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Anatomical Characteristics and Fibre Quality of Grapevine (*Vitis vinifera* L.) Stem Wood

Anatomska obilježja i kvaliteta vlakana stabljike vinove loze (*Vitis vinifera* L.)

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ABSTRACT • *This study investigated the anatomical characteristics and fibre quality for papermaking indices of Vitis vinifera L. (grapevine) stem wood, which is extracted as agricultural waste. Two grapevine trunks were collected from the Gülnar region in Turkey. Observations on microscopic anatomical characteristics were carried out on sectioned and macerated wood samples. According to the measurements conducted, the following mean anatomical characteristics were determined: earlywood vessel tangential diameter 258.81 µm, latewood vessel tangential diameter 35.52 µm, ray width 197.19 µm, ray height 4618.67 µm, vessel length 498.85 µm, fibre length 1.03 mm, fibre diameter 22.05 µm, and fibre wall thickness 4.23 µm. Based on the determined characteristics linked to the fibre quality, the fibres of the grapevine can be placed in Quality Class III for pulp and paper processing. All derived indices of grapevine met the acceptable threshold except for the flexibility ratio. Examining the anatomical structure of the grapevine will enable a database to be created for further studying of wood anatomy and these characteristics can be evaluated with respect to other possible areas of use.*

KEYWORDS: *wood anatomy, fibre quality, fibre dimensions, fibre derivative indices*

SAŽETAK • *U ovom su radu istražena anatomska obilježja i indeksi kvalitete vlakana za proizvodnju papira od stabljika vinove loze (Vitis vinifera L.) koje se ekstrahiraju kao poljoprivredni otpad. Dva uzorka stabljike vinove loze prikupljena su iz regije Gülnar u Turskoj. Promatranja mikroskopskih anatomskih obilježja provedena su na presječenim i maceriranim uzorcima vinove loze. Prema provedenim mjerenjima, utvrđene su ove srednje anatomske vrijednosti: tangentni promjer traheje ranog drva 258,81 µm, tangentni promjer traheje kasnog drva 35,52 µm, širina drvnog traka 197,19 µm, visina drvnog traka 4618,67 µm, duljina traheje 498,85 µm, duljina vlakana 1,03 mm, promjer vlakana 22,05 µm i debljina stijenke vlakana 4,23 µm. Na temelju utvrđenih obilježja vezanih za kvalitetu vlakana, vlakna vinove loze mogu se svrstati u III. razred kakvoće materijala za preradu celuloze i papira. Svi proizvodni indeksi vinove loze, osim omjera fleksibilnosti, zadovoljili su prihvatljivi prag. Ispitivanje anatomske strukture vinove loze omogućit će stvaranje baze podataka za daljnje proučavanje anatomije vinove loze i na taj će se način navedena obilježja moći proučavati u drugim područjima uporabe.*

KLJUČNE RIJEČI: *anatomija drva, kvaliteta vlakana, dimenzije vlakana, proizvodni indeksi vlakana*

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1 INTRODUCTION
1. UVOD

Nowadays, obtaining a continuous supply of wood raw materials is becoming difficult because of limited wood resources and high demand, resulting in the gradual reduction of forest resources. The need for wood and wood-based composites will definitely increase in the future. The most obvious factor for this demand is the population growth, which is increasing rapidly. In addition, many different sectors have begun to use wood raw material. Therefore, the imbalance between the demand for wood raw materials and the current supply is inevitable. It is predicted that instead of wood fibre, the use of agricultural and other sourced alternative fibres will play an important role in the future wood supply-and-demand table (Cooper and Balatineez, 1999).

The paper and paperboard industry is one of the most important sectors in which wood fibre is used, with global paper and paperboard production reaching 401 million metric tons in 2020 (FAO, 2022). In the future (by 2050), worldwide paper production is expected to increase to approximately 700 million metric tons (low estimate) - 900 million metric tons (high estimate) (Bajpai, 2016). One ton of paper is produced from around 2.5 tons of wood. The limited wood resources are being increasingly used not only for papermaking, but also for production of furniture, plywood, and many other products, and therefore, other types of fibrous biomass must be considered for paper manufacturing (Przbysz *et al.*, 2018).

The decrease in the availability of raw materials for pulp and paper production have led papermakers to search for new raw material resources. Several studies have been carried out to identify these resources (Sabharwal and Young, 1996; Chandra, 1998). As an alternative to wood-based raw materials, annual plants and agricultural wastes are the most important raw material resources for pulp and paper production. In fact, they provide excellent specialty paper and constitute the sole source of paper raw materials in some regions (Jiménez *et al*., 1997).

