ISSN impresa 0717-3644
ISSN online 0718-221X

Maderas. Ciencia y tecnología 2021 (23): 52, 1-12

DOI: 10.4067/s0718-221x2021000100452

INFLUENCES OF DIFFERENT DRYING CLIMATES ON *Eucalyptus camaldulensis* WOOD PROPERTIES

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ABSTRACT

One of the most important disadvantages of the wood material, whose usage is becoming more and more widespread, is the dimensional instability that occurs in its interaction with water. Therefore, studies to improve these drawbacks of wood, remain always up to date. For the mentioned purpose in this study, some chemical, morphological, physical and mechanical properties of *Eucalyptus camaldulensis* woods, which were naturally dried in outdoor and indoor climate in Eastern Mediterranean (Kahramanmaraş province) atmosphere conditions of Turkey, were investigated. According to the results of the study, chemical properties of *Eucalyptus* woods dried indoor were measured as merely 0,23 % higher than dried ones outdoor. The results of morphological measurements indicated that the fiber dimensions of eucalypt wood dried in indoor were average 1,48 % lower than the ones dried out outdoor. Also, as a result of statistical analysis, it was found that there were significant differences ($\rho < 0,000$) between the physical properties of *Eucalyptus* wood samples indoor and outdoor according to the t-test. At the same time, as a result of the t-test applied to determine the effect of drying conditions on mechanical properties of *Eucalyptus* wood, modulus of elasticity, compression, tensile, dynamic bending and shear strength did not cause any significant difference between indoor and outdoor, while bending and Janka hardness strengths showed significant differences at $\rho < 0,000$ level. Finally, when the data obtained as a whole is considered, it can be said that testing of *Eucalyptus* wood which requires a very sensitive drying in different climates has important contributions on the subject. Regarding eucalypts, which has a high distribution area (20 million hectares) in the world, it is recommended to relevant institutions and organizations to expand and maintain such study in the future. Lastly, according to obtained data from this study, it can be said that the experiments of *Eucalyptus* woods which require a very delicate drying in different environments provide important contributions on the subject.

Keywords: Basic density, chemical properties, morphological properties, mechanical properties, shrinkage.

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Received: 26.02.2020 Accepted: 07.06.2021

INTRODUCTION

One the most important disadvantages is the change in the dimensions of wood material during its interaction with water. As a result of the reduction of wood-based resources, demand for wood cannot be adequately met and price increases are higher than expected. For these and similar reasons, the studies on reducing the objectionable aspects of the wood material and increasing their positive properties are always keep up-to-date (Kocaefe *et al.* 2008, Aytin *et al.* 2015, Cetin and Gunduz 2016).

As is known, wood is an anisotropic material and its properties differ in various directions (Dahl and Malo 2009, Dackermann *et al*. 2016). Knowing of the physical, mechanical and chemical properties of wood makes it easier to compare wood materials with others and gives ideas about processing and usage characteristics (Sancak 2010, Duzkale *et al.* 2014, Cetin and Gunduz 2017). Mechanical properties are defined as the degree and condition of the wood to resist external forces and various types of loads, such as mechanical and external forces, which lead to dimension and deformation, stress and rupture (Bozkurt and Goker 1996). Due to its hygroscopic properties, wood material or any wood-based product can reach certain equilibrium moisture content by adapting to weather conditions in various places of use. In dimensions of wood material, which is not dried sufficiently changes occurs such as shrinkage or swelling during utilization (Kantay 1993, Bergman 2021). Because of these changes, defects such as cracking, separation from joints, and deformation of wood material can take place (Ors and Keskin 2008). There are two main components in wood: lignin (18 % - 35 %) and carbohydrates (cellulose and hemicellulose) (Ors and Keskin 2008). These components are complex and polymeric materials. There are minor extraneous materials in structure of wood, which are organic extractives and inorganic minerals (ash). Generally, wood has an elemental composition of about 50 % carbon, 6 % hydrogen, 44 % oxygen, and trace amounts of several metal ions (Pettersen 1984).

Australia is the homeland of the genus *Eucalyptus*. *Eucalyptus camaldulensis* is cultivated for commercial purposes in Turkey and this plant of foreign origin has become native (Davis 1988). Eucalypts, which is grown especially in the southern regions of Turkey, is a type of tree that has an important role for forest industry in the world due to its large diameter arises in a short time and has smooth trunk. This plant, which has been grown in Turkey since 1939, obtains different forest products for various purposes, primarily for railroad tie and bridge production, followed by cellulose, which is the raw material of paper industry (Karsavuran 2008). *Eucalyptus*, which was considered as a packing case at first, is nowadays used in many areas such as building constructions, veneer, furniture, chest, turnery, agricultural tools, musical instruments, sports equipment, stull, trolley pole and fiber-chip wood (Yaltirik and Efe 1994, Korkut *et al.* 2008).

The water present in new-cut trees should be eliminated from wood before using as end product. Hence, rough and fresh timber should be exposed to drying process. Depending on species, weather conditions, timber dimensions and the season when the wood piled, natural-drying times vary widely. Temperature, relative humidity and airflow effect the drying process of wood piles (Bektas *et al.* 2017). Different timber dimensions, bark content and piling specifications may strongly affect natural-drying times (Simpson and Wang 2004, Bown and Lasserre 2015). The drying process has several important advantages such as increases some strength properties and improves dimensional stability of wood (Forest Products Laboratory 1999). However, drying defects such as cracks, hardening, cell collapse, shape changes, color changes adversely affect the quality of the wood material (Kantay 1993).

