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PHYSICAL AND MECHANICAL PROPERTIES OF WOOD OF NORTHERN RED OAK IN THE VICINITY OF BELGRADE (SERBIA)

Ivana ŽIVANOVIĆ[1], Nebojša TODOROVIĆ[2], Nenad ŠURJANAC[1], Milan KABILJO[1], Filip JOVANOVIĆ[1]

Abstract: *The wood of northern red oak (Quercus rubra L.), considered to be a very high-quality material for processing in the wood industry, has not been tested in Serbia so far. To date, there are only small areas under northern red oak in Serbia, but there are significant stands of this species in the vicinity of Belgrade. In this paper, the basic physical and mechanical wood properties of northern red oak in Serbia were tested. The examined 57 years old tree was located in the forest of Lipovica, near Belgrade. The tree was cut down and two small logs were taken to the laboratory for analysis. The results show that the properties of wood of northern red oak do not differ significantly from the properties of native oak species in Serbia – sessile and pedunculate oak. In addition, the values of basic mechanical properties of wood of northern red oak in Serbia were similar to the relevant values obtained by other researchers in Europe and the USA. Thus, the utilization of wood of northern red oak in the local wood processing industry should be considered.*

Key words: northern red oak, Serbia, wood physical properties, wood mechanical properties, wood industry.

[1] B.Sc. Ivana Živanović, B.Sc. Nenad Šurjanac, M.Sc. Milan Kabiljo, Dr. Filip Jovanović, Institute of Forestry, 3 Kneza Višeslava, 11030 Belgrade, Serbia.
[2] Prof. Dr. Nebojša Todorović, Faculty of Forestry, 1 Kneza Višeslava, 11030 Belgrade, Serbia
Corresponding author: B.Sc. Ivana Živanović, e-mail: ivana.radovanovic1712@gmail.com

FIZIČKA I MEHANIČKA SVOJSTVA DRVETA CRVENOG HRASTA U OKOLINI BEOGRADA (SRBIJA)

Izvod: *Drvo crvenog hrasta (Quercus rubra L.), koje se smatra visokokvalitetnom sirovinom za obradu u drvnoj industriji, do sada nije bilo ispitivano u Srbiji. Trenutno u Srbiji postoje samo male površine pošumljene crvenim hrastom, ali su u okolini Beograda prisutne značajne sastojine ove vrste. U ovom radu su ispitana osnovna fizička i mehanička svojstva drveta crvenog hrasta u Srbiji. Ispitano stablo, starosti oko 57 godina, posečeno je u Lipovici, kraj Beograda, i uzeta su dva trupčića radi laboratorijskih analiza. Rezultati istraživanja pokazuju da se svojstva drveta crvenog hrasta ne razlikuju značajno od svojstava autohtonih vrsta hrastova u Srbiji – kitnjaka i lužnjaka. Sem toga, vrednosti osnovnih mehaničkih svojstava drveta crvenog hrasta u Srbiji su bile približne odgovarajućim vrednostima koje su ustanovili istraživači u Evropi i SAD. Iz tog razloga bi trebalo razmotriti primenu drveta crvenog hrasta u domaćoj drvnoj industriji.*

Ključne reči: crveni hrast, Srbija, fizičke osobine drveta, mehaničke osobine drveta, drvna industrija.