Vitis L. (grapevine) is one of the 16 genera of the *Vitaceae* family distributed in the tropics and subtropics and has 84 species distributed in the temperate regions of the northern hemisphere. One of the important species, *Vitis vinifera* L., has a natural distribution in the Caucasus region and is widely cultivated today. The grapevine is cultivated for its fruit in Turkey and in many Mediterranean regions and has a high economic value and deep-rooted history (Kayacik, 1982; Akkemik, 2020). The grapevine is a woody plant that sheds its leaves in winter and climbs by using its tendrils to twine around a support.

Turkey has produced 3 670 000 tons of grapes in an area of 4 170 410 decares. With this amount, grapes constitute 19.26 % of Turkey's fruit production and rank first among fruits in terms of quantity (TUIK, 2021). Accordingly, the amount of leftover stem wood and pruning waste is quite high during the year. It is known that pruning residues amount to approximately 2 420 000 tons per year. A study conducted by Yeniocak *et al.* (2014) on the production of particleboard from grapevine pruning residues determined that these residues are suitable for particleboard production. The suitability of composite production from vine pruning has been explored by several researchers (Ntalos and Grigoriou, 2002; Yaşar *et al.,* 2009; Mancera *et al.,* 2011; Yeniocak *et al.,* 2016; Auriga *et al.,* 2022; Santos *et al.,* 2022). Studies conducted on the use of vine pruning residues in pulp production have concluded that the pulp is of lower quality than that produced from other agricultural wastes (Jiménez *et al*., 1990). In another study, experiments were carried out with other agricultural wastes (olive trimmings, wheat straw, and sunflower) using different pulp production techniques to increase the quality (Jiménez *et al.,* 2006).

The use of vine pruning residues in pulp and composite board production has been investigated by many researchers, but the information available in terms of grapevine stem wood is insufficient. This study aimed to preliminarily investigate the anatomical characteristics of grapevine stem wood, which contains a great deal of woody material compared to pruning residues, and its suitability for papermaking in terms of fibre morphology and fibre quality.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

Wood samples of *Vitis vinifera* L. were collected from the Gülnar District of Mersin Province. Located in the Taşeli section of the Mediterranean Region, Gülnar is at an altitude of 950 m a.s.l. It is located between 36º - 37º North parallels and 33º-34º East meridians. Most of the land in the district land is forested, followed by agricultural areas, pastures, and unused land. The typical Mediterranean climate prevails in the region. In the higher areas, winters are cold and snowy and summers are cool and relatively rainy. The area experiences a mean annual rainfall of 627 mm and annual temperature of 14.3 ºC (Anonymous, 2022).

The anatomical characteristics of two previously felled grapevine trunks (15 cm) were studied based on the International Association of Wood Anatomists (IAWA) hardwood list (Wheeler *et al*., 1989). Two small wood samples from each trunk were obtained from the outer region of cross-sections in order to eliminate juvenile wood. Samples in dimensions of 10 (R) × 10 (T) ×

20 (L) mm were prepared for wood anatomical measurements. These samples were boiled to soften them and then cut into thin sections (about 20-30 µm) using a Leica SM 2010R sliding microtome. The sections were stained with 1 % safranin for 5 min. and dehydrated in ethanol series (50 %, 70 % and 96 %). Then, they were transferred to xylene in two steps of pure xylene, each step lasting for 10 min. The sections were transferred to glass slides and mounted with Entellan.

For measuring vessel and fibre lengths, grapevine wood was separated with a razor blade in the size of half a matchstick. Maceration was performed according to Schultz's method, which was adopted by Merev (1998). Accordingly, the samples placed in test tubes were treated with potassium chlorate ($KClO_3$) and nitric acid (HNO_3) (1:1). The set up was allowed to react in a fume cupboard while standing on a test-tube rack until the chips were softened and bleached. When the reactions were slow, the racks were heated to 60 °C until the maceration of the chips occurred. Macerated chips were washed with distilled water several times until they became clear. The resultant samples were transferred into well-labelled specimen bottles. Glycerine was added to each bottle, and the samples were stained with safranin to highlight the thickness of the cell wall and lumen.

The earlywood and latewood vessels were evaluated separately according to the IAWA list (Wheeler *et al*., 1989). Tangential and radial earlywood/latewood vessel diameter (µm), ray width (µm), multiseriate ray width (number of cells), ray height (µm), and ray frequency (number of rays per millimetre) were measured. From the macerated samples, fibre length (FL in mm), fibre diameter (FD in µm), fibre lumen diameter (FLD in µm), and fibre cell wall thickness (FCWT in µm) were measured. Twenty-five measurements were taken for vessels and rays and fifty measurements for fibres. An Olympus BX51 microscope connected to an Olympus DP71 camera was used to acquire images, and measurements were taken via BAB Bs200Pro Image Processing and Analysis Software.