As far as can be researched, no studies have encountered effect of different drying climates on the properties of *Eucalyptus* wood. Closest to the subject of this study, mechanical properties of *Eucalyptus urophylla* wood (Lahr *et al.* 2017) and *Eucalyptus grandis* wood (Lahr *et al.* 2018) of different moisture (12 %, 30 %) levels were investigated. Eventually, Lahr *et al.* (2018) found that mechanical properties were significantly affected by moisture content, and the behavior pattern consisted in increasing the values of the properties with reduction of moisture content. Other researchers also investigated *Eucalyptus saligna* (Nogueira *et al.* 2019) and *Eucalyptus maidenii* wood's properties in abovementioned moisture contents (Nogueira *et al.* 2018). In another study, pine (*Pinus sylvestris*) and beech (*Fagus sylvatica*) woods were subjected to steam kiln-drying. Modulus of elasticity and bending strength for steam dried, air-steam mixture dried and air-dried samples as reference were measured. They concluded that steam and air-steam mixture drying cause changes of the mechanical properties of analyzed wood species (Baranski *et al.* 2014).

In the light of the above explanations, the effects of natural drying climates on some chemical, morphological, physical and mechanical properties of *Eucalyptus* wood, one of the fast growing tree species with high distribution areas, was investigated in this study.

MATERIALS AND METHODS

Materials

The freshly sawn lumbers were obtained from Mersin-Karabucak Forest Sub-district Directorate. Lumbers were cut into the dimensions of 6 cm x 15 cm x 300 cm and the ends of edged timbers were not sealed. When the timbers were brought to drying environments, their starting moisture content (MC) varied between 57 % to 72 %. Twenty timbers were dried in each environment in order to minimize random variations and the test samples were randomly selected from the piles.

Drying process

Air drying method was applied to the timbers stacked in Kahramanmaraş Province. Timbers were piled in two different environments: Outdoor (OD) and Indoor (ID). Drying process was began in summer period (effective drying) on June and followed during one year. The data were taken from meteorological station for OD and Geratech DT-172 was used to measure temperature and relative humidity of ID.

Determination of physical and mechanical properties

Test specimens were obtained from eucalypts (*Eucalyptus camaldulensis* Dehnh.) timbers supplied in Mersin-Karabucak territory. Test specimens were prepared on the basis of TS 2470 (1976). Some physical properties such as air-dry density, oven-dry density and basic density values were determined with the sample dimension of 20 mm × 20 mm × 30 mm, based on TS 2472 (1976). Additionally, volumetric shrinkage and swelling was calculated according to TS 4083 (1983), TS 4084 (1983), TS 4085 (1983), TS 4086 (1983) with the sample dimension of 20 mm × 20 mm × 30 mm. As for the mechanical properties, static bending strength and modulus of elasticity was designated on the sample dimensions of 20 mm × 20 mm × 300 mm based on TS 2474 (1976) and TS 2478 (1976), respectively. With the same sample size, dynamic bending strength was also calculated according to TS 2477 (1976). Furthermore, compression strength parallel to grain (20 mm × 20 mm × 30 mm), Janka hardness (50 mm × 50 mm × 50 mm), tensile and shear strength samples were prepared for the laboratory experiment and strength values were determined TS ISO 13061-17 (2019), TS 2479 (1976), TS 2475 (1976) and TS 3459 (2012), respectively.

The Independent Samples t-test was performed to determine if there were statistically significant differences between the properties of ID and OD dried wood.

Determination of chemical and morphological properties

Eucalyptus samples were chipped to matchstick size and in order to determine chemical components, chips were ground in a laboratory type Wiley mill according to TAPPI T257 om-85 standard. Samples passing through 40-mesh sieve and remaining over 60-mesh sieve were stored in closed containers for chemical analysis and moisture contents were determined. Holocellulose, cellulose, alpha cellulose, lignin, extractive and ash contents of the samples were determined according to Wise and Karl (1962), Kurschner and Hoffer (1969), TAPPI T203 cm-99 (1999), TAPPI T222 om-15 (2015), ASTM D1107-96 (2013) and TAPPI T211 om-16 (2016), respectively. Cold water, hot water and 1% NaOH solubilities of the samples were determined according to TAPPI T207 cm-08 (2008) and TAPPI T212 om-18 (2018) standards.

The maceration process was carried out with chlorite method to make the woody fibers individual. Fiber slides were prepared for determination of fiber dimensions by using Nikon FS1 photo microscope; the average fiber width, length, lumen diameter, and cell wall thickness of 100 fibers were measured.

RESULTS AND DISCUSSION

The results obtained from the experiments on the chemical contents of *Eucalyptus* wood dried in indoor and outdoor conditions are given in Table 1.

Table 1: Chemical compositions and solubilities of dried *Eucalyptus camaldulensis* samples under different climates.