1. INTRODUCTION

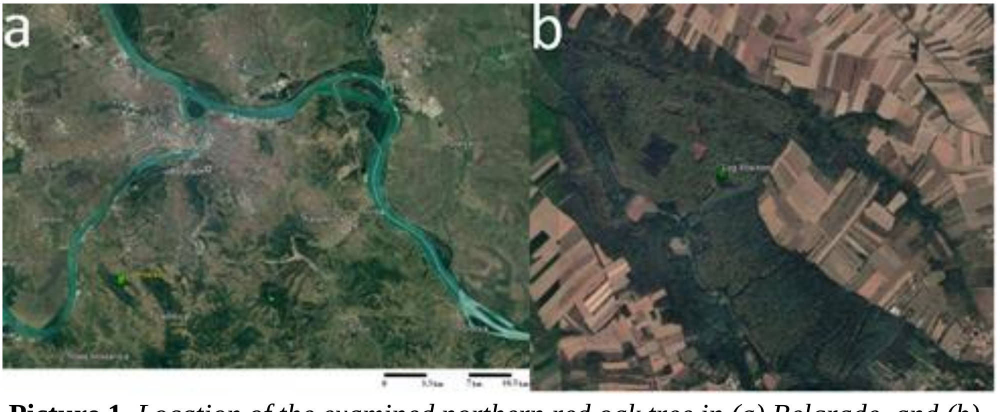
Oak (*Quercus* L., fam. Fagaceae Dumort.) is a genus composed of a diverse group of tree species that have been reported as one of the most widely used hardwoods in Europe and North America (Čufar *et al*., 2013). Among these species, northern red oak (*Quercus rubra* L.) grows naturally in the eastern and central parts of the United States of America (Uzcategui *et al.*, 2020). It was introduced to Europe in 1691 (Gubka and Špišák, 2010). To date, there are only small areas under northern red oak in Serbia (c. 60 ha), but there are significant stands of this species in the vicinity of Belgrade (Lazarević, 2020). Northern red oak has shown exceptional results in the xeromesophilic and xerothermophilic oak habitats. It is a species that tolerates aridity better than sessile oak (*Q. petraea* L.) and has fewer demands on soil fertility. Also, it easily adapts to different climatic conditions and tolerates low temperatures well. Decorativness, high vitality of wood, as well as resistance to pests, drought, frost, windbreaks and snow breaks, make this species very suitable for introduction into special-purpose oak forests (Isajev *et al*., 2006). Northern red oak is considered to be a very high-quality material for processing in the wood industry (Vansteenkiste *et al*., 2005).

The development of the wood processing industry is causing a growing demand for high-quality wood raw materials (Marković *et al.*, 2015). With the current decrease of qualified forestry resources, wood materials should be used more scientifically and efficiently in wood products like furniture (Hu *et al*., 2021). Wood properties are mainly determined by its structure, biological and organic origin, but also by the conditions in which the wood is used and exploited (Živanović *et al*., 2019). Oak species are ring-porous hardwoods with high density in the latewood part of the growth ring. Because the changes in the ring width of oaks have been more associated with the change in width of latewood, the percentage of latewood increase alongside ring width. Generally, this allows the wood density of oak, as well as other strength properties, to increase as the growth rate increases. However, the density of some trees may decline with a further increase in width ring generated from a very fast growth rate (Zhang *et al*., 1993). Variations in latewood density can be associated with variation in the latewood structure, as well as with changes in the proportions between earlywood and latewood (Rao *et al*., 1997). By summarizing various literature data, Šoškić and Popović (2002) claim that the properties of wood of northern red oak are very similar to the properties of the domestic species of the genus *Quercus*. For instance, the authors stated that the wood density amounts to around 700 kg/m^3 in the dried state of wood, whereas in the most important industrial species in Serbia [i.e., sessile oak and pedunculate oak (*Quercus robur* L.)] the density is around 675 kg/m^3. In addition, Green and McDonald (2007) determined that northern red oak has a Janka hardness of 54.3 MPa, a modulus of elasticity of 12.14 MPa, and compressive strength of about 47 MPa.

Given that the quality of wood of northern red oak has not been tested in Serbia so far, it would be of scientific and practical importance to study the properties of wood of this very resistant and fast-growing oak species in the area. Hence, this paper aims to examine the physical and mechanical properties of wood of northern red oak, as an introduced tree species in Serbia, and to compare them with the same properties of the native oak species.

2. MATERIAL AND METHODS

The examined northern red oak tree was located in the forest of Lipovica, near Belgrade, Serbia (lat. 44.697165, long. 20.356815). The area has been mapped by the unmanned aerial system (drone) DJI Phantom 4 Pro.



