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Comparison of Reaction Wood and Normal Wood of Some Commercial Tree Species

Usporedba reakcijskoga i normalnog drva nekih komercijalnih vrsta drva

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ABSTRACT • *This study aims to analyze the reaction wood samples for some industrial tree species naturally grown in Kastamonu province in Turkey and compare them with the relevant standards. Some anatomical, chemical, fiber morphological, optical properties, and color changes before and after drying were analyzed for the reaction wood (RW) samples. While the holocellulose content of fir and pine compression wood (CW) was found to be lesser (~3-4 %), the lignin content was higher than those of the opposite wood (OW) (~34 % for pine and 12 % for fir). On the contrary, the amount of holocellulose was found to be higher (~1-4 %), and the lignin was lower (at about 6-15 %) in the tension wood (TW) samples. It was observed that average lengths are more extended in TW (~50-54 %) and shorter in CW (~13-17 %) than those of OW. Significant differences were observed between the anatomical structures of the coniferous and deciduous species studied. Although, the greatest color differences in wet and oven-dried samples of coniferous trees were measured in CW (~15-17 %), it has been found as about 0.7-3 % in TW for deciduous species. Some differences were observed in the anatomical, optical, fiber morphological, and chemical properties of the RW for the studied wood species. Due to its higher lignin content and better physical properties, CW can be used for producing small households and hand tools, ornaments, toys, etc. It will also be appropriate for use in milling and turning work. It is recommended that, because of the lower lignin content and higher polysaccharide ratio, TW should be primarily used for the cellulose, pulp, and paper industries, where high mechanical resistance values are required. Consequently, RW formation causes some physical, chemical, mechanical, anatomical, and optical differences compared to OW in deciduous and coniferous species.*

KEYWORDS: *pine; fir; oak; beech; anatomical and chemical structure*

SAŽETAK • *Cilj ovog istraživanja bio je analizirati uzorke reakcijskog drva nekih industrijskih vrsta drva koje prirodno rastu u pokrajini Kastamonu, u Turskoj, i usporediti ih s relevantnim standardima. Na uzorcima reakcijskog drva (RW) analizirana su njihova anatomska i kemijska svojstva, morfološka svojstva vlakana te optička svojstva i promjena boje prije i nakon sušenja. Sadržaj holoceluloze u kompresijskom drvu (CW) jelovine i borovine bio je manji nego u opozitnom drvu (OW) (~3 – 4 %), dok je sadržaj lignina u kompresijskom drvu bio veći nego u opozitnome (~34 % u borovini i 12 % u jelovini). Naprotiv, utvrđeno je da je u uzorcima tenzijskog drva (TW) količina holoceluloze veća (~1 – 4 %), a lignina manja (~6 – 15 %). Uočeno je također da su prosječne duljine*

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vlakanaca u tenzijskom drvu veće (~50 – 54 %), a u kompresijskom drvu manje (~13 – 17 %) nego u opozitnome. Nadalje, uočene su značajne razlike u anatomskoj strukturi između proučavanih crnogoričnih i bjelogoričnih vrsta drva. Iako su u crnogoričnih vrsta drva razlike u boji između mokrih i suhih uzoraka bile najveće u kompresijskom drvu (~15 – 17 %), u bjelogoričnih su vrsta drva razlike u boji bile veće u tenzijskom drvu, i to za oko 0,7 – 3 %. U proučavanih vrsta drva uočene su neke razlike u anatomskim, optičkim, morfološkim i kemijskim svojstvima reakcijskog drva. Zbog većeg sadržaja lignina i boljih fizičkih svojstava kompresijsko se drvo može upotrebljavati za proizvodnju malih kućanskih i ručnih alata, ukrasa, igračaka itd., a prikladno je i za glodanje odnosno tokarenje. Preporučuje se da se tenzijsko drvo zbog nižeg sadržaja lignina i većeg omjera polisaharida primarno rabi u industriji celuloze i papira, gdje je potrebna velika mehanička otpornost. Stvaranje reakcijskog drva posljedično uzrokuje neke fizičke, kemijske, mehaničke, anatomske i optičke razlike u usporedbi s opozitnim drvom bjelogoričnih i crnogoričnih vrsta.

KLJUČNE RIJEČI: *borovina; jelovina; hrastovina; bukovina; anatomska i kemijska struktura*

1 INTRODUCTION
1. UVOD

The wood material is important globally because it is both natural and sustainable. Turkey has a total forest area of 22,740,297 hectares, while the productive forest area is 13,830,510 hectares. Oak, pine, beech, juniper, and fir are the first five most important commercial tree species, with the highest distribution in Turkey (Kuzka, 2013; OGM, 2021).