The fibre morphology measurements were used to calculate the slenderness (felting) ratio (FL/FD), flexibility (elasticity) ratio [(FLD/FD)x100], Runkel ratio ($2\times FCWT/FLD$), rigidity coefficient ($2\times FCWT/FD$), Luce's shape factor [(FD^2-FLD^2)/FD^2], F-factor [($FL/\underline{FCWT}$)x100], and Muhlsteph ratio [(cell wall thickness area/fibre cross-sectional area)x100] of the samples (Saikia *et al.,* 1997; Ohshima *et al.,* 2005; Mousavi *et al.,* 2013; Pirralho *et al.,* 2014; Saeed *et al.,* 2017; Afrifah *et al*., 2022). The derived values were evaluated in order to determine fibre quality class following Rachman and Siagian (1976).

Descriptive statistical analysis of anatomical characteristics and derived values were performed using the SPSS 21 software package. Descriptive statistics include mean values, standard deviation values, minimum and maximum values and coefficients of variation, and these values are shown in tables.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Anatomical characteristics
3.1. Anatomska svojstva

The examination of the grapevine wood sections and the evaluation of the measurements were performed. Microscopic transverse, radial, and tangential wood sections are shown in Figures 1A, 1B, 1C, respectively. A summary of the descriptive statistics is given in Table 1. The annual ring boundaries are distinct due to the difference in diameter of the earlywood and latewood vessels and the flattening of the fibres at the end of the annual ring, which has a porous structure. The earlywood vessels were quite large and often solitary (Fig 1D). On the other hand, the latewood vessels consisted of 3 to 6 cells radially spaced (Figure 1E). The tangential diameter of the thin-walled, earlywood vessels was 258.81 µm, while that of the latewood vessels was 35.52 µm. The radial diameter of the earlywood vessels was 260.18 µm, while that of the latewood vessels was 33.01 µm. The vessel elements were 498.85 µm long (medium length) (Wheeler *et al.,* 1989), the perforation plates were simple, and the intervessel pits were large, elongated, and mostly scalariform types (Figure 1F). The vessel-parenchyma and vessel-ray pits were similar, and half bordered. The narrow vessel members occasionally exhibited irregular spiral thickenings. Tyloses occurred frequently in the earlywood vessels.

The paratracheal axial parenchyma cells were solitary, scattered, and irregularly arranged (Figures 2A, 2B). The fibres were of the libriform type, septate and 1.03 mm long. The libriform fibres had very small simple pits on radial and tangential walls. There were vascular tracheids with irregular, very fine spiral thickenings in the latewood. The multiseriate rays consisted of nine cells on average and were 197.19 µm wide and 4.62 mm high (Figure 2C). The rays were heterogeneous, with procumbent body ray cells and 1-4 rows of upright square marginal cells (Figure 2D, arrows 1 and 2). Secretory cells were associated with the ray parenchyma.

The mean values and standard deviation values for each wood anatomical characteristic are summarized in Table 1. In the present study, the tangential vessel diameter ranged from 35.52 to 258.81 µm. The literature reports on the tangential vessel diameter ranged from 60 to 220 µm in Merev *et al.* (2005), and from 30 to 300 µm in Yaşar *et al.* (2009). The vessel