Chemical components and solubilities	Indoor (ID) (%)	Outdoor (OD) (%)	Difference (ID – OD) (%)
Toluene-Acetone-Ethanol solubility	12,8	12,8	0,00
1 % NaOH solubility	23,4	23,5	-0,10
Cold water solubility	11,1	11,7	-0,60
Hot water solubility	15,6	14,9	0,70
Ash content	0,24	0,21	0,03
Holocellulose content	77,4	77,9	-0,50
Cellulose content	48,2	47,8	0,40
Alpha cellulose content	47,5	47,1	0,40
Lignin content	35,2	35,3	-0,10
Sum of differences	-	-	0,23

According to Table 1, toluene-acetone-ethanol solubilities and lignin contents of *Eucalyptus* wood dried ID and OD were found to be similar. Hot-water solubility of woods dried OD is lower than that of ID. The cold-water solubility of OD dried *Eucalyptus* wood was about 5,1 % lower than that of the ID. The holocellulose content of the OD dried wood was 0,5 units higher than that of the ID. In terms of cellulose and alpha cellulose contents, woods dried ID are richer than woods dried OD. When Table 1 is examined in general, there are significant differences between water solubility values of *Eucalyptus* wood dried ID and OD climates, but there is no significant difference between other chemical components and solubilities. Ayata (2008) determined holocellulose and lignin contents of *Eucalyptus grandis* wood as 81,2 % and 25,7 %, respectively. In the same study, ash and extractives contents were found to be 0,3 % and 2,4 %. It was found that holocellulose content was lower and lignin and extractive contents were higher than those of undried *Eucalyptu*s wood.

Table 2 indicates the differences revealed in fiber dimensions of *Eucalyptus* samples dried in ID and OD climates.

Table 2: Fiber morphological properties of *Eucalyptus* woods dried under different climates.

Fiber dimensions	ID	OD	Difference (ID - OD)
Fiber length (mm)	0,81	0,82	-0,01
Fiber width (µm)	14,9	15,7	-0,80
Lumen diameter (µm)	3,26	3,78	-0,52
Cell wall thickness (µm)	5,79	5,94	-0,15
Sum of differences	-	-	-1,48

When fiber dimensions of *Eucalyptus* woods dried in different climates are examined, it is seen in Table 2 that there are no differences between fiber lengths and cell wall thicknesses. The most significant difference is in fiber width, and wood dried OD is about 5,4 % wider than the one dried ID. Likewise, lumen diameter of wood dried OD was found to be wider 0,52 units than that of dried ID. It can be thought that these differences can be occurred due to relative humidity of OD climate being higher than that of ID. In the literature, no study has been found on the effects of drying climates on fiber morphological properties. However, it is seen that

the fiber dimensions of the samples dried in both conditions are similar with the literature (Bhat *et al.* 1990, Gurboy and Ozden 1994, Trevisan *et al.* 2017).
Statistical analysis data of air-dry, oven-dry and basic density values are given in Table 3.

Table 3: Densities values of the samples dried in ID and OD climates.

Properties	DC	N	Mean (kg/m^3)	SD	SE	CV (%)	t_{value}	Sig. (2-tailed)
Air-dry density	ID	27	680	49,8	9,6	7,32	4,583	0,000
	OD	27	754	67,2	12,9	8,92		
Oven density	ID	27	585	41,6	8,0	7,11	5,620	0,000
	OD	27	664	59,9	11,5	9,02		
Basic density	ID	27	535	40,3	7,8	7,52	-4,021	0,000
	OD	27	588	55,3	10,6	9,40		

DC: Drying climate, N: Number of samples; SD: Standard deviation, SE: Standard error, CV: Coefficient of variation.

According to data in Table 3, differences of drying condition on air-dry density, oven-dry density and basic density values were found to be significant at $\rho < 0{,}000$ level. In same table, it can be seen that the air-dry density, oven-dry density and basic density values of the samples dried in OD were higher than those of dried in ID. These increases were determined as 10,88 % in air-dry density, 13,50 % in oven-dry density and 9,91 % in basic density. In a study conducted in the literature, air-dry density, oven-dry density and basic density values were found as 670 kg/m^3, 620 kg/m^3, 510 kg/m^3, respectively (Aslan *et al.* 2008). In another study performed between two different types of *Eucalyptus*, these values were found to be 530 kg/m^3, 520 kg/m^3, 460 kg/m^3 for *Eucalyptus grandis*. and 700 kg/m^3, 680 kg/m^3, 570 kg/m^3 for *Eucalyptus camaldulensis* Dehn., respectively (Ayata 2008). The results obtained from this study are similar with the literature.

Shrinkage values made to determine the dimensional stability of the *Eucalyptus* wood dried in ID and OD conditions are given in Table 4.

Table 4: The shrinkage values of the samples dried in ID and OD.

Measurement direction	DC	N	Mean (%)	SD	SE	CV (%)	t_{value}	Sig. (2-tailed)
Radial	ID	40	5,24	5,140	0,813	98,14	0,183	0,855
	OD	40	5,08	1,552	0,245	30,55		
Tangential	ID	40	5,01	1,398	0,221	27,94	-3,688	0,000
	OD	40	5,97	0,896	0,142	15,00		
Longitudinal	ID	40	0,65	0,738	0,117	113,32	-1,382	0,169
	OD	40	0,85	0,566	0,090	66,28		
Volumetric	ID	40	10,89	5,224	0,826	47,95	1,169	0,246
	OD	40	11,91	1,724	0,273	14,47		

As it can be seen in Table 4, tangential shrinkage values constitute significant differences ($\rho < 0{,}000$) between *Eucalyptus* timber dried in ID and OD climates, however in radial, longitudinal and volumetric shrinkage values did not demonstrate same trend.

