. 6. *Mean values of fibre wall thickness for Turkey oak grown on good and poor soil, and as a mono and mixed-speciesstand; the error bars are the standard error of the mean*

Statistically, the influence of the soil quality was highly significant only on the fibre length and its double wall thickness as shown in Table 3. Stand composition also had a very high statistical influence (p-value = <0.001) on the fibre characteristics, except the lumen width.

P-values derived from ANOVA for the measured fibre characteristics Table 3

Factors	Fibre length	Fibre diameter	Fibre lumen width	Fibre double wall thickness
Soil quality	<0.001***	0.15	0.089	<0.001 ***
Stand composition	<0.001 ***	<0.001 ***	0.679	<0.001 ***
Combination of soil quality and species composition	<0.001 ***	<0.001 ***	<0.001 ***	<0.001 ***

* – significant, ** – high significant, *** – highly significant

The effects on the combination of soil quality and stand composition are shown in Figure 7 to Figure 10. The results indicate that Turkey oak wood from mixed stands, irrespective of soil quality, produced wood with longer fibres and thicker walls (Figures 7 and 10, respectively).

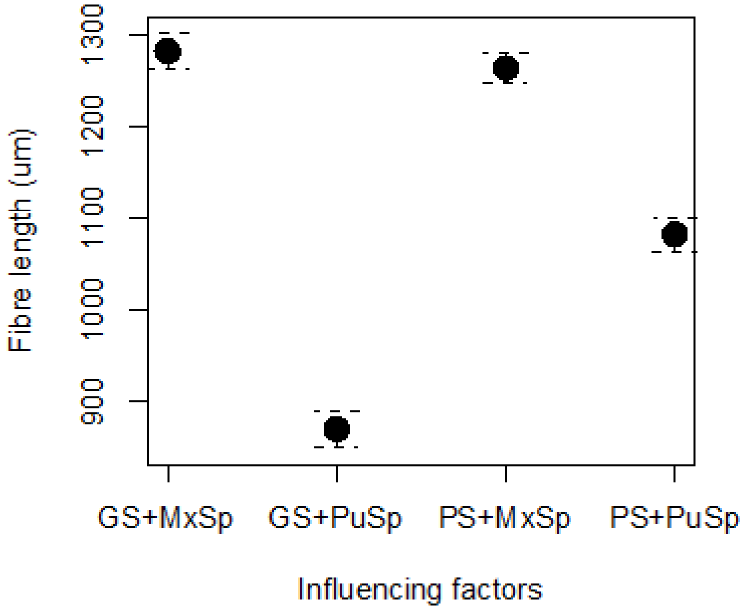

Fig. 7. *Mean values of fibre length for Turkey oak grown under four different conditions; abbreviations: GS – Good Soil, PS – Poor Soil, PuSp – Pure Species stand, MxSp – Mixed Species stand; the error bars are the standard error of the mean*

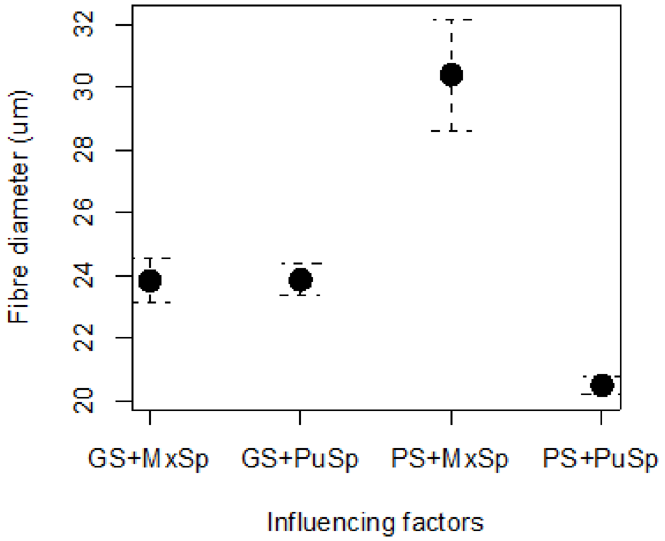

Fig. 8. *Mean value of fibre diameter for Turkey oak grown under four different conditions; abbreviation: GS – Good Soil, PS – Poor, PuSp – Pure Species stand, MxSp – Mixed Species stand; the error bars are the standard error of the mean*