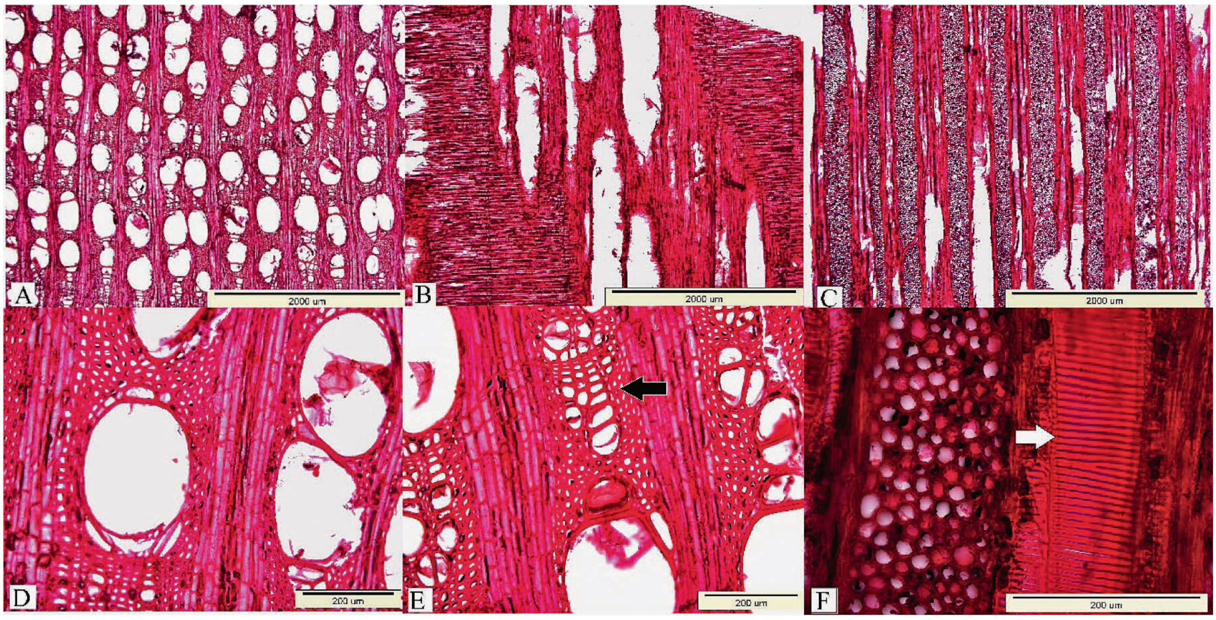

Figure 1 Microscopic view of grapevine wood: A) cross-section, B) radial section, C) tangential section, D) scattered solitary earlywood vessels, E) latewood vessels arranged in radial rows (indicated by arrow), F) elongated intervessel pits (indicated by arrow)
Slika 1. Mikroskopski prikaz vinove loze: A) poprečni presjek, B) radijalni presjek, C) tangentni presjek, D) pojedinačne traheje ranog drva, E) traheje kasnog drva u radijalnim nizovima (označene strelicom), F) izdužene intervaskularne jažice (označene strelicom)

length of the grapevine was 498.85 µm in the present study, similar to the vessel length of 500 µm in Crivellaro and Schweingruber (2013) and the vessel length of 476.7 µm in Hashemi and Tabei (2015). The multiseriate ray width (9 cell) was similar to the values (7 to 13 cell) in the study by Merev *et al.* (2005).

Grapevine fibre lengths belong to the medium length class (900-1600 µm). Fibres were longer in comparison with Hashemi and Tabei (2015) (0.96 mm) and shorter in comparison with Merev *et al.* (2005) (1.25 mm) (Table 1). Despite this, the length class remained the same in all the above sources. Gra-

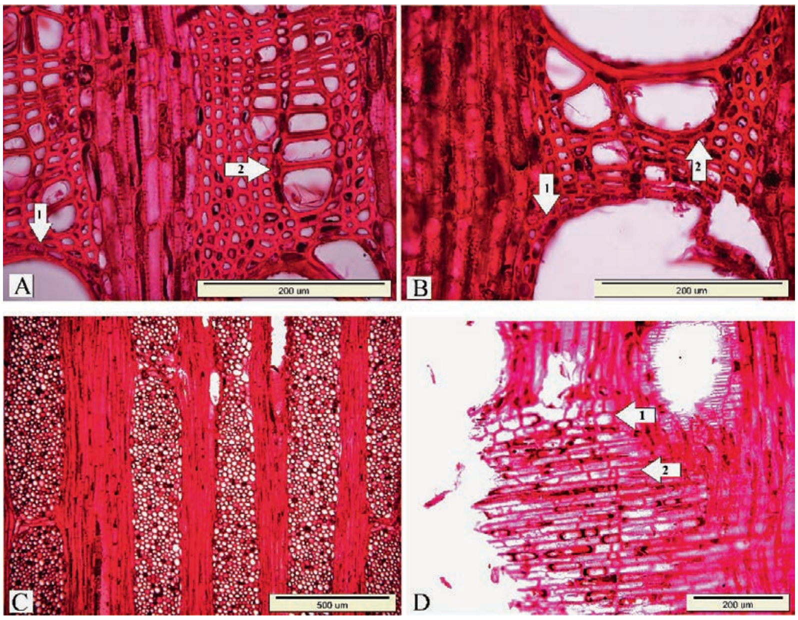

Figure 2 A-B) solitary longitudinal parenchymas (indicated by arrows 1-earlywood, 2-latewood) located irregularly around vessels, C) multiseriate rays in tangential sections, D) square ray cells (arrow 1) and procumbent ray cells (arrow 2)
Slika 2. A) – B) Pojedinačni aksijalni parenhimi nepravilno raspoređeni oko traheja (označeni strelicama: 1 – rano drvo, 2 – kasno drvo), C) višeredni drvni traci na tangentnom presjeku, D) kvadratične parenhimske stanice (strelica 1) i pravokutne parehnimske stanice (strelica 2)