Wood materials are used for various purposes, such as fiber-firewood in the paper industry, wood-based material production, etc. Although Turkey's total annual wood consumption is 32 million m^3, the annual wood production is 26.3 million m^3. The difference between production and consumption is supplied from private plantation forests (5 million m^3) and covered by imports (1.5-2 million m^3) (OGM, 2021).

Reaction wood, formed under the effect of forces that bend wood due to external factors (wind, etc.), affects the end-product properties of the wood (Rowell, 2005). These defects are CW (compression wood) in coniferous trees and TW (tension wood) in hardwoods. In CW, force is exerted on the lower side of the bent stem to make the trunk upright, while in TW, pressure is applied on the upper side of the bent stem. These abnormal formations in wood sourced from RW (reaction wood) are seen as defects in living trees and sawn timber (Donaldson and Singh, 2016). Almost all forests are located on sloping lands in Turkey. Therefore, the reaction wood formation rate is high in industrial woods (OGM, 2022).

There are many studies on reaction wood in the literature. Köksal and Kılıç Pekgözlü (2016) investigated the microscopic structures of *Pinus sylvestris L.*, *Pinus nigra Arnold,* and *Pinus brutia Ten.* compression woods in their study. Ruelle *et al.* (2010) examined the physical and mechanical properties of CW and OW (opposite wood) samples from three different tropical tree species. It has been determined that the compressive strength of TW is generally lower than that of OW. Geffertova *et al.* (2019), in their study with beech TW samples, determined that the samples fiber length and width were higher than those of OW.

In this study, RW samples taken from fir (*Abies nordmanniana* (Stev.) Spach. subsp. *bornmuelleriana*), pine (*Pinus nigra Arn.* subsp. *pallassiana* (Lamb.) Holmboe), oak (*Quercus robur* L.), and beech (*Fagus orientalis* Lipsky) were studied in terms of anatomical, chemical, fiber morphological, and optical properties. Besides, some evaluations and comparisons between RW and OW, coniferous and deciduous woods, and inter-species properties have been reported.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Materijal
2.1. Materijal

2.1.1 Study area
2.1.1. Istraživani lokalitet

The wood samples were taken from Bostan Forestry Management Chiefdom, located within the borders of Kastamonu/Turkey. The area of the management directorate is 8,287.7 hectares, the forest area is 6,378.4 hectares, and the open area is 1,910.3 hectares. It is located between 41º02'58''- 41º09'57'' north latitude and 33º40'33''- 33º51'50'' east longitude. The highest point is Büyük Hacet Hill, with a height of 2,587 m, and the lowest point is 1,155 m, where Karasu Stream and Açlık Stream meet. Samples containing RW were selected from log storage areas of the Kastamonu Forest Regional Directorate.

2.1.2 Sample collection and preparation
2.1.2. Prikupljanje i priprema uzoraka

For each tree species, three wood disks were taken from 1.30 m of breast height with a 10 cm thickness. The RW and OW zones of the disk samples were determined according to Figure 1. All RW and OW zones of the wood disks were cut carefully and chipped to the size of a matchstick (0.5-1.0 mm). Air-dried and grounded in a Willey-type mill, wood samples were

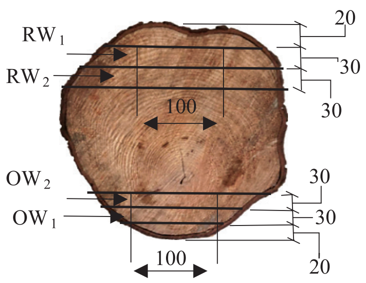

Figure 1 Preparation of RW (reaction wood) and OW (opposite wood) samples for analyses (mm)
Slika 1. Priprema uzoraka RW-a (reakcijskog drva) i OW-a (opozitnog drva) za analizu (dimenzije su u milimetrima)

screened through 40 to 60 mesh sieves. The coarse and thick parts were eliminated by staying above 40 mesh, and the thin pieces were eliminated by going below 60 mesh. The remaining material over 60 mesh was used for experiments. The powdered wood was stored in a dry and clean glass jar with its mouth closed.

2.2 Methods
2.2. Metode

To determine the chemical analyses, lignin (TAPPI T 222 om-88), holocellulose (Wise's Chlorite method), alpha-cellulose (TAPPI T 203 os-71), ethanol solubility, 1 % NaOH solubility, hot water and cold water solubility (TAPPI T 207 om-88) experiments were done according to the above applicable standards.