Picture 1. *Location of the examined northern red oak tree in (a) Belgrade, and (b) Lipovica forest*

The drone was equipped with a 20 Mpix RGB sensor, and onboard GPS. In total, 263 images were collected of the area of interest. All images were processed in Professional photogrammetry software and the resulting orthomosaic had a resolution of 2.17 cm/pix. The tree location was identified on the resulting orthomosaic. The specific location of the tree is shown on the map (Picture 1).

Northern red oaks in this area are about 60 years old, and they are growing in a mixed forest with Scotch pine (*Pinus sylvestris* L.).

2.1. Specimen preparation and testing methods

The tree was cut down and two small logs of 400 mm length from 1.3 m and 4.4 m heights were taken to the laboratory of the Faculty of Forestry, University of Belgrade, Serbia. In addition, two wheels from the same zones were taken to the laboratory for ring width measuring. Two small logs were cut, and two radial planks from each direction were obtained. Forty-one samples with dimensions 20 x 20 x 320 mm were cut and grouped according to the tree height and cardinal direction. They were tested for elastic moduli. After breakage, the rest of the samples were cut on 20 x 20 x 40 mm and tested for compressive strength parallel to the grain. Two wheels were tested for the size of the growth rings and latewood share. The cardinal sides were marked on both wheels. On the south side, growth rings are counted with the magnifying glass. To determine the size of the growth rings and the latewood inside the ring, a microscope (Digital Microscope with stand INSIZE, and magnification up to 200 times) and graph paper were used to calibrate the microscope. The measurement was performed on the sample from the south side. Samples and dimensions were measured as raw material, then after standing in water for four days and after drying in the dryer (T = 60°C, 1 day; T = 103±2°C to an absolutely dry state). The humidity of the samples in the raw state was determined by the gravimetric method (Šoškić and Popović, 2002). Linear and volumetric shrinkages were calculated. Average values were calculated based on 55 samples for radial, 56 for tangential, and 51 for axial shrinkages. Fifty samples were used to determine total volumetric shrinkage. Considering the formula for calculating the total volumetric shrinkage, obtaining the average size for volumetric shrinkage included 28 samples from the first wheel and 22 samples from the second one. The density of wood is calculated from the ratio of mass and volume of wood using standard equitation (Šoškić and Popović, 2002). Tests of wood density, static bending, and compression parallel to grain were conducted according to SRPS ISO 13061 standard. Each specimen was weighed and measured before testing. The mechanical tests were performed using SCAL WOOD TESTER with the LabVIEW software to control operations. The specific gravity specimen's sizes were 20 × 20 × 20 mm. Each specimen was measured, and oven-dried (103±2°C). Oven-dried weights were recorded after the mass was stabilized. According to the standard SRPS ISO 13061, static bending (modulus of rupture MOR) specimens were 20 × 20 × 320 mm. The test was conducted using center point loading in radial and tangential directions. The failure type was recorded for each specimen. Modulus of elasticity was calculated using standard equations (Šoškić and Popović, 2002). For the compression parallel to grain analysis, the test specimens measured 20 × 20 × 40 mm, according to the standard SRPS ISO 13061. The load was applied at a rate of 0.003 in/in (0.00762 cm/cm) of nominal specimen length/min. The type of deformation was recorded for each specimen.

2.2. Statistical analysis

The obtained numerical data were processed using descriptive statistical methods. Raw data were used to calculate the mean values of all variables and to determine the average standard deviation and coefficient of variation for every mean. The observed variables were also studied by comparing their minimum and maximum values with literature records. The statistical analysis was performed using the statistical software STATGRAPHICS XVI (StatPoint Technologies, Inc., Warrenton, VA, 2009).

3. RESULTS AND DISCUSSION

The results of the analysis of basic macroscopic and physical properties of wood of northern red oak, sampled in the vicinity of Belgrade in Serbia, are shown in Table 1.