Table 1 Statistical values of wood anatomical characteristics of grapevine wood
Tablica 1. Statističke vrijednosti anatomskih svojstava vinove loze

Features / *Svojstva*	**Mean** *Srednja vrijednost*	**Std. Dev.**	**Max.**	**Min.**	**Coefficient of variation, %** *Koeficijent varijacije, %*
Earlywood vessel tangential diameter, µm *tangentni promjer traheide ranog drva,* µm	258.81	59.87	393.04	155.44	23.13
Earlywood vessel radial diameter, µm *radijalni promjer traheide ranog drva,* µm	260.18	55.99	386.51	174.47	21.52
Latewood vessel tangential diameter, µm *tangentni promjer traheide kasnog drva,* µm	35.52	10.64	58.18	13.77	29.96
Latewood vessel radial diameter, µm *radijalni promjer traheide kasnog drva,* µm	33.01	13.28	63.41	11.11	40.23
Ray width, µm / *širina drvnog traka,* µm	197.19	42.28	284.89	66,62	21.44
Multiseriate ray width (number of cells) *širina višerednoga drvnog traka (broj stanica)*	9.24	1.60	12	4	17.32
Ray height, µm / *visina drvnog traka,* µm	4618.67	2292.49	12115.45	1552.28	49.64
Rays per mm / *broj trakova po* mm	3.5	0.54	5	3	15.43
Vessel length, µm / *duljina traheje,* µm	498.85	136.73	785.16	243.57	27.41
Fibre length, mm / *duljina vlakana,* mm	1.03	0.19	1.54	0.55	18.45
Fibre diameter, µm / *promjer vlakana,* µm	22.05	4.58	33.25	13.25	20.77
Fibre lumen diameter, µm / *promjer lumena vlakana,* µm	13.59	3,38	24.11	7.35	24.87
Fibre wall thickness, µm / *debljina stijenke vlakana,* µm	4.23	1.17	7.35	2	27.66

pevine fibres are in the same length category as the fibres of many hardwoods, e.g., *Quercus robur* (Gülsoy *et al.,* 2005), *Alnus glutinosa* (Tırak Hızal and Erdin, 2016), *Populus alba* (Ištok *et al*., 2019), *Fraxinus angustifolia* (Tırak Hızal and Erdin, 2020), *Fagus orientalis* (Gülsoy *et al.,* 2021) and *Eucalyptus globulus* (Gominho *et al*., 2014; Rahmanto *et al.,* 2021). Compared with other agricultural fibres, some species, e.g., *Corylus avellana* L. (Gençer and Özgül, 2016), *Diospyros lotus* (Topaloğlu *et al.,* 2019), *Persea americana* (Altunışık Bülbül and Gençer, 2021) and *Crataegus azarolus* (Nazari *et al.,* 2021) have a similar fibre length, whereas others, such as *Actinidia deliciosa* (Yaman and Gençer, 2005; Vaysi and Yosefi, 2008), *Gossypium hirsutum* (Tutuş *et al*., 2010), and *Diospyros lotus* (Kiaei and Bakhshi, 2014) showed longer fibres. The grapevine has a longer fibre length than *Persea americana (*Ajuziogu *et al.,* 2010), *Olea europaea* (Ali and Ali, 2014), *Rosmarinus officinalis* (Serin *et al*., 2017), *Populus alba* (Ištok *et al*., 2017), *Prunus armeniaca* (Gençer *et al.,* 2018), and *Crataegus azarolus* (Dong *et al.,* 2021) (Table 2). Fibre length has been reported to play an important role in the processing and mechanical performance of fibre-based products such as paper and fibreboard (Migneault *et al.,* 2008). Ogunkunle and Oladele (2008) reported that long fibres produce paper with higher tear resistance, although Kırcı (2000) and Eroğlu and Usta (2004) reported that long fibres may cause formation defects. The opacity, printability, and stiffness properties improve when short fibres are mixed with longer fibres (Sadiku and Abdukareem, 2019).