When shrinkage percentages of the samples dried in ID and OD were evaluated, radial shrinkage showed a decrease of approximately 3 % in OD (5,08 %) measurements compared to ID (5,24 %). Tangential and longitudinal shrinkage values of samples dried ID were found to be lower about 19 % and 30,8 % than those of samples dried OD, respectively. Finally, volumetric swelling is less with a rate of 9,4 % compared in ID climate (10,89 %) to OD (11,91 %). All shrinkage and deformations in the wood, from cutting to usage area, are the main reasons why the need to be dried before use (Kilic Ak 2016). In this study, volumetric swelling results (ID: 10,89 %, OD: 11,91 %) different when compared from other species of *Eucalyptus*: lower than that mentioned by Lima *et al.* (2014) for *Eucalyptus resinifera* (16,67 %), by As *et al.* (2001) for *Eucalyptus rostrata* (12,7 %). Moreover, similar results were found for *Eucalyptus camaldulensis* as 11,4 % and 11,8 %

(Aslan *et al.* 2008, Ay *et al.* 2008).

Table 5 shows percentages of swelling calculated in *Eucalyptus* samples dried in ID and OD climates.

Table 5: The swelling values of the samples dried in ID and OD.

Measurement direction	DC	N	Mean (%)	SD	SE	CV (%)	t_{value}	Sig, (2-tailed)
Radial	ID	40	9,07	3,078	0,487	33,94	1,476	0,144
	OD	40	8,04	3,163	0,500	39,34		
Tangential	ID	40	7,59	1,734	0,274	22,85	-5,198	0,000
	OD	40	9,57	1,675	0,265	17,50		
Longitudinal	ID	40	0,75	0,537	0,085	71,87	-3,231	0,002
	OD	40	1,29	0,909	0,144	70,69		
Volumetric	ID	40	17,41	3,030	0,479	17,41	1,837	0,070
	OD	40	18,90	4,153	0,657	21,98		

According to the results of t-tests applied to swelling measurements presented in Table 5, tangential and longitudinal swelling values have significant differences in terms of drying climate, whereas the effect of climate is found to be insignificant on the radial and volumetric swelling percentages. When swelling values of the samples dried in OD compared with ID, a decrease of approximately 11,4 % was observed in the radial direction, whereas in increase was observed 26,1 % in the tangential, 72 % in the longitudinal direction and 8,6 % in the volumetric dimension. The values found for volumetric swelling were determined to be lower to those reported in the literature (Aslan *et al.* 2008, Ay *et al.* 2008). From these results, it can be said that a more protective drying was performed in ID climates.

Mechanical properties and statistical analysis of the wood samples dried in ID and OD climates are presented in Table 6.

Table 6: The mechanical properties the samples dried in ID and OD.

Mechanical properties (*)		DC	N	Mean (MPa)	SD	SE	COV (%)	t_{value}	Sig, (2-tailed)
$\sigma_{CS//}$		ID	50	53,18	7,026	0,994	13,21	0,829	0,409
		OD	50	52,03	6,890	0,974	13,24		
σ_{SBS}		ID	28	83,39	7,783	1,471	9,33	-2,076	0,043
		OD	28	92,10	20,794	3,930	22,58		
MOE		ID	28	6915,2	740,20	139,89	10,70	-1,712	0,093
		OD	28	7444,3	1458,59	275,65	19,59		
$\sigma_{TS//}$		ID	33	74,14	15,251	2,655	20,57	-0,245	0,807
		OD	33	75,26	21,421	3,729	28,46		
σ_{DBS}		ID	27	0,51	0,208	0,040	40,82	1,111	0,272
		OD	27	0,46	0,114	0,022	24,77		
$\sigma_{SS//}$		ID	36	9,93	1,422	0,237	14,32	-0,839	0,404
		OD	36	10,25	1,786	0,298	17,42		
Janka hardness	C_{rs}	ID	30	81,36	16,574	3,026	20,37	-5,418	0,000
		OD	50	103,21	17,971	2,542	17,41		
	R	ID	30	72,91	17,900	3,268	24,55	-5,613	0,000
		OD	50	98,18	20,374	2,881	20,75		
	T	ID	30	78,46	15,610	2,850	19,90	-4,363	0,000
		OD	50	97,21	20,171	2,853	20,75		

(*) $\sigma_{CS//}$: Compression strength parallel to grain, σ_{SBS}: Static bending strength, MOE: Modulus of Elasticity, $\sigma_{TS//}$: Tensile strength parallel to grain, σ_{DBS}: Dinamic bending strength, $\sigma_{SS//}$: Shear strength, C_{rs}: Cross section, R: Radial section, T: Tangential section.

The results of the t-test given in Table 6, which were applied to reveal effect of ID and OD drying climates showed differences on mechanical properties. Significant differences were found between the bending strength and modulus of elasticity of the samples dried in ID and OD climates according to t-test results at $\rho < 0{,}050$ significance level. Likewise, Janka hardness values measured in cross sectional, radial and tangential directions constituted significant differences at $\rho < 0{,}000$ level according to ID and OD drying climates. T-test results introduced that there is no significant effect of drying climate differences on compression, tensile, dynamic bending and shear strength samples. On the other hand, calculations based on data in Table 6 revealed that the compression strength and dynamic bending strength for the samples dried in OD were 2,3 % and 9,8 % lower than those dried in ID, respectively. However, the modulus of elasticity, static bending strength, tensile strength and shear strength values of the samples dried in ID were determined as 8,6 %, 11,3 %, 0,80 % and 2,11 % lower than those of dried in OD climates, respectively.