For microscopic examinations, 1.5 cm × 1.5 cm × 1.5 cm samples were taken from the RW and OW regions of the wood. The samples were boiled with distilled water to soften them for better sectioning. The samples were boiled in distilled water until they softened, and then they were soaked in a solution mixture of glycerine, ethyl alcohol, and distilled water (6:2:2 v/v/v) for 20 days (Köksal and Kılıç Pekgözlü, 2016). For diffuse-porous anatomical structured wood species, vessel cells were sampled from the area near the previous annual ring boundary of earlywood zones and from the area near the next annual ring boundary of latewood zones. For the morphological properties of fibers, the chlorite method was used for maceration (Wise and Karl, 1952), and measurements were taken using Digimiser® for at least 150 fiber samples.

For the determination of the optical properties of the samples, the samples were optically measured after both fresh cutting and oven-dried conditions at (37±3) °C for four days. The color coordinates (L^*, a^*, b^*) were measured according to the D65 standard with the Konica Minolta CM2500d device (Geffertova *et al.,* 2019). The percentage rates can be found by dividing the value by the total value and then multiplying the result by 100. The formula used to calculate the percentage is (value/total value) × 100 %.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Chemical analysis
3.1. Kemijska analiza

The holocellulose content in the pine CW was 3.87 % less than in OW and 4.97 % less in fir CW than in OW. Studies conducted on pine show that the holocellulose content is around 60-70 %, and in some studies, its amount increases up to 75 % (Ateş, Kırcı and Tutuş, 2008). In studies on fir species, 70-80 % holocellulose content was determined (Topaloğlu and Erisir, 2018). The details are given in Figure 2.

It has been determined that there may be differences in both the amount of CW and holocellulose content of the coniferous wood samples according to harvested regions (Arslan *et al.*, 2021; As *et al.*, 2001; Ataç and Eroğlu, 2013; Gülsoy and Öztürk, 2015; Popescu *et al.*, 2011).

Lignin content was 12.6 % and 34.8 % higher in coniferous trees compared to OW. Wood properties vary from species to species and within the same species depending on many factors (age, genetic charac-

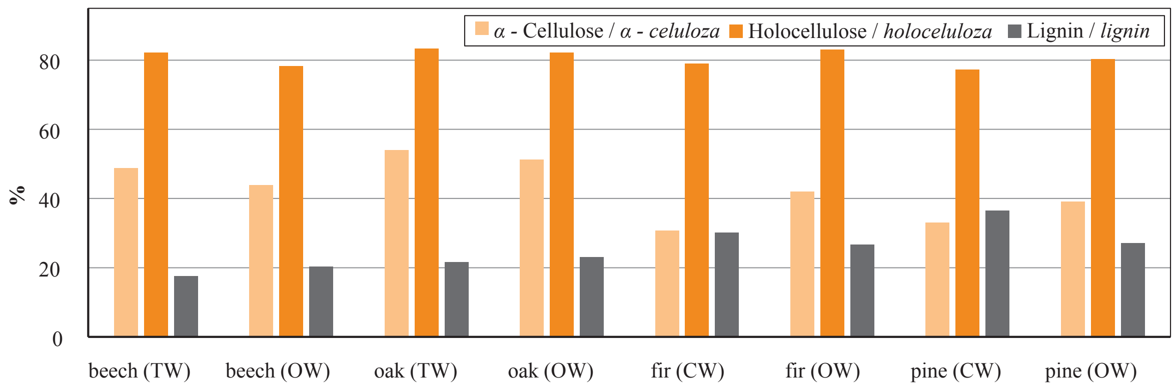

Figure 2 Chemical compositions of reaction and opposite wood of tree species (TW – Tensile wood, CW – Compression wood, OW – Opposite wood)
Slika 2. Kemijski sastav reakcijskoga i opozitnog drva različitih vrsta (TW – tenzijsko drvo, CW – kompresijsko drvo, OW – opozitno drvo)