The mean fibre diameter value was measured as 22.05 µm and the mean fibre lumen diameter as 13.59 µm. These values are lower than the values found in the study by Hashemi and Tabei (2015) (Table 2). Recent studies have determined that the fibre diameter, fibre lumen diameter, and fibre cell wall thickness are important factors affecting paper properties. To ensure easy collapsibility and provide an effective surface, a thinner cell wall is more appropriate in papermaking (Panshin and de Zeeuw, 1980). The walls of the fibres were classified as having medium thickness (Wheeler *et al*., 1989), and although the thickness class did not change, their values were much lower than those in the literature. The cell wall thickness values of grapevine fibres are given in Table 2. The values indicate that fibres have thinner cell walls in comparison with *Actinidia deliciosa* (Yaman and Gençer, 2005), *Actinidia deliciosa* (Vaysi and Yosefi, 2008), *Olea europaea* (Topaloğlu *et al.,* 2019), *Quercus robur* (Gülsoy *et al*., 2005), *Eucalyptus globulus* (Gürboy and Özden, 1994; Gominho *et al.,* 2014), *Eucalyptus* sp. (Rahmanto *et al*., 2021), *Salix alba* (Eroğlu and Usta, 2004), *Fraxinus angustifolia* (Tırak Hızal and Erdin, 2020), and *Alnus glutinosa* (Tırak Hızal and Erdin, 2016), but thicker in comparison with *Populus alba* (Ištok *et al*., 2017). Fibre cell wall thickness is similar to that of *Gossypium hirsutum* (Tutuş *et al.,* 2010), *Prunus armeniaca (*Tajik *et al.,* 2015), *Corylus avellana* (Gençer and Özgül, 2016) and *Rosmarinus officinalis* (Serin *et al.,* 2017). Hashemi and Tabei (2015) determined the grapevine fibre cell wall thickness to be 5.49 µm, which is considerably higher than the value found in this study.

Table 2 Fibre morphology of grapevine wood and other species in literature
Tablica 2. Morfologija vlakana vinove loze i drugih vrsta u literaturi

Species / *Vrsta*	***FL*** mm	***FD*** µm	***FLD*** µm	***FCWT*** µm	**References** / *Reference*
Vitis vinifera L.	1.03	22.05	13.59	4.23	This study
Vitis vinifera L.	0.58-1.25	-	-	-	Merev *et al.,* 2005
Vitis vinifera L.	0.96	26.45	15.48	5.49	Hashemi and Tabei, 2015
Actinidia deliciosa (A. Chev.)	1.59	35.97	22.30	6.84	Yaman and Gençer, 2005
Actinidia deliciosa (A. Chev.)	1.37	30.04	14.17	7.93	Vaysi and Yosefi, 2008
Corylus avellana L.	1.04	22.20	13.66	4.30	Gençer and Özgül, 2016
Corylus avellana L.	1.06	23.8	14.08	4.8	Merev, 1998
Crataegus azarolus L.	0.84	20.93	-	5.76	Dong *et al.,* 2021
Crataegus azarolus L.	0.93	18.91	-	5.89	Nazari *et. al.,* 2021
Diospyros lotus L.	1.13	12.05	4.89	3.58	Kiaei and Bakhshi, 2014
Diospyros lotus L.	0.94	16.59	6.17	5.21	Topaloğlu *et al*., 2019
Gossypium hirsutum L.	0.81	24.98	16.75	4.12	Tutuş *et al*., 2010
Olea europaea L.	1.11	25.12	14.36	5.38	Topaloğlu *et al*., 2019
Olea europaea L.	0.81	15.60	10.94	2.33	Ali and Ali, 2014
Persea americana Mill.	1.06	25.78	16.18	4.87	Altunışık Bülbül and Gençer, 2021
Persea americana Mill.	0.89	23.00	12.00	5.00	Ajuziogu *et al.,* 2010
Rosmarinus officinalis L.	0.36	12.84	4.22	4.31	Serin *et al*., 2017
Alnus glutinosa L. Gaertner	1.20	26.46	17.32	4.57	Tırak Hızal and Erdin, 2016
Eucalyptus globulus Labill.	0.93	21.4	9.1	6.1	Gominho *et al*., 2014
Eucalyptus globulus Labill.	0.69	20.78	6.42	7.18	Gürboy and Özden, 1994
Eucalyptus sp.	1.16			5.2	Rahmanto *et al.,* 2021
Fagus orientalis Lipsky	1.16	0.60	20.20	5.70	Gülsoy *et al.,* 2021
Fraxinus angustifolia L.	1.20	23.62	18.74	4.88	Tırak Hızal and Erdin, 2020
Populus alba L.	0.87	-	13.38	3.72	Ištok *et al*., 2017
Populus alba L.	0.91	-	-	-	Ištok *et al*., 2019
Prunus armeniaca L.	0.69	12.08	5.69	3.19	Gençer *et al.,* 2018
Prunus armeniaca L.	1.18	14.75	6.11	4.30	Tajik *et al.,* 2015
Quercus robur L.	1.35	18.60	7.40	5.60	Gülsoy *et al*., 2005
Salix alba L.	0.92	20.8	-	5.0	Eroğlu and Usta, 2004