As it can be seen from Table 6, effect of drying climates difference on the tensile strength parallel to the fibers was calculated as much lower (0,80 %) than OD climate, in contrast to the compressive and bending strengths. Another interesting data is also that the dynamic bending strength value of samples (0,51 MPa) dried in ID climate is approximately 10 % higher than the other one (0,46 MPa). Since dynamic bending strength is particularly prominent for using structural wood in the seismic zones, the effect of the drying environment difference in such usage areas should be take into account. Regarding Janka hardness values, it can be seen from the data in Table 6 that the difference between the samples dried in OD and ID is much higher than other mechanical properties. The Janka hardness values measured in ID all three directions (C_{rs}, R, T) are lower than those measured in the OD. These decreases were calculated as 12,17 %, 25,74 % and 19,29 % according to C_{rs}, R and T directions, respectively. There are many studies on the mechanical properties of *Eucalyptus* woods in the literature; however, there have been any research dealing with the differences in drying climates (Aslan *et al.* 2008, Ay *et al.* 2008, Bektas *et al.* 2008).

On the other hand, temperature and relative humidity, which are two of main drying factors of environment where this research was carried out, were investigated by Kilic Ak (2016) and obtained data are illustrated in Figure 1. The most effective period for fast drying is summer period called "effective drying period". This period is between intersection points of curves showing the change of air temperature and relative humidity within one year at place of drying (Kantay 1993). The effective drying periods were indicated in Figure 1 with arrows.

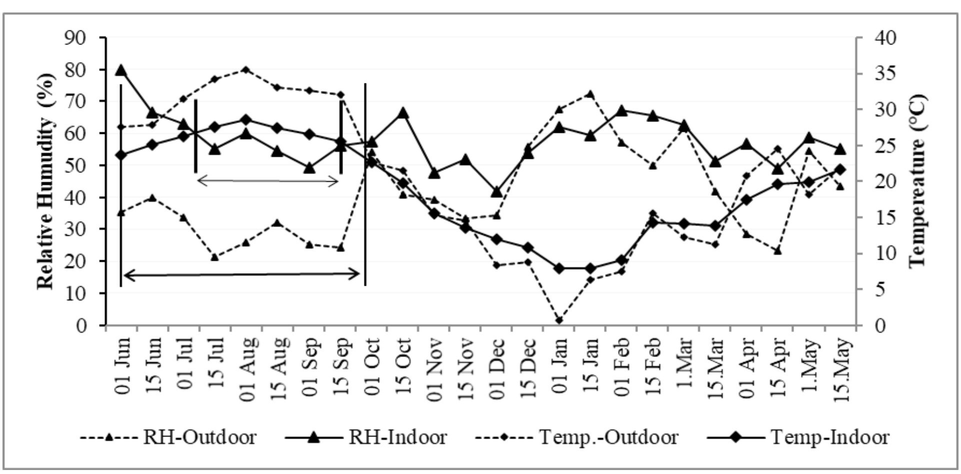

Figure 1: Temperature and relative humidity values of different climates.

According to Figure 1, the temperature in summer is higher in OD than ID, but it is lower in winter. Relative humidity values are generally higher in ID than those of in OD. It is understood from Figure 1 that the fastest drying in both (ID, OD) climate took place between June and September, when the temperature was higher and the relative humidity was lower. Furthermore, these data indicate that the effective drying period in Kahramanmaraş province occurred between June and September.

CONCLUSIONS

The results of the tests to investigate effect of drying climate on the chemical, morphological, physical and mechanical properties of *Eucalyptus* woods can be summarized as follows;

There was no significant difference between the chemical compositions of *Eucalyptus* woods dried in ID and OD. The fiber width and lumen diameters of the wood dried in OD were wider than those of dried in ID due to differences relative humidity.

As a result of the physical tests, significant differences were found between the air-dry and oven-dry density, basic density, tangential shrinkage, tangential and longitudinal swelling values at the level of $\rho < 0,05$, while there was no significant difference between radial-, volumetric-swelling, radial-, longitudinal-, volumetric-shrinkage.

Significant differences were found between the some mechanical properties such as static bending strength, modulus of elasticity and Janka hardness (cross section, radial, tangential) of the *Eucalyptus* samples dried in ID and OD climates. On the other hand, it was found that drying climate had no significant effect on compression, tensile, dynamic bending and shear strength values.

Finally, in the light of the data obtained in this study, it is suggested to take into account the differences in chemical, morphological, physical and mechanical properties of *Eucalyptus* wood in drying process and solid usage areas.

ACKNOWLEDGEMENTS

This project was supported by the Kahramanmaras Sutcu Imam University, Research Project Coordination Unit, under project number 2018/2-55 M.

REFERENCES

ASTM. 2013. Standard test method for ethanol-toluene solubility of wood. ASTM D1107-96. ASTM: Pennsylvania, USA. https://www.astm.org/Standard/standards-and-publications.html

As, N.; Koc, K.H.; Dogu, D.; Atik, C.; Aksu, B.; Erdinler, S. 2001. Türkiye'de yetişen endüstriyel öneme sahip ağaçların anatomik, fiziksel, mekanik ve kimyasal özellikleri (in Turkish). *İstanbul Üniversitesi Orman Fakültesi Dergisi* 51(1): 71-88. https://dergipark.org.tr/tr/download/article-file/176141

Aslan, S.; Demetci, E.; Sozen, R.; Ilter, E.; Balkiz, O.D. 2008. Okaliptüs (*Eucalyptus camaldulensis* Dehn.) odununun bazı fiziksel, kimyasal, mekanik ve anatomik özellikleri (in Turkish). In: Proceeding of the 1st Ulusal Okaliptüs Sempozyumu, Tarsus, Turkey. pp. 151-161. https://doa.ogm.gov.tr/Yayinlar/Muhtelif%20Yay%C4%B1nlar/DOA-%20Okaliptus%20Sempozyumu%20Bildiriler%20Kitab%C4%B1.pdf