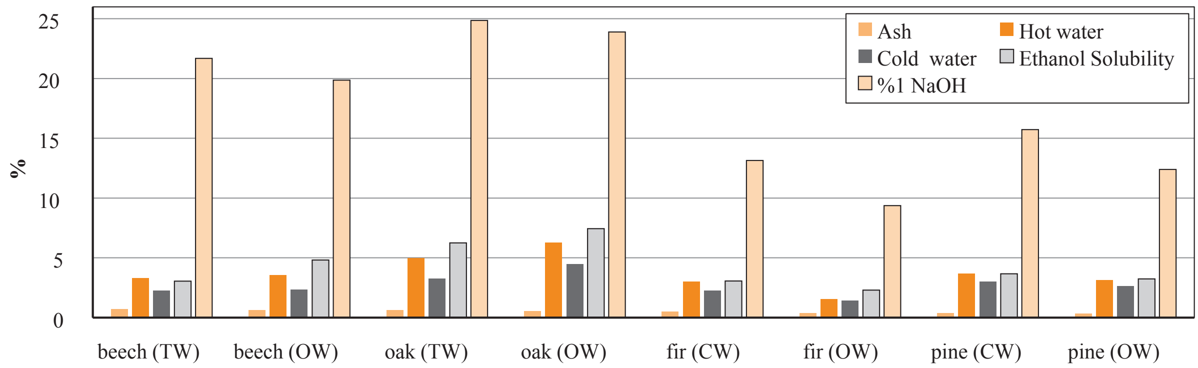

Figure 3 Solubility of reaction and opposite wood of tree species (TW – tensile wood, CW – compression wood, OW – opposite wood)
Slika 3. Topljivost reakcijskoga i opozitnog drva različitih vrsta (TW – tenzijsko drvo, CW – kompresijsko drvo, OW – opozitno drvo)

teristics, environmental characteristics, etc.) (Doğu *et al.,* 2001). The reason why lignin contents are different between pine and fir species is thought to be due to genetic factors. It was observed that the lignin content of TW in the deciduous trees was 15.74 % and 6.68 % in the beech and oak OW, respectively.

Figure 3 shows that ethanol solubility in RW is ~18.25 % greater than that of OW for coniferous wood. The difference is assumed to be caused by changes in the quantity of CW in the tree species (Kılıç *et al*., 2010). While the ethanol solubility of fir species is commonly considered to be around 3 %, pine species have a solubility of 3-4 % (Rowell, 2005). Similar to previous investigations, ethanol solubility was shown to be 11.39 % greater in pine CW compared to OW (Kılıç *et al*., 2010). It demonstrates that fir OW has a lower extractive content than pine samples of about 1.37 %. The extractive content of wood samples for the same species is also affected by variables such as altitude, climate, and so on (Akyıldız and Ateş, 2008). Also, it was determined that the amount of ash in CW of coniferous species was higher (13.15 % in pine and 26 % in fir) than in OW. Compared to the literature findings, alcohol benzene solubility is rising up to ~5.9 % in oak wood (Miranda *et al.,* 2017), and this rate is coming to around 3 % in beech (Malakani *et al.,* 2014). As a result, ethanol solubility was determined to be 5.38 % in coniferous trees (fir, pine) and 3 % in deciduous trees (oak, beech) on average.

The amount of α-cellulose in the samples was 18.48 % and 37.08 % less than OW and CW of pine and fir, respectively. Similarly, α-cellulose content in pine wood was found to be between 35 % and 50 % (Arslan *et al.,* 2021; Kılıç *et al*., 2010). It has been determined that the cellulose content of CW is reduced by up to 30 % compared to normal wood (Bozkurt and Erdin, 2011). The α-cellulose content in fir CW was found to be 58.94 % and 75.82 % lower than beech and oak TW, respectively. It has been observed that the amount of α-cellulose in deciduous trees is generally around 40-50 % (Fišerová *et al*., 2013; Rowell, 2005). The average amount of α-cellulose was found to be 29.82 % lower in CW than in TW.

The hot water solubility of pine CW was found to be 3.69 % and 3.0 % for fir CW. The same solubility was found at 3.16 % and 1.56 % for pine and fir OW, respectively. Compared to deciduous species, hot water solubility is 37.08 % lower in coniferous species. Similar studies were found in the literature (Kılıç *et al*., 2010; Hafızoğlu and Usta, 2005). Cold water solubility was found to be 32.11 % higher in TW of deciduous tree species compared to CW of coniferous species. Also, cold water solubility was found to be 24.67 % higher for deciduous trees than for coniferous species. It was observed that the cold water solubility of TW was 4.54 % higher than that of CW. Tutuş *et al.* (2010) determined the cold water solubility as 3.42 % in their research on pine wood.

1 % NaOH solubility of fir CW and pine CW was found to be 13.15 % and 15.73 %, respectively; it was determined as 9.37 % for fir OW and 12.40 % for pine. 1 % NaOH solubility of RW of deciduous species was found to be greater at about 78.27 % than RW of coniferous species, and TW was also higher at a rate of 61.14 % compared to CW. Similar studies were found in the literature (Benouadah *et al.,* 2018).

3.2 Anatomical properties
3.2. Anatomska svojstva

Earlywood vessel and tracheid diameters on transverse sections were greater than latewood cross sections in all studied species. In Figure 4, the tangential diameter of the earlywood tracheid in OW of coniferous species was found to be larger (~1.4 μm) than that of CW, while the latewood tracheid was found to be larger (~2.94 μm) in CW.