3.2 Derived morphological quality parameters
3.2. Proizvodni morfološki parametri kvalitete

Fibre characteristics are one of the most important parameters in determining paper properties. In order to evaluate paper properties with an objective approach, the slenderness (felting) ratio, flexibility ratio, coefficient of rigidity, Muhlsteph ratio, and F-factor ratio determined from the fibre dimensions should be considered (Kırcı, 2000). The fibre length and fibre parameters of grapevine wood are shown in Table 3.

The slenderness ratio, which is one of the important factors, has a positive effect on the strength, tear, burst, tensile and double-folding resistance of paper (Ekhuemelo and Udo, 2016; Takeuchi *et al*., 2016). The slenderness ratio of the grapevine was 48.57, which is higher than that of *Punica granatum* (35.8) (Gülsoy *et al.,* 2015), *Persea americana* (41) (Altunışık Bülbül and Gençer, 2021), *Olea europea* (44.76) (Topaloğlu *et al*., 2019) and *Rosmarinus officinalis* L. (27.77) (Serin *et al*., 2017) and lower than that of *Eriobotrya japonica* (69.17) (Topaloğlu *et al.,* 2019), *Cornus australis* (52.84) (Gençer and Aksoy, 2017) and *Prunus armeniaca* (55.09) (Gençer *et al.,* 2018). The preferable slenderness ratio for papermaking fibre should exceed 33 (Xu *et al*., 2006). Considering that the slenderness ratio value required for the best papermaking is 70-90 for softwoods and 40-60 for hardwoods, it was concluded that grapevine wood should produce paper with good properties.

Bektas *et al*. (1999) and Ogunleye *et al.* (2017) determined four groups for fibre elasticity: high elastic fibres (flexibility ratio>0.75), elastic fibres (flexibility ratio=0.50-0.75), rigid fibres (flexibility ratio=0.30-0.50), and highly rigid fibres (flexibility ratio<0.30). The flexibility ratio of grapevine fibres was found to be 0.33; therefore, the fibres were determined to be rigid and thus not suitable for paper production. The flexibility ratio value of the grapevine was lower than that of hardwoods and softwoods (0.55–0.75) (Smook, 1997). A lower value on this index gives a higher possibility of paper tearing, collapse, and opacity (Foelkel *et al*., 1978). As the fibres of grapevine wood are rigid, they would not be suitable for paper production.

The acceptable Runkel ratio for papermaking fibres is close to or higher than 1 (Xu *et al*., 2006). Fibres with a Runkel ratio less than 1 are considered as thin-walled fibres (Oluwadare and Sotannde, 2007), while fi-

Table 3 Fibre length and derived values of grapevine wood
Tablica 3. Duljina vlakana i proizvodne vrijednosti vinove loze

Derivative fibres *Proizvedena vlakna*	**Mean** *Srednja vrijednost*	**Std. Dev.**	**Max.**	**Min.**	**Coefficient of variation, %** *Koeficijent varijacije, %*
Fibre length, mm / *duljina vlakana,* mm	1.03	0.19	1.54	0.55	18.45
Slenderness ratio (Felting power) *omjer vitkosti (brzina filcanja)*	48.57	13.45	92.64	19.57	27.69
Flexibility ratio / *omjer fleksibilnosti*	0.33	0.10	0.61	0.15	30.30
Runkel ratio / *Runkelov omjer*	0.65	0.21	1.21	0.3	32.31
Rigidity coefficient / *koeficijent krutosti*	38.47	7.35	54.83	22.83	19.11
Luce's shape factor / *Lucein faktor oblika*	0.61	0.09	0.8	0.4	14.75
F-factor	260.76	83.97	571.60	97.37	32.20
Muhlsteph ratio / *Muhlstephov omjer*	61.61	9.03	79.6	40.45	14.66

bres with a Runkel ratio above 1 are considered as thick-walled fibres (Ezeibekwe *et al.,* 2009). The Runkel ratio is related to paper conformity, pulp yield, and digestibility (Ohshima *et al.,* 2005). The Runkel ratio of grapevine wood fibres was 0.65 and therefore, the value was below 1. This value is similar to that of *Olea europea* (0.78) (Topaloğlu *et al.,* 2019) and *Eucalyptus* sp. (0.70) (Rahmanto *et al.,* 2021), and lower than that of *Cornus australis* (1.16) (Gençer and Aksoy, 2017) and *Prunus armeniaca* (0.99) (Gençer *et al.,* 2018). The morphological characteristics of the grapevine indicate that it possesses good fibre felting power since all the Runkel ratio values were below 1. According to this parameter, the fibres could be satisfactory for papermaking.