Ay, N.; Topaloglu, E.; Tan, H. 2008. Okaliptüs (*Eucalyptus camaldulensis* Dehn.) odununun bazı fiziksel, mekanik özellikleri ve kullanım alanları (in Turkish). In Proceeding of the 1st Ulusal Okaliptüs Sempozyumu, Tarsus, Turkey. pp. 78-83. https://doa.ogm.gov.tr/Yayinlar/Muhtelif%20Yay%C4%B1nlar/DOA-%20Okaliptus%20Sempozyumu%20Bildiriler%20Kitab%C4%B1.pdf

Ayata, U. 2008. Okaliptüs (*Eucalyptus camaldulensis* ve *Eucalyptus grandis*)'ün odun özellikleri ve kağıt endüstrisinde kullanımının araştırılması (in Turkish). Master Thesis, Kahramanmaras Sutcu Imam University, Kahramanmaraş, Turkey. https://tez.yok.gov.tr/UlusalTezMerkezi/TezGoster?key=biL2P3cCsPgUNjVdV2BsGKm0Sp-Sd7lOMSYMktjCr3Z2PjWVVxs_TWNvyhBtfvmD

Aytin, A.; Korkut, S.; As, N.; Unsal, O.; Gunduz, G. 2015. Effect of heat treatment of wild cherry wood on abrasion resistance and withdrawal capacity of screws. *Drvna* 66(4): 297-303. https://hrcak.srce.hr/file/221880

Baranski, J.; Wierzbowski, M.; Konopka, A. 2014. The change of mechanical properties of selected wood species after drying process under various conditions *SGGW* 86: 13-17. https://mostwiedzy.pl/en/

publication/the-change-of-mechanical-properties-of-selected-wood-species-after-drying-process-under-various-cond,130751-1

Bektas, I.; Alma, M.H.; Bal, B.C.; Ayata, U. 2008. Okaliptüs (*Eucalyptus grandis* W. Hill.) odununun dinamik eğilme direncinin belirlenmesi ve bazı ağaç türleri ile karşılaştırılması (in Turkish). In Proceeding of the 1st Ulusal Okaliptüs Sempozyumu, Tarsus, Turkey. pp. 274-280. https://doa.ogm.gov.tr/Yayinlar/Muhtelif%20Yay%C4%B1nlar/DOA-%20Okaliptus%20Sempozyumu%20Bildiriler%20Kitab%C4%B1.pdf

Bektas, I.; Kilic Ak, A.; Cicekler, M.; Tutus, A. 2017. Effects of different drying environments on the dimensional stability of *Eucalyptus* wood. In Proceeding of the International Symposium on New Horizons in Forestry (ISFOR), Isparta, Turkey. pp. 334-336. http://ormanweb.isparta.edu.tr/isfor2017/documents/pdf/334.pdf

Bergman, R. 2021. Drying and control of moisture content and dimensional changes. *Wood handbook: wood as an engineering material*: Chapter 13. Centennial ed. General technical report FPL; GTR-190. Madison, WI: US Dept. of Agriculture, Forest Service, Forest Products Laboratory, p. 13.1-13.20. https://www.fpl.fs.fed.us/documnts/fplgtr/fplgtr282/chapter_13_fpl_gtr282.pdf

Bhat, K.M.; Bhat, K.V.; Dhamodaran, T.K. 1990. Wood density and fiber length of *Eucalyptus grandis* grown in Kerala. *Wood Fiber Sci* 22(1): 54-61. https://wfs.swst.org/index.php/wfs/article/view/1862

Bown, H.E.; Lasserre, J. 2015. An air-drying model for piled logs of *Eucalyptus globulus* and *Eucalyptus nitens* in Chile. *New Zealand Journal of Science* 45(1): 1-9. https://link.springer.com/content/pdf/10.1186/s40490-015-0047-6.pdf

Bozkurt, A.Y.; Goker, Y. 1996. *Fiziksel ve mekanik ağaç teknolojisi* (in Turkish). İstanbul Üniversitesi, Orman Fakültesi Yayınları, Yayın No: 436, Istanbul, Turkey. ISBN 9754044201. https://www.worldcat.org/title/fiziksel-ve-mekanik-agac-teknolojisi-ders-kitab/oclc/192012408

Cetin, F.; Gunduz, G. 2016. Türkiye'deki bazı ağaç türü odunlarının fiziksel özellikleri üzerine yapılan araştırmaların değerlendirilmesi (in Turkish). *Bartın Orman Fakültesi Dergisi* 8(2): 175-193. https://dergipark.org.tr/tr/download/article-file/272873

Cetin, F.; Gunduz, G. 2017. Türkiye'deki bazı ağaç türü odunlarının mekanik özellikleri üzerine yapılan araştırmaların değerlendirilmesi (in Turkish). *Bartın Orman Fakültesi Dergisi* 19(1): 161-181. https://dergipark.org.tr/en/download/article-file/302267

Dackermann, U.; Elsener, R.; Li, J.; Crews, K. 2016. A comparative study of using static and ultrasonic material testing methods to determine the anisotropic material properties of wood. *Constr Build Mater* 102(2): 963-976. https://www.sciencedirect.com/science/article/pii/S0950061815302178

Dahl, K.B.; Malo, K.A. 2009. Planar strain measurements on wood specimens. *Experimental Mechanics* 49: 575-586. https://doi.org/10.1007/s11340-008-9162-0

Davis, P.H. 1988. *Flora of Turkey and the East Aegean Islands - Vol: 10*. Edinburgh University Press: Edinburgh, Scotland, United Kingdom. https://www.amazon.com/Flora-Turkey-10-Aegean-Islands/dp/0852245599