Table 1. *The basic macroscopic and physical properties of wood of the northern red oak in Serbia*

Macroscopic and physical properties	Wheel 1	Wheel 2	Average
Number of growth rings	57	48	52
Heartwood	41	34	37
Sapwood	16	14	15
Mean value of increment ring size (mm)	3.575	3.397	3.486
Mean value of latewood ring size (mm)	2.324	2.457	2.391
Share of latewood in the growth ring (%)	67.032	72.314	69.673
Average radial shrinkage (%)	4.73	4.34	4.535
Average tangential shrinkage (%)	10.78	9.483	10.131
Average axial shrinkage (%)	0.793	0.459	0.626
Average total volumetric shrinkage (%)	15.41	13.86	14.635
Basic density (kg/m³)	679	629.40	654.20
Average moisture content in the raw state (%)	-	-	51.40

According to Zeidler and Borůvka (2016), the average ring width in northern red oak is 4.4 mm (range 2.8–7.1 mm). If we compare these data with the data obtained in our study for the 57 years old northern red oak tree (mean size of the growth ring is 3.486 mm, and the range is 0.438–9.379 mm), it can be noticed that the average ring width is smaller, but also that the variation in ring width is larger. The observed differences could be attributed to the different habitats and conditions in which the examined trees grew. Moreover, according to Zeidler and Borůvka (2016), the share of latewood is 68.80% to 90.40%, which is larger than the value obtained in our study (the average share of latewood is 69.673%). In addition, Uzcategui *et al.* (2020) obtained the result that the average percentage of latewood of northern red oak varied between 42.20% and 98.40%, with a mean value of 71.30, and a coefficient of variation of 18.17%. Büyüksarı *et al.* (2018)

calculated the average earlywood, latewood, and annual ring widths and latewood proportion of sessile oak wood, for trees aged 190 to 211 years, as 0.50 mm, 0.49 mm, 0.99 mm, and 49.30%, respectively. Gursu (1966) determined that the annual ring width of oak wood grown in the Karabuk region was 1.58 mm for trees aged 97 to 156 years, and 0.80 mm for trees aged 186 to 247 years. The proportion of latewood was determined to be 66% in *Quercus faginea* Lam. (Knapic *et al*., 2011) and 61% in *Quercus suber* L. (Knapic *et al*., 2008). Table 2 presents descriptive statistics for annual ring width and latewood width of both wheels examined. Considering the average values, it can be noticed that similar results for both tree zones were obtained. The average wood ring width was 3.616 mm for the lower wheel (LWW1), and 3.527 mm for the upper wheel (LWW2). The proportion of the latewood was on average 2.458 mm (68%) for LWW1, and 2.630 mm (74%) for wheel that was cut at 4.4 m above ground (LWW2). Vavrčik and Gryc (2012) obtained the value of 2.1 mm for the ring width of pedunculate oak and 1.4 mm for sessile oak. They reported that, at the same ring width, pedunculate oak had a higher latewood proportion. These differences could be a result of growth conditions, such as precipitation, air temperature, aspect, soil characteristics, etc.

In the present study, the average radial shrinkage is 4.535%, tangential 10.131%, axial 0.626% and the total volumetric shrinkage was 14.635% (Tab. 1). By comparing these results to the assertion of Šoškić and Popović (2002) that the radial shrinkage is 4.9%, tangential – 9.4%, axial – 0.4%, and total volumetric shrinkage – 14.2% for pedunculate oak, and radial shrinkage – 4.8%, tangential – 9.3%, axial – 0.4% and total volumetric shrinkage – 13.9% for sessile oak, it can be noticed that northern red oak from our experiment had somewhat higher shrinkage values in all directions, except for axial. The shrinkage values found in our study fall in the interval of literature data for northern red oak and the native oak species in Serbia (Šoškić *et al*., 2005; Šoškić, 2006), although total volumetric shrinkage was higher by about 0.5% than those in the native oak species.