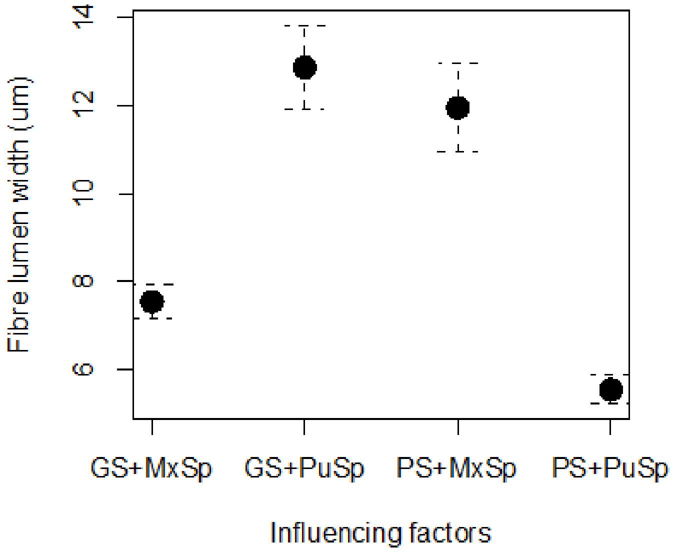

Fig. 9. *Mean values of fibre lumen width for Turkey oak grown under four different conditions; abbreviation: GS – Good Soil, PS – Poor, PuSp – Pure Species stand, MxSp – Mixed Species stand; the error bars are the standard error of the mean*

The poor soil produced wood with a larger fibre diameter and fibre lumen width. Comparatively, wood extracted from a pure Turkey oak stand on good soil had intermediate fibre diameter but larger lumen width. The influence of the combination of categories under the two factors were statistically highly significant on all the fibre characteristics as shown in Table 3.

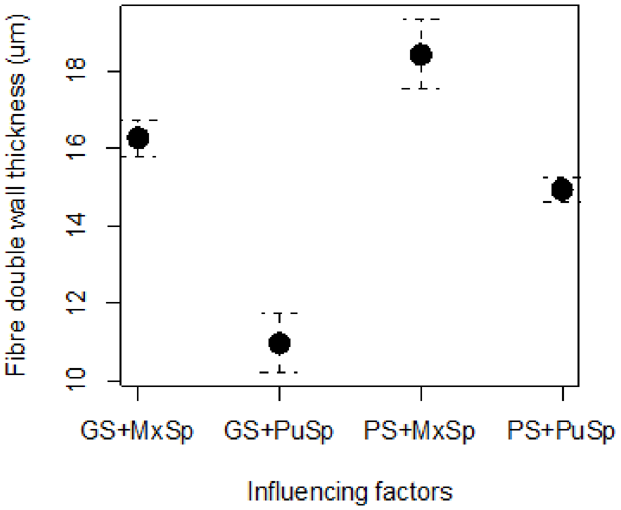

Fig. 10. *Mean values of fibre double wall thickness for Turkey oak grown under four different conditions; abbreviation: GS – Good Soil, PS – Poor, PuSp – Pure Species stand, MxSp – Mixed Species stand; the error bars are the standard error of the mean*

3.2. Vessel Characteristics

The vessel characteristics measured were diameter and length. The findings, presented in Table 4, are comparable among the sampled Turkey oak trees. In the latewood portion, vessel length has less variability than vessel diameter. On good soil, the average vessel diameter was 111.44±38 µm whereas on poor soil, the average was 236.87±140 µm. In earlywood portions, the average vessel length was similar to the length values in the latewood portion. Certainly, the vessel diameters are far larger in the earlywood part. Statistically, ANOVA proved that soil quality and stand composition had a highly significant influence on vessel characteristics only in the latewood portion (Table 5).