Duzkale, G.; Bektas, I.; Tunc, H.H.; Doganlar, Y. 2014. Zeytin ağacı (*Olea Europaea)* odununun bazı fiziksel ve mekanik özelliklerinin belirlenmesi (in Turkish). *Ormancılık Dergisi* 10(2): 29-35. https://dergipark.org.tr/en/download/article-file/272118

Forest Products Laboratory. 1999. *Air drying of lumber. Gen. Tech. Rep.* FPL–GTR–117. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 62 p. https://www.fpl.fs.fed.us/documnts/fplgtr/fplgtr117.pdf

Gurboy, B.; Ozden, O. 1994. *E. camaldulensis* ve *E. grandis* odununun hacim-ağırlık değerleri ve lif morfolojisi (in Turkish). *İstanbul Üniversitesi Orman Fakültesi Dergisi* 44(1): 101-109. https://dergipark.org.tr/tr/download/article-file/176620

Kantay, R. 1993. *Kereste kurutma ve buharlama.* Yayın 6. Ormancılık Eğitim ve Kültür Vakfı: Istanbul, Turkey. https://www.nadirkitap.com/kereste-kurutma-ve-buharlama-ramazan-kantay-kitap3189376.html

Karsavuran, Y.; Ayvaz, A.; Doganlar, M. 2008. Okaliptüste zararlı olan *Leptocybe invasa* Fisher and La Salle ve *Ophelimus maskelli* (Ashmead) (Hym.: Eulophidae)'nin Muğla ili'nde yayılışı (in Turkish). *Ege Univ Ziraat Fak Derg* 45(2): 91-94. https://dergipark.org.tr/tr/download/article-file/59283

Kilic Ak, A. 2016. Okaliptüs kerestesinin doğal kurutma şartları üzerine denemeler: Kahramanmaraş ili örneği (in Turkish). Master Thesis, Kahramanmaras Sutcu Imam University, Kahramanmaraş, Turkey. https://tez.yok.gov.tr/UlusalTezMerkezi/TezGoster?key=cbOXH84ZayrLjc0tI-QXKsJJChjMEmY2LWn2Qb57c9BwlyjP-b-6BDJLBirvKL7M

Kocaefe, D.; Poncsak S.; Boluk, Y. 2008. Effect of thermal treatment on the chemical composition and mechanical properties of birch and apsen. *Bioresources* 3(2): 517-537. https://ojs.cnr.ncsu.edu/index.php/BioRes/article/view/BioRes_03_2_Kocaefe_PB_ThermalTreatment_Birch_Aspen/199

Korkut, S.; Korkut, D.S.; Bekar, I. 2008. Okaliptüs (*Eucalyptus camaldulensis* Dehn.) odununun bazı teknolojik özellikleri üzerine ısıl işlemin etkisi (in Turkish). In: Proceeding of the 1st Ulusal Okaliptüs Sempozyumu, Tarsus, Turkey. pp. 209-214. https://doa.ogm.gov.tr/Yayinlar/Muhtelif%20Yay%C4%B1nlar/DOA-%20Okaliptus%20Sempozyumu%20Bildiriler%20Kitab%C4%B1.pdf

Kurschner, K.; Hoffer, A. 1969. Ein neues verfahren zur bestimmung der zellulose (in German). *Technol und Chemie der Pap Zellstoff- Fabrikation* 26: 125-139.

Lahr F.A.R.; Nogueira M.C.; De Araujo, V.A.; Vasconcelos, J.S.; Christoforo, A.L. 2018. Wood utilization of *Eucalyptus grandis* in structural elements: Densities and mechanical properties. *Engenharia Agrícola* 38(5): 642-647. https://doi.org/10.1590/1809-4430-eng.agric.v38n5p642-647/2018

Lahr, F.A.R.; Nogueira, M.C.; De Araujo, V.A.; Vasconcelos, J.S.; Christoforo, A.L. 2017. Physical-mechanical characterization of *Eucalyptus urophylla* wood. *Engenharia Agrícola* 37(5): 900-906. https://doi.org/10.1590/1809-4430-eng.agric.v37n5p900-906/2017

Lima, I.L.; Longui, E.L.; Freitas, M.L.M.; Zanatto, A.C.S.; Zanata, M.; Florsheim, S. M. B.; Bortoletto, G. 2014. Physical-mechanical and anatomical characterization in 26-year-old *Eucalyptus* resinifera wood. *Floresta Ambiente* 21(1): 91-98. https://doi.org/10.4322/floram.2014.006

Nogueira, M.C.; Almeida, D.H.; Araujo, V.A.; Vasconcelos, J.S.; Christoforo, A.L.; Almeida, T.H.; Lahr, F.A.R. 2019. Physical and mechanical properties of *Eucalyptus saligna* wood for timber structures. *Ambient constr* 19(2): 233–239. https://doi.org/10.1590/s1678-86212019000200319

Nogueira, M.C.; De Araujo, V.A.; Vasconcelos, J.S.; Cruz, J.N.; Vasconcelos, J. C.S.; Prataviera, F.; Christoforo, A.L.; Lahr, F.A.R. 2018. Characterization of *Eucalyptus maidenii* timber for structural application: Physical and mechanical properties at two moisture conditions. *South-east European forestry* 9(2): 141-146. https://doi.org/10.15177/seefor.18-10