The tangential diameter of the latewood vessel cells in beech TW was found to be 12.44 % and was narrower than that of OW. It has been stated in the literature that the beech has a circular vessel structure,

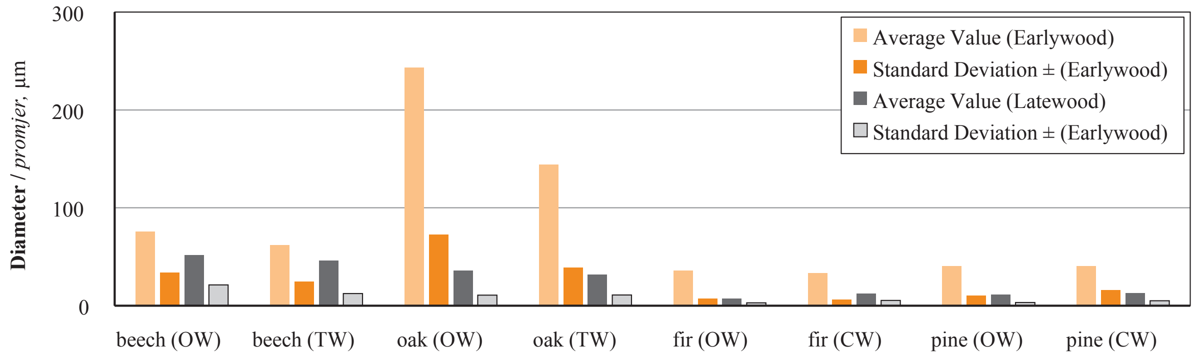

Figure 4 Average tangential diameters of vessel or tracheid (TW – tensile wood, CW – compression wood, OW – opposite wood)
Slika 4. Prosječni tangentni promjeri traheja ili traheida (TW – tenzijsko drvo, CW – kompresijsko drvo, OW – opozitno drvo)

the latewood vessels are smaller in diameter and few in number, and the rays are in the form of longitudinal lines in the transverse section (Safdari *et al.*, 2008).

While the tangential direction of tracheid diameters was found to be 1.69 % wider in the average latewood dimeters of pine CW in cross-section, it was found to be 54.24 % wider in the earlywood than that of OW (Figure 4). The earlywood and latewood widths of fir and pine CW were found to be wider (Fir: ~63.5 % earlywood, 55 % latewood. Pine: 28.3 % earlywood, 34.8 % latewood) than those of OW. The earlywood widths of oak (~60.8 %) and beech (~15.8 %) TW were found to be less than those of OW, and the latewood (~2.7 % beech, ~22.2 % oak) widths were higher than those of TW. Earlywood tracheids had a larger lumen and a thin wall structure (Esteban and Palacıos, 2009). For pine wood, tracheid diameters were averagely narrower in CW (about 0.22 %) than in OW, and they were also 8.59 % wider in latewood. CW transition from earlywood to latewood is gradually compared to OW.

The average number of rays per mm^2 of pine CW was found to be 4.58, and the average number of rays per mm^2 of OW was found to be 4.00. In Figure 5, it was observed that the average number of rays per mm^2 of pine CW in the tangential section was 14.50 % larger than that of OW. The average number of rays 1 mm^2 in fir CW was 6.24 and 5.74 in OW. This rate was found to be 8.70 % for fir in the same direction. On average, about two times more ray numbers were found on 1mm^2 in fir wood. The average number of rays in 1 mm^2 was 9.60 and 7.40 in the beech TW and OW, respectively.

The average number of rays in 1 mm^2 of oak TW was 10.20, and the average number of rays in 1 mm^2 of oak OW was 9.63. For oak and beech TW, 5.91 % and 29.72 % more ray numbers were measured, respectively, in 1mm^2 than for OW. The average ray number was determined to be 16.0 % higher in oak wood than in beech. The average number of rays per 1mm^2 in deciduous species was 78.98 % higher than in coniferous species. Similarly, the average number of rays in 1mm^2 of TW was 82.99 % higher than that of CW. Compared to pine and fir woods, the average number of rays in 1mm^2 was higher in beech and oak. Similar results were obtained for *Quercus aucheri* Jaub. and Spach (11.17), *Quercus cocifera* L. (16.23), and *Quercus ilex* L. (7.03) (Kadem and Fakir, 2017).

