The Within-Tree Variation in Some Physical Properties in Eucalyptus Wood (*Eucalyptus Grandis* W. Hill ex Maiden) Grown in Karabucak Region

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Abstract

In this study, the variations in some physical properties in the *E.grandis* stem at radial and longitudinal directions were investigated. Relationships between density and shrinkage were determined. For this aim, the samples were cut from only one tree. The samples were taken from stem in four equidistant positions in bark to pit direction and in eight equidistant positions from breast height to crown. On these samples, green moisture content, oven dry density, basic density and volumetric shrinkage were determined and the lowest and highest results were 56-111%, 483-837 kg/m^3, 440-722 kg/m^3, 10.4-16.2%, respectively. In addition, regression analysis exposed positive-strong relationship between oven dry density and volumetric shrinkage.

Key words: *Eucalyptus grandis*, green moisture content, oven dry density, basic density.

Karabucak Yöresinde Yetişen Okaliptüs Odununda (*Eucalyptus Grandis* W. Hill ex Maiden) Bazı Fiziksel Özelliklerin Ağaç Içersindeki Değişimi

Özet

Bu çalışmada, *E.grandis* ağacında, radyal ve boyuna yönlerde, bazı fiziksel özelliklerdeki değişmeler incelenmiştir. Yoğunluk ile daralma miktarı arasındaki ilişki belirlenmiştir. Bu amaç için, örnekler sadece bir ağaçtan alınmıştır. Örnekler, gövdeden kabuktan öze doğru, dört eşit aralıklı noktadan ve gögüs seviyesinden taca doğru 8 eşit aralıklı noktadan alınmıştır. Bu örnekler üzerinde, taze hal rutubeti, tam kuru yoğunluk, hacim-ağırlık değeri ve hacmen daralma miktarı belirlenmiştir ve en düşük ve en yüksek sonuçlar sırasıyla; %56-111, 483-837 kg/m^3, 440-722 kg/m^3, %10.4-16.2 olarak ölçülmüştür. Ayrıca, regrasyon analizi hacmen daralma miktarı ile tam kuru yoğunluk arasındaki pozitif-güçlü ilişkiyi ortaya koymuştur.

Anahtar kelimeler : Okaliptüs, taze hal rutubeti, tam kuru yoğunluk, hacim ağırlık değeri.

1. Introduction

Eucalyptus was introduced firstly by a French company constructed Adana-Mersin railroad in 1885 (Adalı 1944). In Turkey, researches related to *Eucalyptus* have been carried on by Eastern Mediterranean Forestry Research Institute since 1967. Since then, 609 origins of 191 *Eucalyptus* species were experimented by this institute (Özkurt 2002).

First *E. Camaldulensis* plantation was carried out in Tarsus-karabucak in 1939. As to data of 1993 year, it is notified that there are 20.000 ha *Eucalyptus* plantations in Turkey. At the results of origin experiments, an average annual increment for *E. camaldulensis* 35 and for *E. grandis* 50 m^3/ha/year was obtained (Gürses et al. 1995).

“Large areas of different *Eucalyptus* species are being planted in many parts of the world due to the rapid growth rate of this species and increasing demand for wood” (Githiomi and Kariuki 2010). “The deficit of wood production in meeting the demand is increasing in many countries. Establishment of plantations with poplar, salix and other fast growing forest tree species is one of the most effective way to meet the growing demand for wood” (Zoralioğlu 2003).

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Eucalyptus species have important role among fast growing forest tree species. Poplar and eucalyptus from fast growing angiosperm species are preferred but the usage areas of eucalyptus species are limited in Turkey.

Hillis and Brown state that eucalyptus species are known as a fundamental tree of Australia and its near islands. But, their spread isn't limited these areas. Recently, outside of Australia, the most planted species are *E. grandis, E. saligna, E.globulus, E. camaldulensis, E. tereticornis, E. europhylla, E. robusta, E.maculata, E. paniculata* and *E. viminalis* (Yıldızbakan et al. 2007).

It was expressed by Githiomi and Kariuki (2010) referred to Hillis (1984) that the density of eucalyptus wood is a complex characteristic since the tissue is made up of different types of cells with varying properties such as cell wall diameter, wall thickness and length and contains variable amounts of nonstructural materials such as extractives and tyloses. The density is further reported to vary depending on harvesting age; young eucalyptus plantation trees have lower density wood than that of mature wood.

Malan (1988) observed that *E. grandis* density exhibited a strong linear increase with increasing distance from the pith and increasing height. The significance of the latter suggests that wood formed by cambia of approximately the same physiological age but formed in successive years, varies with height above ground level.