A rigidity coefficient value of ≤50 increases the collapsibility of the fibres and thus flexible and strong papers are obtained (Tamolang and Wangaard, 1961). The average rigidity coefficient was 38.47 %. This value is higher than that of other species, and it affects the tensile, tear, burst, and double-fold resistance of paper (Huş *et al.,* 1975). This implies that the low rigidity coefficient of grapevine wood should make it suitable as a raw material for pulp and papermaking.

The Luce's shape factor is related to paper sheet density (Kaur and Dutt, 2013), and a low value could be significantly correlated to the breaking length of paper (Ona *et al.,* 2001). A low Luce's shape factor value has been reported to indicate decreased resistance to beating in paper production (Luce, 1970). The mean value of Luce's shape factor for grapevine wood was 0.61. The determined value is similar to the range of values (0.50 - 0.60) for *Eucalyptus* spp. used in cellulose and paper production (Pirralho *et al.,* 2014; Baldin *et al*., 2017).

The Muhlsteph ratio determines the effect of the cell wall on the physical properties of paper. Thin-walled fibres are easily crushed during paper production and this positively affects paper density or resistance properties (Akgül and Tozluoğlu, 2009). The reason for the low pulp sheet density with low pulp strength is the low Muhlsteph ratio (Przybysz *et al.,* 2018).

For paperboard and corrugated board production, a higher Muhlsteph ratio would be more suitable (Elmas *et al.,* 2018). The Muhlsteph ratio of grapevine wood was 61.61, which was higher than that of *Populus tremula* (47.4) (Atik, 1995), *Acer platanoides* (48.4) (Durmaz and Ateş, 2016), and *Salix excelsa* clones (8.4) (Elmas *et al.,* 2018), but lower than that of *Fagus orientalis* (76.7) (Akgül and Tozluoğlu, 2009) and *Elaeagnus angustifolia* (70.45) (Akgül and Akça, 2020).

The F-factor, which is one of the important parameters for the papermaking industry, indicates the flexibility of fibres. Higher F-factor values yield usable fibres (İstek *et al.,* 2009). The F-factor of grapevine wood was calculated to be 260.76. Thus, the grapevine has a higher F-factor than *Eucalyptus camaldulensis* (249.1) (Huş *et al.,* 1975), *Fagus orientalis* (140.4) (Akgül and Tozluoğlu, 2009), *Acer platanoides* (141.7) (Durmaz and Ateş, 2016), and *Salix excelsa* clones (231.4-233.9) (Elmas *et al.,* 2018), and a lower F-factor than *Populus tremula* (415.1) (Atik, 1995).

According to the Rachman and Siagian (1976) criteria, grapevine fibres had a score of 175, which places the fibre in Class III quality of pulp and paper. Fibres in Quality Class III have moderate to heavy density with a thick wall and narrow lumen. During the sheet forming, fibres do not flatten easily, and felting and bending among fibres are poor, producing low quality in tear, burst and tensile strength.

4 CONCLUSIONS
4. ZAKLJUČAK

In this preliminary study, the suitability of the wood fibres of *Vitis vinifera* L. based on fibre dimensions and fibre parameters was investigated. The anatomical characteristics and fibre quality parameters were compared with those of the same and some other species. Grapevine wood has porous rings, with large vessels. The grapevine wood vessel would be classified as medium-long, having simple perforation plates, large intervessel pits (mostly scalariform type), and scattered paratracheal parenchyma cells.

The fibre length and fibre wall thickness are considered to be two important parameters for pulp and papermaking. Grapevine fibres were classified as medium-long (1.03 mm) and medium thick (4.23 µm). Except for the flexibility ratio, the derived indices of slenderness, Runkel, and Muhlsteph ratios, coefficient of rigidity, Luce's shape factor, and F-factor met the acceptable threshold. In general, the derivative indices of grapevine wood fibres were ranked in Quality Class III. The preliminary results indicate that grapevine wood fibres could be used in the production of paper by blending them with other fibres. However, in order to reach a definite conclusion on this issue, it is necessary to determine the contents of cellulose, hemicellulose, lignin, and extractive substances in grapevine fibres (Eroğlu and Usta, 1989). The fibres might be used in paperboard and corrugated board production and they could be used for papermaking by mixing them with fibres of other suitable species or recycled fibres.

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