3.3 Annual ring widths
3.3. Širina godova

Figure 6 shows that annual ring widths are almost 100 % higher in pine OW than fir OW. The earlywood zone for pine CW was 1.20 % greater than that of fir

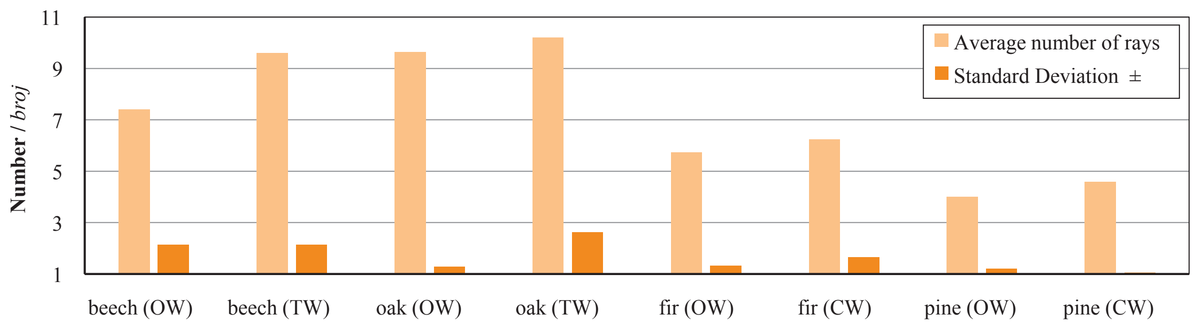

Figure 5 Number of ray cells in 1 mm^2 of tangential section of wood species (TW – tensile wood, CW – compression wood, OW – opposite wood)
Slika 5. Broj stanica trakova na 1 mm^2 tangentnog presjeka različitih vrsta drva (TW – tenzijsko drvo, CW – kompresijsko drvo, OW – opozitno drvo)

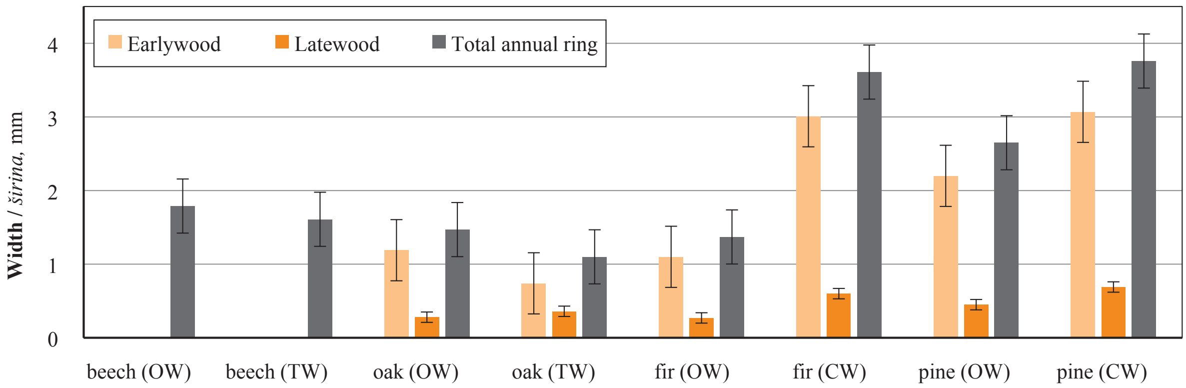

Figure 6 Earlywood and latewood widths of studied wood species (TW – tensile wood, CW – compression wood, OW – opposite wood)
Slika 6. Širine ranoga i kasnog drva ispitivanih vrsta (TW – tenzijsko drvo, CW – kompresijsko drvo, OW – opozitno drvo)

CW. The latewood portion of pine OW was wider (66.67 %) than that of fir OW. Also, the late wood of pine CW was 15 % wider than that of fir TW.

The total annual ring width found for beech OW was 21.77 % wider than that of oak OW, although the annual ring widths of pine OW were on average 93.43 % greater than those of fir OW. However, the annual rings for the beech TW are on average 46.36 % broader than those of oak TW. This ratio for pine TW was 4.15 % higher than for fir TW. Bektaş *et al.,* (2016) have found an annual ring width of 2.11mm in oak. The average width of oak annual rings was between 1.09 and 2.94 mm (Matisons and Brümelis, 2012). Another study stated that climate significantly impacts annual ring width (Pourtahmasi *et al.,* 2011; Roibu *et al.,* 2020; Yaman *et al*., 2020). In the literature, it has been reported that the anatomical characteristics of oak are affected by environmental conditions (Bozkurt and Erdin, 1995; Gricar *et al.*, 2013).

3.4 Morphological properties of fibers
3.4. Morfološka svojstva vlakana

Morphological measurements of the studied wood fibers are presented in Figures 7 and 8. Although the fiber length of pine OW was 10.61 % longer than that of fir OW, pine CW had 14.04 % longer fiber length than fir CW. Also, the average fiber length of oak OW is 1.79 % longer than that of beech OW, and this rate for oak TW is 9.35 % higher than for beech TW. Figure 8 shows that both fiber and lumen widths are decreasing in CW (~19.75 %) and increasing for TW samples (~7.13 %). However, the average fiber width of beech OW was 24.83 % greater than that of oak OW.