Calvo et al. (2006) noted that swelling and the coefficient of anisotropy decrease with height and increase with the distance from the pith. Wood of the outer part of the tree stem exhibits more problems related to dimensional changes than wood of the inner part of the tree stem, even though it presents higher density and higher quality for many purposes.

The aim of this study was to investigate the variation in some physical properties in *E.grandis* stem grown in Karabucak and to determine the relationship between oven dry wood density and shrinkage.

2. Material and Methods

2.1 Material

The test tree used in this study was obtained from Karabucak eucalyptus plantations. In this research, only one tree was used (age: 20 years old, diameter at breast height: 40 cm and total height 42 m). Physical properties were carried out at 4 different sections in radial direction at 1, 2, 3 and 4th longitudinal position and 3 different sections in radial direction at 5, 6, 7 and 8th longitudinal position. In equidistant longitudinal direction with an interval of 2.5 m, 8 different sections were cut from breast level to crown. The first section at longitudinal direction was taken at breast level (at 1.3rd m). The last section was taken at commercial height near the crown (about 21st m). From these sections, samples (2x2x3 cm^3) were prepared in the pith to bark direction and numbered. Green moisture content samples and other physical properties samples were prepared separately. Green moisture content samples were put into plastic bags right after preparation.

2.2 Methods

2.2.1 Green Moisture Content

The green moisture content (GMC) were determined according to TS 2471 (Anonymous, 1976b). Samples were measured using an electronic balance to the nearest 0.01 g. before and after dried at 103 ± 2 ^{o}C. GMC was calculated below formula 1.

$$GMC=\frac{w_r - w_o}{w_o} \quad (\%) \qquad (1)$$

Where: w_r: weight before dry (g), w_o: weight after dry (g)

2.2.2 Oven Dry Density and Basic Density

Oven dry density (D_o) and basic density (R) were determined according to TS 2472 (Anonymous, 1976a) and calculated below formula 2 and 3:

$$D_o = \frac{W_o}{V_o} (kg/m^3) \qquad (2)$$

Where; D_o:Oven dry density (kg/m^3), W_o:Oven dry weight (kg), V_o:Oven dry volume (m^3).

$$R = \frac{W_o}{V_{max}} \quad (kg/m^3) \qquad (3)$$

Where; R: Basic Density (kg/m^3), W_o: Oven dry weight (kg), V_{max}: green volume (m^3).

2.2.3 Shrinkage Amount

Shrinkage amount (β) was determined TS 4083 and 4085 (Anonymous, 1983a, 1983b) and calculated below formula 4 and 5.

$$\beta= \frac{L_{max} - L_{min}}{L_{max}} \quad (\%) \qquad (4)$$

$$\beta_V = \beta_r + \beta_t + \beta_l \quad (\%) \qquad (5)$$

Where: β: Shrinkage amount, l_{max}: green dimension, l_{min}: dry dimension. β_r, β_t, β_l, β_V are radial, tangential, longitudinal and volumetric shrinkage, respectively.

3. Results and Discussions

GMC in radial and longitudinal directions and Tukey multiple range test results were given in Table 1. Multifactor variance analysis results of GMC were given Table 2. According to variance analysis, the effects of radial and longitudinal position and its interaction on the GMC were statistically significant. As to these results, the effect of position where samples were cut from tree is important. *E. grandis* has juvenile wood and mature wood evidently. In juvenile wood, density is low and GMC is high but in mature wood this case is opposite. The contrast is connected with fiber and vessel properties. Lima et al. (2010) were determined that from pith to bark, fiber wall thickness increases from 3.9 to 5.4 µm and vessel frequency decreased from 19.6 to 11.7 in mm^2. Rowell (2005) stated that the moisture content of green wood varies from species to species and depends on the specific gravity. Lumen volume decreases as the specific gravity increases so the GMC decreases with increasing specific gravity.

Table 1 and Table 3 show that GMC is low in mature wood, where oven dry density is high, and GMC is high in juvenile wood, where oven dry density is low. The lowest GMC was measured in mature wood near the bark and crown (58%) and the highest GMC was measured in juvenile wood near the pith and breast height (111%). In a study related to this subject an average GMC 84% was determined by Santos at al. (2004).