Ors, Y.; Keskin, H. 2008. *Ağaç malzeme teknolojisi* (in Turkish). Gazi Kitabevi: Ankara, Turkey. https://finalpazarlama.com/kitap/gazi-kitabevi/agac-malzeme-teknolojisi/010133777

Pettersen, R.C. 1984. *The Chemical composition of wood*. Chapter 2. In: *The chemistry of solid wood*. American Chemical Society: Madison, WI, USA. 57-126. https://www.fpl.fs.fed.us/documnts/pdf1984/pette84a.pdf

Simpson, W.T.; Wang, X. 2004. Estimating air-drying times of small-diameter ponderosa pine and Douglas fir logs. *Forest Prod J* 54(12): 24-28. https://www.fpl.fs.fed.us/documnts/pdf2004/fpl_2004_simpson002.pdf

Sancak, S. 2010. Kızılcık (*Cornus mas* L.) odununun bazı fiziksel, mekanik ve teknolojik özelliklerinin belirlenmesi (in Turkish). Master Thesis, Kastamonu University, Kastamonu, Turkey. https://tez.yok.gov.tr/UlusalTezMerkezi/TezGoster?key=zD1B0cW7zVr3VcnZjitVXmXz9GnM8q66JMfip1nmLfq-bqMHxf1xZVN8MevJJ63w

TAPPI. 1999. TAPPI T203 cm-99: Alpha-, beta- and gamma-cellulose in pulp. TAPPI: Atlanta, USA.

TAPPI. 2008. TAPPI T207 cm-08: Water solubility of wood and pulp. TAPPI: Atlanta, USA.

TAPPI. 2015. TAPPI T222 om-15: Acid-insoluble lignin in wood and pulp. TAPPI: Atlanta, USA.

TAPPI. 2016. TAPPI T211 om-16: Ash in wood, pulp, paper and paperboard: combustion at 525 °C. TAPPI: Atlanta, USA.

TAPPI. 2018. TAPPI T212 om-18: One percent sodium hydroxide solubility of wood and pulp. TAPPI: Atlanta, USA.

Trevisan, R.; Rosa, M.; Haselein, C.R.; Santini, E.J.; Gatto, D.A. 2017. Dimensões das fibras e sua relação com a idade de transição entre lenho juvenil e adulto de *Eucalyptus grandis* W. Hill ex maiden (in Portuguese). *Cienc Florest* 27(4): 1385-1393. http://dx.doi.org/10.5902/1980509830220

TSI. 1976. TS 2470: Wood - sampling methods and general requirements for physical and mechanical tests. TSE: Ankara, Turkey. https://intweb.tse.org.tr/Standard/Standard/StandardAra.aspx

TSI. 1976. TS 2472: Wood - determination of density for physical and mechanical tests. TSE: Ankara, Turkey. https://intweb.tse.org.tr/Standard/Standard/StandardAra.aspx

TSI. 1976. TS 2474: Wood - determination of ultimate strength in static bending. TSE: Ankara, Turkey. https://intweb.tse.org.tr/Standard/Standard/StandardAra.aspx

TSI. 1976. TS 2475: Wood - detemination of ultimate tensile stress parallel to grain. TSE: Ankara, Turkey. https://intweb.tse.org.tr/Standard/Standard/StandardAra.aspx

TSI. 1976. TS 2477: Wood - determination of ımpact bending strength. TSE: Ankara, Turkey. https://intweb.tse.org.tr/Standard/Standard/StandardAra.aspx

TSI. 1976. TS 2478: Wood - determination of modulus of elasticity ın static bending. TSE: Ankara, Turkey. https://intweb.tse.org.tr/Standard/Standard/StandardAra.aspx

TSI. 1976. TS 2479: Wood - determination of static hardness. TSE: Ankara, Turkey. https://intweb.tse.org.tr/Standard/Standard/StandardAra.aspx

TSI. 1983. TS 4083: Wood - determination of radial and tangential shrinkage. TSE: Ankara, Turkey. https://intweb.tse.org.tr/Standard/Standard/StandardAra.aspx

TSI. 1983. TS 4084: Wood - determination of radial and tangential swelling. TSE: Ankara, Turkey. https://intweb.tse.org.tr/Standard/Standard/StandardAra.aspx

TSI. 1983. TS 4085: Wood - determination of volumetric shrinkage. TSE: Ankara, Turkey. https://intweb.tse.org.tr/Standard/Standard/StandardAra.aspx

TSI. 1983. TS 4086: Wood - determination of volumetric swelling. TSE: Ankara, Turkey. https://intweb.tse.org.tr/Standard/Standard/StandardAra.aspx

TSI. 2012. TS 3459: Wood - determination of ultimate shearing stress parallel to grain. TSE: Ankara, Turkey. https://intweb.tse.org.tr/Standard/Standard/StandardAra.aspx

TSI. 2019. TS ISO 13061-17: Physical and mechanical properties of wood - Test methods for small clear wood specimens - Part 17: Determination of ultimate stress in compression parallel to grain. TSE: Ankara, Turkey. https://intweb.tse.org.tr/Standard/Standard/StandardAra.aspx

Wise, E.L.; Karl, H.L. 1962. *Cellulose and hemicelluloses in pulp and paper science and technology*. McGraw Hill Book Co: New York City, USA

Yaltirik, F.; Efe, A. 1994. *Dendroloji = gymnospermae - angiospermae* (in Turkish). İstanbul Üniversitesi, Orman Fakültesi Yayınları: Istanbul, Turkey. Yayın No: 431. https://books.google.com.tr/books/about/Dendroloji.html?id=fMF2MwEACAAJ&redir_esc=y