Table 2. *Descriptive statistics for wood ring width (WRW) and latewood width (LWW) for two wheels of the northern red oak in Serbia*

Wood property	Count	Average (mm)	Standard deviation	Coefficient of variation	Minimum	Maximum	Range
WRW1	57	3.616	2.091	0.58	0.465	9.558	9.093
LWW1	57	2.458	1.709	0.70	0.251	6.623	6.372
WRW2	48	3.527	2.644	0.75	0.400	9.379	8.979
LWW2	48	2.630	2.210	0.84	0.300	7.776	7.476

The average moisture content of wood of northern red oak in Serbia is 51.40% (Tab. 1). The trend of decreasing moisture content in the samples from sapwood to heartwood was noted. According to Šoškić and Popović (2002), the average moisture content of sessile and pedunculate oak is 60–65%. Compared to sessile and pedunculate oak, lower moisture content was obtained from the samples of northern red oak wood. This can be explained by the time when the tree was cut (springtime), and by the fact that the moisture content in a standing tree is low (Šoškić and Popović, 2002).

Table 3 and Graph 1 present descriptive statistics for wood density (WD), compressive strength parallel to the grain (Hp), modulus of elasticity (MOE), and modulus of rupture (MOR), obtained with the standard, destructive method.

Table 3. *Descriptive statistics for wood properties of the northern red oak in Serbia determined with the standard destructive method*

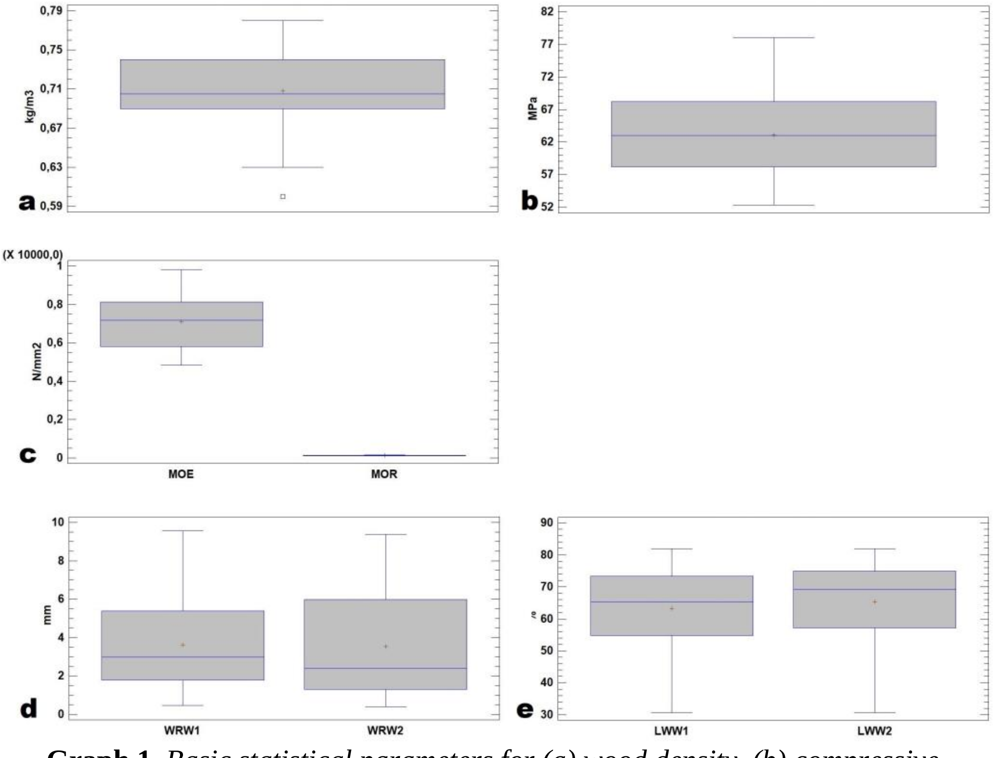
Wood property	Count	Average (mm)	Standard deviation	Coefficient of variation	Minimum	Maximum	Range
WD (kg/m^3)	40	0.72	0.03	0.04	0.67	0.78	0.11
Hp (MPa)	40	64.43	5.67	0.09	53.15	75.75	22.60
MOE (N/mm^2)	40	7381.50	1573.58	0.21	4829.96	9795.76	4965.80
MOR (N/mm^2)	40	102.23	14.43	0.14	73.43	127.26	53.83