Table 1. Variations in GMC at different points within the stem of *E.grandis*

BASE(1.3 m)———CROWN (21 m)	PITH---BARK				x
	4	**3**	**2**	**1**	
8		76 (6,9)	56 (7,1)	58 (4,8)	63,5 a
7		73 (2,5)	62 (3,9)	60 (3,2)	64,9 a
6		83 (3,6)	73 (1,5)	71 (6,5)	75,7 b
5		78 (1,2)	82 (4,2)	77 (9,2)	79,1 bc
4	85 (5,6)	89 (2,2)	84 (4,2)	71 (4,3)	82,4 cd
3	93 (3,5)	91 (6,7)	86 (9,8)	77 (5,4)	86,8 d
2	107 (4,3)	100 (4,4)	96 (7,6)	79 (8,4)	95,7 e
1	108 (1,3)	111 (3,0)	103 (6,2)	88 (5,2)	102,6 f
x	98,3 d	87,8 c	80,4 b	72,7 a	

Means with the same letter are not significantly different (Tukey HSD test, P<0.05) (Values in parentheses are standard deviations)

Table 2. Variance analysis of green moisture content of *E.grandis* wood at different points

Source of variation	Sum of squares	df	Mean squares	F	Significant level
Longitudinal	14701	7	2100	72,7	0,000
Radial	4524	3	1508	52,2	0,000
Long. x Radial	1573	17	92	3,2	0,000
Error	2424	84	28		
Total	795698	112			

As can be seen in Table 3 below, oven dry density, basic density and volumetric shrinkage increase in pith to bark and base to crown directions. Table 4 shows that the effects of radial and longitudinal position and its interaction on the D_o is statistically significant ($P<0,001$). Table 5 shows Tukey multiple range test results relating to D_o. In respect of these results, D_o is low near the pith and breast high, on the contrary D_o is high near the bark and crown. Average basic density at breast height was calculated 511 kg/m^3. Similar results for basic density were determined (517 kg/m^3) by Githiomi and Kariuki (2010) on *E. grandis* wood which was 10 years old.

Table 3. Variations in oven dry density, (D_o-kg/m^3), volumetric shrinkage (β_V -%) and basic density (R-kg/m^3) at different points within the stem.

BASE----------CROWN	PITH--BARK												
		4			3			2			1		
		D_o	β_V	R	D_o	β_V	R	D_o	β_V	R	D_o	β_V	R
					639	13,1	558	828	14,9	709	837	14,2	722
	8				(60,5)	(1,4)	(45)	(26,3)	(1,2)	(28,7)	(42,3)	(0,4)	(38,1)
					570	11,9	504	644	14,3	553	803	14,2	693
	7				(37,0)	(1,9)	(22)	(64,2)	(2,0)	(50,4)	(33,4)	(1,1)	(34,6)
					560	11,8	496	632	13,7	548	820	14,8	703
	6				(41,2)	(0,6)	(36)	(64,6)	(1,6)	(48,3)	(25,4)	(1,4)	(25,7)
					545	11,3	485	644	14,2	555	765	14,6	657
	5				(36,4)	(1,3)	(30)	(36,6)	(1,7)	(22,3)	(24,7)	(1,4)	(22,1)
		519	10,7	465	526	11,2	469	637	13,4	554	693	14,4	597
	4	(51,2)	(0,5)	(44,0)	(28,5)	(0,6)	(25)	(56,3)	(1,3)	(42,0)	(18,0)	(1,3)	(18,9)
		483	10,4	434	530	10,7	475	595	12,3	524	678	14,6	583
	3	(5,2)	(1,4)	(8,9)	(45,1)	(1,9)	(34)	(29,7)	(0,6)	(24,3)	(29,6)	(0,9)	(21,6)
		493	10,8	441	510	10,6	457	569	12,6	500	681	14,3	587
	2	(22,9)	(1,2)	(16,3)	(38,4)	(1,3)	(30)	(38,5)	(0,9)	(30,9)	(34,2)	(0,8)	(32,1)
		493	11,0	440	521	10,7	466	609	12,6	534	700	14,0	605
	1	(24,5)	(1,2)	(20,8)	(32,8)	(0,8)	(26)	(65,7)	(0,9)	(55,7)	(67,8)	(1,0)	(53,3)

Table 4. Variance analysis of oven dry density and volumetric shrinkage of *E.grandis* wood at different points

	D_o			β_V		
Source of variation	Sum of squares	F	Sign. level	Sum of squares	F	Sign. level
Longitudinal	567202,8	46,0	0,000	52,3	4,9	0,000
Radial	1371459,7	259,9	0,000	341,2	75,5	0,000
Lon. x Rad.	120803,1	4,0	0,000	38,1	1,4	0,101
Error	323540,2			276,8		
Total	87299817,1			35824,1		