It was determined that the tracheid width of pine OW was 18.11 % wider than that of fir OW. Oak TW fibers were 16.71 % smaller than those of beech TW. Tracheid widths of fir CW were on average 27.79 % narrower than those of pine CW. It was also determined that the lumen width of fir OW cells was 43.15 % less than that of pine OW, and oak OW had 58.53 % less fiber cell lumen than beech OW. While this rate for oak TW was 50.83 % smaller than that of beech TW, fir CW cell lumen widths were 41.95 % less than those of pine CW.

Comparing the cell wall thickness, beech OW was 8.48 % thicker than oak. This rate was 2.95 % higher for pine OW than for fir OW. Also, 0.15 % thicker beech TW was observed than oak TW. This rate for pine CW was 15.70 % higher than for fir CW. Although the difference is not significant, all RW samples have a thicker cell wall than the OW zone. The growth location characteristics and the growth environment af-

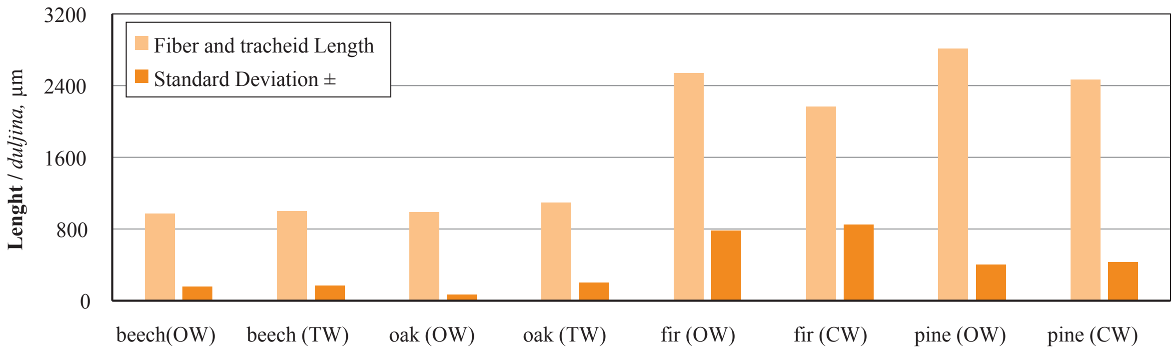

Figure 7 Fiber length of the studied wood samples (TW – tensile wood, CW – compression wood, OW – opposite wood)
Slika 7. Duljina vlakana ispitivanih uzoraka drva (TW – tenzijsko drvo, CW – kompresijsko drvo, OW – opozitno drvo)

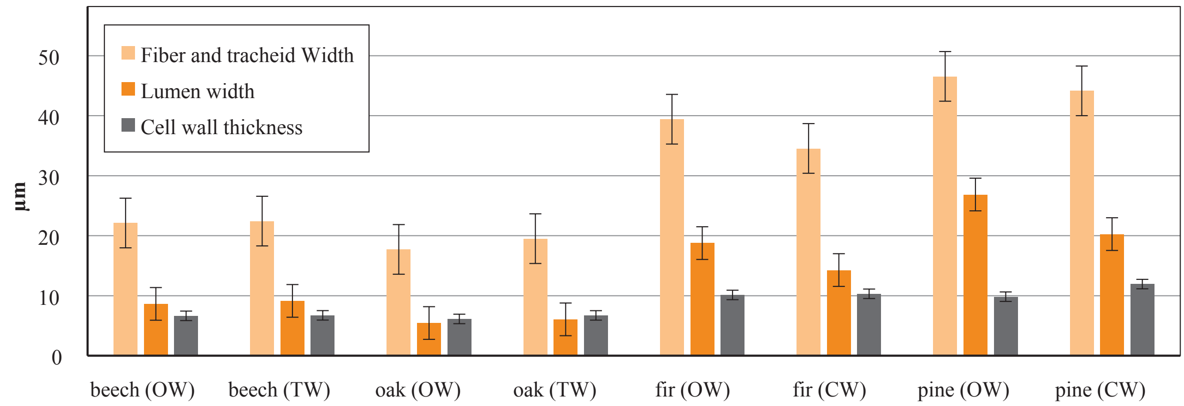

Figure 8 Fiber width, lumen width and cell wall thicknesses (TW – tensile wood, CW – compression wood, OW – opposite wood)
Slika 8. Širina vlakana, širina lumena i debljina stanične stijenke (TW – tenzijsko drvo, CW – kompresijsko drvo, OW – opozitno drvo)

fect the characteristics of the same type of tree (Abuamoud *et al.*, 2018).