According to Šoškić *et al*. (2005), the basic density of sessile oak is 665 kg/m^3, and the basic density of pedunculate oak is 650 kg/m^3, whereas the density of northern red oak is 740 kg/m^3. In Zeidler and Borůvka (2016), the average density of northern red oak was similar to the value obtained in our study. The density of northern red oak in our study does not differ significantly from the density of sessile and pedunculate oak. Specifically, wood density was between 670 and 780 kg/m^3, with an average value of 720 kg/m^3, and a coefficient of variation of 4%. Uzcategui *et al.* (2020) obtained wood density for northern red oak that varied between 571 and 853 kg/m^3, with an average value of 699 kg/m^3, and a coefficient of variation of 8.31%. Klašnja *et al*. (2006) obtained the total mean value of 673 kg/m^3 for the oven-dried volume density of wood of *Quercus robur*, with a standard deviation of 49.785, a maximum value of 769 kg/m^3, and a minimum value of 573 kg/m^3. Therefore, it can be noticed that northern red oak tree described in our study has a larger basic density than native oak species by about 10%. Still, this is not considered to be a significant difference.

The values of compression parallel to grain ranged from 53.15 to 75.75 MPa, with an average value of 64.43 MPa, and a coefficient of variation of 8.80%. These values are very close to those obtained by Uzcategui *et al.* (2020) for the northern red oak in the southeastern part of the USA.

Among the analyzed wood properties, MOE had the highest coefficient of variation (21.32%). Still, the mean value (7381.5 MPa) was slightly lower than those given in the literature (Uzcategui *et al.*, 2020). On the other hand, MOR has shown similar mean value (102.23 MPa) to those given in the literature. For example, Vansteenkiste *et al.* (2005) obtained a value of 12.500 MPa for MOE and 99 MPa for MOR. Wang and Allison (2008) obtained 9.810 MPa for MOE and 62.1 MPa for MOR. Uzcategui *et al.* (2020) obtained 12.211 MPa for MOE and 120 MPa for MOR. Since wood properties depend on many factors, such as climate, soil, elevation, exposition, etc., and the results originate from different parts of the world, such variations are expected.

The results obtained in our investigation are the most similar to those presented by Uzcategui *et al*. (2020). It can be assumed that the reason for this is similar climate conditions due to the similar geographical positions of the trees examined and the use of similar testing machines and sample dimensions.



Graph 1. *Basic statistical parameters for (a) wood density, (b) compressive strength parallel to the grain, (c) modulus of elasticity (MOE) and modulus of rupture (MOR), (d) wood ring width (WRW), and (e) latewood width (LWW) for two wheels of the northern red oak in Serbia. Middle sign = mean, middle line = median, box = mean and standard deviation, whisker = variation range*

4. CONCLUSIONS

Based on the results obtained in this study, the following conclusions can be drawn:

- In comparison with literature data, the average ring width in the examined 57 years old northern red oak tree was small, but the variation in the ring width was large (the mean size of the growth ring was 3.486 mm, and the range was 0.438–9.379 mm). These differences could be a result of different growth conditions, such as precipitation, temperature, aspect, soil characteristics, etc.;
- The shrinkage values found in this study fall in the interval of literature data for northern red oak and the native oak species in Serbia (sessile oak and pedunculate oak);
- The density of wood of northern red oak in this study does not differ

significantly from the density of sessile oak and pedunculate oak;

- Among the wood properties analyzed, MOE had the highest coefficient of variation (21.32%), and MOR has shown an expected mean value.

Based on the results of the study and the similarities and differences noted by comparing them with the results in other relevant studies, it can be concluded that wood of northern red oak has similar mechanical and physical properties to those of sessile oak and pedunculate oak in Serbia, and it should be considered for utilization in the local wood processing industry.