Table 5. Tukey HSD multiple comparison test results of oven dry density and volumetric shrinkage of *E.grandis* wood at different points

Long. Direction	N	D_o	β_V	Radial Direction	N	D_o	β_V
1	32	580,5ab	12,0a	1	24	495,5a	10,8a
2	32	563,3a	12,0a	2	60	548,9b	11,4a
3	28	584,2ab	12,2a	3	64	644,6c	13,5b
4	28	604,4b	12,7ab	4	64	747,1d	14,3c
5	24	651,3c	13,3bc				
6	24	670,4cd	13,4bc				
7	20	692,9d	13,7c				
8	24	767,9e	14,0c				

Bhat et al. (2007) determined that basic density was 495 kg/m^3 in 3 years old *E.grandis* wood. Basic density was measured 520, 543 and 620 kg/m^3 in only one tree, at breast height and in different three radial points (Gomes et al, 2006). Aslan et al. (2008) noted basic density of *E.camaldulensis* grown in the same region was 504 kg/m^3.

The results related to volumetric shrinkage were given in Table 3. Variance analysis of β_V at radial and longitudinal directions was given in Table 4. Tukey multiple comparison test results of volumetric shrinkage were given Table 5. As to these results, volumetric shrinkage is low near the pith and breast high and is high near the bark and crown. These results are similar to D_o. It is known that β_V increases when D_o increases in wood. Figure 1 shows relationship between β_V and D_o. In this relationship, coefficient of determination (R^2) was calculated as 0.59. This number shows the presence of strong-positive relationship between β_V and D_o.

As to the results of mean values of all samples; tangential shrinkage of 7.7%, radial shrinkage 4.9%, longitudinal shrinkage 0.3% and volumetric shrinkage 12.9%, tangential/radial shrinkage ratio 1.6 were determined. The coefficient of determination (R^2) between tangential shrinkage and oven dry density was 0.43, radial shrinkage and oven dry density was 0.42 and longitudinal shrinkage and oven dry density was 0.001. As to these results, it can be say that there is a positive relationship between tangential-radial shrinkage and oven dry density, but there is not a positive or negative relationship between longitudinal shrinkage and oven dry density.

Similar results were determined by Gomes et al. (2006) about shrinkage of *E.grandis* wood. Different results were determined by Silva et al. (2006) about shrinkage of *E.grandis* wood. Mean values of volumetric shrinkage, at different ages and different distances in the pith-to-bark direction were measured 14.6%, 16.6%, 18.8% and 22.3% Shrinkage were measured with mean values of radial, tangential, longitudinal and volumetric of 6.09%, 10.44%, 0.45%, 18.11 %, respectively. They noted that shrinkage increases in pith to bark direction (Silva et al. 2006). It is thought that the difference arise from density, clone and cultivation factors.

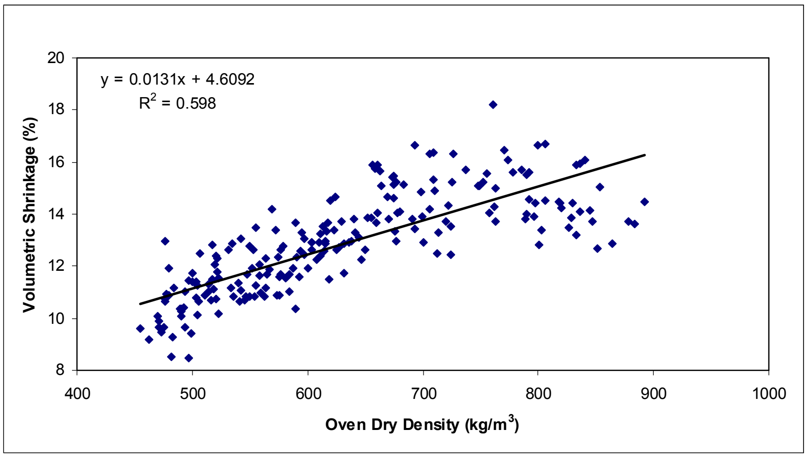

Figure 1. Relationship between oven dry density and volumetric shrinkage

4. Conclusions

In this study, the variations occurred in some physical properties in the *E.grandis* stem at radial and longitudinal directions were investigated. It can be said that:

- Green moisture content decrease pith to bark and base to crown directions but oven dry density, basic density and volumetric shrinkage increase in the same directions. The decrease and increase in physical properties in these directions varied statistically significant.
- It was determined that there is a strong-positive relationship between volumetric shrinkage and oven dry density.

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