3.5 Optical properties
3.5. Optička svojstva

Wood samples were oven-dried. As shown in Figure 9, the color changes (ΔE^*) of green wood and dried wood were 36.86 % higher in coniferous species compared to deciduous species. The color change in CW was higher (42.23 %) than that of TW. The total color change in fir CW was 15.09 % higher than in fir OW, and 17.01 % higher in pine CW than that of OW. It was determined that the total color change of oak and beech TW was higher than that of OW, 2.66 % and 0.72 %, respectively. As a result, it was assumed that the color differences between the different wood species may be due to the different chemical content, especially the extractive contents.

The average color change in fir and pine species was 8.87 % higher than in oak and beech species. The red color parameter (a^*) was 1.92 % lower in fir and pine CW than in OW; it was observed that the TW of oak and beech was 0.09 % higher than that of OW. While the yellow color parameter (b^*) was 1.42 % lower in fir and pine CW than in OW, it was also 1.04 % lower in oak and beech TW than in OW. The brightness parameter (L^*) was 2.65 % higher in fir and pine CW than in OW; it was observed that the TW of oak and beech was 0.35 % lower than OW.

In similar studies, it has been stated that the color of the wood is generally dark, and that the temperature is the main factor. Also, RW caused an increase in the color change in the wood. Due to the high content of extractive substances and lignin in coniferous species, the color difference in wood is found to be high (Aydemir and Gündüz, 2009; Tarmian *et al.*, 2011; Yazıcı and Özlüsoylu, 2020).

4 CONCLUSIONS
4. ZAKLJUČAK

This study investigated the anatomical and chemical structures, fiber, and optical properties of the RW and

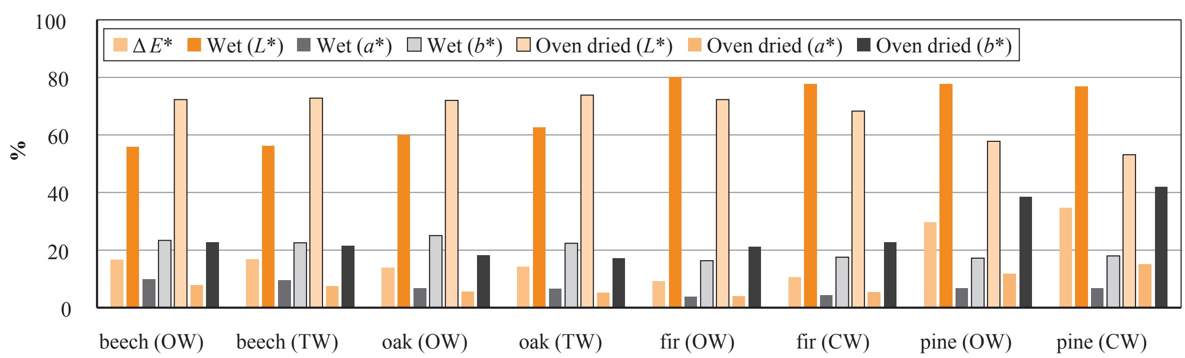

Figure 9 Optical properties of reaction and opposite woods of fir, pine, beech and oak species (ΔE^* – total color change value, L^* – brightness value, a^* – red color value, b^* – yellow color value, TW – tensile wood, CW – compression wood, OW – opposite wood)
Slika 9. Optička svojstva reakcijskoga i opozitnog drva jelovine, borovine, bukovine i hrastovine (ΔE^* – ukupna promjena boje, L^* – svjetlina, a^* – crvenozeleni ton, b^* – žutoplavi ton, TW – tenzijsko drvo, CW – kompresijsko drvo, OW – opozitno drvo)

OW parts of the beech, oak, pine, and fir wood species naturally grown in a specific environment over time.

The amount of ash was found to be higher in deciduous species compared to other wood species. Besides, it was determined to be higher in TW and CW of coniferous species than in OW.

Although the amount of α-cellulose was higher in TW and lower in CW part than in OW, the lignin amount was higher in CW and lower in TW.

Compared to OW, although fiber and lumen widths are decreasing in CW and increasing for TW samples, the color change ratio is higher for CW than for TW.

TW contains more cellulose and less lignin than normal wood in the production of paper and cellulose. However, the strength of the fibers was lower in samples containing high TW. Since CW and TW are more sensitive than normal wood, they cause problems in applications such as structural elements, carriers, surface treatments, cutting, and sawing.

This study determines the anatomical, chemical, fiber, and optical properties of the four wood species commonly used in industry and gives their comparison with each other. The data obtained will likely provide important benefits in practice. In addition, in scientific terms, such comparison studies fill an important gap in the literature in reaching clear results.

During the growing period of trees, necessary environmental, sylvicultural, and genetic interventions should be taken to prevent the formation of reaction wood and to provide more efficient use of wood in the forest product industry.

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