Table 4

Mean values for vessel characteristics in the earlywood and latewood portions of Turkey oak grown under varied conditions. LW – Latewood, EW–Earlywood

Factor	Category	LW vessel length [µm]	LW vessel diameter [µm]	EW vessel length [µm]	EW vessel diameter [µm]
Soil quality	Good	503.30(73.50)	111.44(38.45)	416.08(83.80)	442.31(79.98)
	Poor	415.73(88.03)	236.87(139.97)	410.78(74.33)	410.34(65.75)
Stand composition	Mixed	488.81(103.37)	132.85(35.59)	362.11(76.11)	307.31(63.23)
	Pure	419.28(82.59)	231.6(145.50)	418.65(84.98)	448.74(75.91)

Abbreviation: LW – Latewood, EW – Earlywood; In parentheses are the standard deviations.

P-values from ANOVA for the measured vessel characteristics Table 5

Factors	LW vessel length [µm]	LW vessel diameter [µm]	EW vessel length [µm]	EW vessel diameter [µm]
Soil quality	<0.001 ***	<0.001 ***	0.651	0.091
Stand composition	<0.001 ***	<0.001 ***	0.523	0.084
Combination of soil quality and stand composition	<0.001***	<0.001 ***	0.041	0.045

* – significant, ** – highsignificant, *** – highly significant;
Abbreviation: LW – Latewood, EW – Earlywood.

3.3. Tree Annual Growth-Ring Width and Sapwood-Heartwood Proportion

Considering soil quality as a single factor, the annual growth-ring width generally decreased from pith (the juvenile) to the sapwood portion on both good and poor soils (Table 6). For easy comparison, as trees are of different ages, the growth-rings were grouped into categories of juvenile, heartwood, and sapwood (Figure 11). Some trees might have already developed heartwood while others are now forming juvenile wood. The mean values for the annual growth ring-width at the Juvenile region ranged from 2465.14 µm to 3285.74 µm; in the heartwood it ranged between 1638.17 and 2315.36; and in the sapwood from 1163.52 to 1601.06 µm.

Table 6

Mean values for tree ring-width for wood portions

Factor	Category	Juvenile wood [µm]	Heartwood [µm]	Sapwood [µm]
Soil quality	Good	2465.14(741)	2075.74(598)	1601.06(361)
	Poor	3276.99(508)	1842.63(534)	1182.09(246)
Stand composition	Mixed	2615.24(721)	2315.36(614)	1543.26(427)
	Pure	3285.74(551)	1638.17(248)	1163.52(150)

*** In parentheses are the standard deviations of the mean.

The effect of the combination of factors is presented in Figure 9. Statistically, soil quality had a slight significance on the ring width in both the juvenile and the sapwood portion. Stand composition rather had a slight statistical significance only on the growth-ring width in the heartwood portion (Table 7).