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Ivana ŽIVANOVIĆ, Nebojša TODOROVIĆ, Nenad ŠURJANAC,
Milan KABILJO, Filip JOVANOVIĆ

Summary

Northern red oak (*Quercus rubra* L.) grows naturally in the eastern and central parts of the United States of America (Uzcategui *et al.*, 2020). It was introduced to Europe in 1691 (Gubka and Špišák, 2010). To date, there are only small areas under northern red oak in Serbia, but there are significant stands of this species in the vicinity of Belgrade (Lazarević, 2020). Given that wood of northern red oak has not been tested in the area so far, it is of scientific and practical importance to study the properties of wood of this very resistant and fast-growing oak species, which is considered to be a very high-quality material for processing in the wood industry. In this study, basic physical and mechanical properties of wood of northern red oak in Serbia were tested.

The location of the examined 57 years old northern red oak tree (Lipovica forest, Belgrade) has been mapped by the unmanned aerial system (Picture 1). The tree was cut down and two small logs of 400 mm length from 1.3 m and 4.4 m heights were taken to the laboratory for analysis. Two wheels from the same tree sections were taken for ring width measuring. Forty-one samples with dimensions 20 x 20 x 320 mm were cut and grouped according to the tree height and cardinal direction. They were tested for elastic moduli (MOE) and modulus of rupture (MOR). After breakage, the rest of the samples were cut on 20 x 20 x 40 mm and tested for compressive strength parallel to the grain. Two wheels were tested for the size of the growth rings and latewood share. The cardinal sides were marked on both wheels. On the south side, growth rings are counted. The moisture content of the samples in the raw state was determined. Average values were calculated based on 55 samples for radial, 56 for tangential, and 51 for axial shrinkages. Fifty samples were used to determine total and average volumetric shrinkages (28 samples from the first wheel and 22 samples from the second wheel). Modulus of elasticity was calculated using standard equations (Šoškić and Popović, 2002). The obtained numerical data were processed using descriptive statistical methods.

For the tree examined, the mean size of the annual growth ring was 3.486 mm (Tab. 1), with a range 0.438–9.379 mm. The average width of the growth ring and latewood percentage have shown similar results for both tree sections examined. The proportion of the latewood was on average 68% for the lower wheel and 74% for the wheel that was cut at 4.4 m above ground (Tab. 2). The average radial shrinkage was 4.535%, tangential – 10.131%, axial – 0.626%, total volumetric shrinkage – 14.635% (Tab. 1). The shrinkage values found in this study fall in the interval of literature data for northern red oak and the native oak species in Serbia (sessile and pedunculate oak). The average moisture content in the raw state was 51.4%. Basic density does not differ significantly from the density of

sessile and pedunculate oak. The values of compression parallel to the grain ranged from 53.15 to 75.75 MPa, with an average value of 64.43 MPa, and a coefficient of variation of 8.80%. The values are very close to those determined for the northern red oak in the southeastern part of the USA. Among the wood properties analyzed, MOE had the highest coefficient of variation (21.32%). Still, the mean value (7381.5 MPa) was slightly lower than those given in the literature. On the other hand, MOR has shown similar mean value (102.23 MPa) (Tab. 3) with those given in the literature. The basic statistical parameters of the studied variables are shown in Graph 1.

Based on the presented results, it can be concluded that wood of northern red oak in Serbia has similar mechanical and physical properties with the native oak species, and it should be considered for utilization in the local wood processing industry.

FIZIČKA I MEHANIČKA SVOJSTVA DRVETA CRVENOG HRASTA U OKOLINI BEOGRADA (SRBIJA)

Ivana ŽIVANOVIĆ, Nebojša TODOROVIĆ, Nenad ŠURJANAC,
Milan KABILJO, Filip JOVANOVIĆ

Rezime

Crveni hrast (*Quercus rubra* L., Fagaceae Dumort.) autohtono raste u istočnim i središnjim delovima Sjedinjenih Američkih Država (Uzcategui *et al.*, 2020). U Evropu je prvi put unet 1691. godine (Gubka, Špišák, 2010). Trenutno u Srbiji postoje samo male površine pošumljene crvenim hrastom, ali su u okolini Beograda prisutne značajne sastojine ove vrste (Lazarević, 2020). Imajući u vidu da drvo crvenog hrasta do sada nije bilo ispitivano u ovom području, od naučnog je i praktičnog značaja ispitati svojstva drveta ove veoma otporne i brzorastuće vrste hrasta, čije se drvo smatra visokokvalitetnom sirovinom za obradu u drvnoj industriji. Stoga su u ovom radu ispitana osnovna fizička i mehanička svojstva drveta crvenog hrasta u Srbiji.