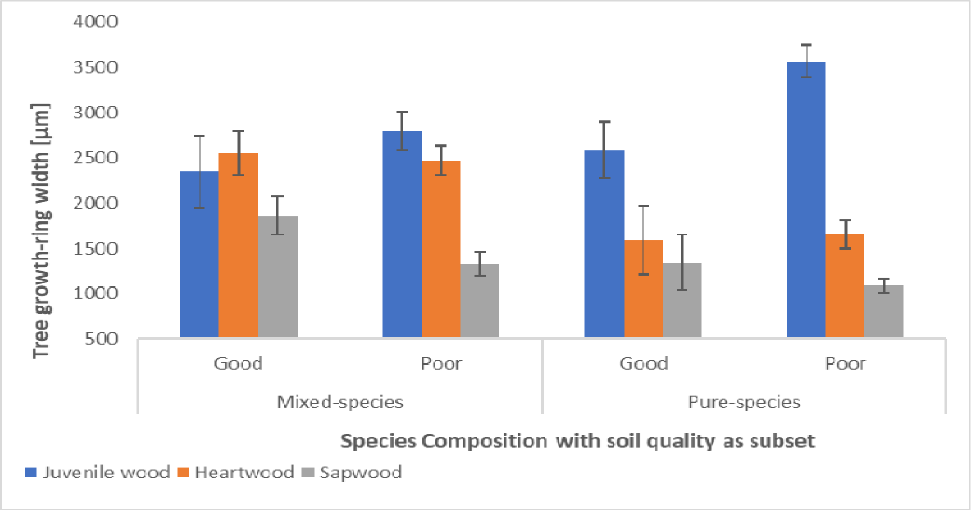

Fig. 11. *Tree annual ring width as radially grouped into Juvenile wood, Heartwood, and Sapwood; the error bars are for the standard error*

The mean values for the heartwood and sapwood proportions were very similar. The sapwood portion was generally about one-fourth of the cross-sectional diameter (Figure 12). The differences in their mean values were not statistically significant under any of the single factors. A combination of the factors, however, had a slight statistical significance over their mean values (Table 7).

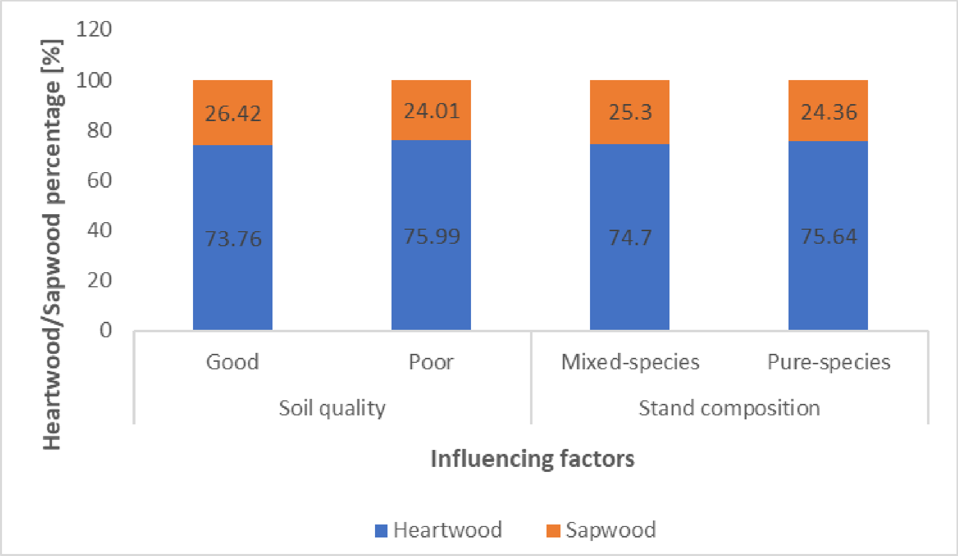

Fig. 12. *Heartwood and sapwood proportions*

Table 7
P-values from ANOVA for the measured tree ring width and sapwood-heartwood proportions

Factors	Juvenile wood ring width	Heartwood ring width	Sapwood ring width	Heartwood portion	Sapwood portion
Soil quality	0.048 *	0.508	0.038 *	0.494	0.448
Stand composition	0.097	0.024 *	0.052	0.765	0.786
Combination of Soil quality and Stand composition	0.073	0.141	0.029 *	0.040 *	0.037 *