Položaj ispitanog stabla crvenog hrasta u Lipovici (Beograd), starosti 57 godina, mapiran je bespilotnom letilicom (slika 1). Stablo je posečeno, uzeta su dva trupca dužine 400 mm, na dve visine od zemlje (1,3 m i 4,4 m), i odneta su u laboratoriju radi analiza. Iz istih delova stabla, isečena su dva kotura za analizu širine prstenova prirasta. Potom je načinjen 41 uzorak, dimenzija 20 x 20 x 320 mm, i sortiran je shodno delu stabla i strani sveta odakle je uzet. Ovi uzorci su korišćeni za određivanje modula elastičnosti (MOE) i modula loma (MOR). Preostali uzorci su isečeni do dimenzija 20 x 20 x 40 mm i na njima je određena pritisna čvrstoća paralelna drvnim vlaknima. Na koturovima je određena širina prstenova prirasta, kao i učešće kasne zone u njima. Na oba kotura su obeležene strane sveta, pri čemu je broj prstenova određen na južnoj strani. U uzorcima je ispitan i sadržaj vlage u sirovom stanju. Prosečno radijalno utezanje je određeno na osnovu 55 uzoraka, tangencijalno na osnovu 56, dok aksijalno na osnovu 51 uzorka. Ukupno i prosečno zapreminsko utezanje je određeno na osnovu 50 uzoraka, od čega je 28 uzeto iz prvog kotura, a 22 iz drugog kotura. Modul elastičnosti određen je prema standardnim formulama (Šoškić, Popović, 2002). Dobijene numeričke vrednosti su obrađene deskriptivnim statističkim metodama.

Na ispitanom stablu, prosečna širina godišnjih prstenova prirasta je bila 3,486 mm (tabela 1), sa opsegom vrednosti od 0,438 do 9,379 mm. Prosečne širine prstenova prirasta, kao i učešće kasne zone u njima, pokazale su slične vrednosti u oba ispitivana dela stabla. Učešće kasne zone je u proseku bilo 68% za kotur sa manje visine, a 74% za kotur koji je isečen na visini 4,4 m od zemlje (tabela 2). Prosečno radijalno skupljanje je iznosilo 4,535%, tangencijalno – 10,131%, aksijalno – 0,626%, a ukupno – 14,635% (tabela 1).

Prosečne vrednosti utezanja utvrđene u ovom istraživanju se uklapaju u raspon literaturnih vrednosti navedenih za crveni hrast i za autohtone vrste hrastova u Srbiji (kitnjak i lužnjak). Prosečni sadržaj vlage u sirovom stanju je 51,4%. Gustina drveta crvenog hrasta se ne razlikuje značajno od gustine drveta kitnjaka i lužnjaka. Vrednosti pritisne čvrstoće paralelne sa drvnim vlaknima varirale su od 53,15 do 75,75 MPa i imale su prosečnu vrednost 64,43 MPa i koeficijent varijacije 8,80%. Ove vrednosti su približne literaturnim vrednostima ustanovljenim za crveni hrast u jugoistočnom delu SAD. Među analiziranim svojstvima drveta, MOE je pokazao najveću vrednost koeficijenta varijacije (21,32%), mada je njegova srednja vrednost (7381,5 MPa) bila nešto manja od one navedene u literaturi. S druge strane, MOR je imao približnu srednju vrednost (102,23 MPa) (tabela 3) literaturnoj. Osnovni statistički pokazatelji analiziranih promenljivih prikazani su na grafikonu 1.

Na osnovu dobijenih rezultata, može se zaključiti da drvo crvenog hrasta u Srbiji ima slična mehanička i fizička svojstva sa autohtonim vrstama hrastova, stoga bi trebalo razmotriti njegovu primenu u domaćoj drvnoj industriji.