* – significant, ** – high significant, *** – highly significant

4. Discussions

4.1. Fibre Characteristics

Considering soil quality as the only influencing factor, trees grown on poor soils produced wood with longer fibres with corresponding thicker walls. On the other hand, trees in mixed-stand forests produced wood with significantly longer fibres, larger diameters, and with associated thicker cell walls. The study findings agree with some reported literature. For *Quercus rubur* (L.), a study found a fibre length range of 1100 – 1350 µm; diameter of 18 – 22 µm; and cell wall thickness of 10 – 14 µm [13]. A study on Persian oak (*Quercus brantii* Lindl.) across three sites in Iran found fibre length in a range of 770 – 940 µm, whereas fibre wall thickness ranged between 5 and 6 µm.The same studyfound that site had a significant influence on the tissue characteristics [7]. In another study on Oregon white oak (*Quercus garryana* Douglas ex. Hook) grown with Douglas fir, fibre length was between 1100 and 1200 µm with stand compositionhaving significant influence [18]. Luostarinen and Hakkarainen [19] also discussed the influence of site conditions on fibre characteristics of *Betula pubescens* (Ehrh.). It is worth mentioning that, besides stand composition and soil quality, the differences in fibre characteristics found by this can be attributed to other unknown factors such as genotype.

4.2. Vessel Characteristics

The capacity of trees to safely transport water along the coordinated interplay of root, stem, and leaf is supported among other factors by vessel diameter. Therefore, vessels contribute to tree growth and survival [3]. Wood from pure Turkey oak stands had considerably larger vessels, irrespective of soil quality. We found that both soil quality and stand composition had a highly significant influence only on the latewood vessel length and diameter. This finding is related to other literature. For instance, studies found earlywood vessel range of 164 – 272 [4, 18]. On the contrary, the site was not a significant source of variation for vessel characteristics, but rather the individual trees [8, 29]. The variation recorded can be attributed to the hydraulic strategies adopted by the trees per their conditions [9] and other unknown factors. A special case is the formation of latewood, where the trees need to regulate their water transport to avoid hydraulic cavitation. Latewood had an average minimum vessel diameter as low as 46.15 µm (Table 8).

Showing vessel characteristics for Turkey oak from Vas County in Hungary Table 8

Stand composition	Soil quality	Year ring portion	Length [µm]		Diameter [µm]	
			Minimum	Maximum	Minimum	Maximum
Pure-species	Good	Early	285.95	566.91	278.09	301.54
		Late	366.05	586.42	63.57	128.93
	Poor	Early	223.62	516.53	274.97	290.78
		Late	224.87	638.64	53.08	176.84
Mixed-species	Good	Early	362.12	381.89	307.31	337.32
		Late	393.89	647.85	46.15	190.08
	Poor	Early	314.88	344.51	345.73	398.22
		Late	184.57	552.76	79.52	180.16

4.3. Tree Annual Ring Width and Sapwood-Heartwood Proportions

Annual tree growth-ring studies are fundamental because they can predict the performance of trees and encode the prevailed ecological information [5, 11, 15, 16]. The findings of this study on ring width agree with the literature [4]. The comparatively higher annual rings width making up juvenile-wood across sites can be attributed to the initial vigorous growth of seedlings, saplings, and young trees. On the other hand, the observation can be attributed to unknown factors like the genotype of *Quercus cerris* (L.). The thinner ring width in the sapwood region can be attributed to the recent alteration in climatic variables crucial for enhanced growth. In a study on *Quercus faginea* (Lam.), site was found to be a significant source of variation in annual growth-ring width [26].

5. Conclusions

The sustained demand for wood and wood products suggests that there should be increased effort in biomass production across all forest types. While plantation wood has almost become the backstop of the natural forest supply, efforts to establish them should be affordable. Turkey oak is naturally capable to perform in a range of sites, even with minimum soil moisture. Unfortunately, the genotype of the trees used for this research is not known. However, it can be inferred from this anatomical study that stand composition is an important factor when considering forest plantations for Turkey oak. Wood from a mixed stand forest had longer, larger, and thicker walled fibres.These traits are promising for better strength properties. Stand composition is also a source of significant variation for vessel characteristics in latewood portions. The co-habitation of Turkey oak with other tree species will not only improve biodiversity and the ecosystem, but also the wood quality of Turkey oak.

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