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The effect of some climate factors on dimensional stability in *Pinus brutia*

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ABSTRACT: This study investigated the effect of climate factors on dimensional stability in *Pinus brutia* Ten. wood in its natural range in the Mediterranean region of Turkey. For this purpose, test trees at approximately the same age and altitude were taken from five different climate regions of the Mediterranean. The results of the statistical analyses indicated that climatological factors had an important impact on dimensional stability in Calabrian pine wood. While there is a significant relation between the direction in which test samples from the test tree were obtained and the amounts of radial and tangential shrinkages, there is a non-significant relationship with the amounts of swellings. Regression analyses showed that volumetric shrinkage and swelling in some regions had a significant correlation with wood properties. Furthermore, differences in dimensional stability between the climatological factors could be attributed to the fast-growing plantations for arid zone forestry.

Keywords: Calabrian pine; shrinkage; swelling; directions; wood properties

Wood is dimensionally stable when moisture content is greater than the fibre saturation point. The dimension changes below the fibre saturation point of wood as it gains moisture (swells) or loses moisture (shrinks), because the volume of the cell wall depends on the amount of bound water (Glass, Zelinka 2010).

Shrinkage and swelling may occur in wood when the moisture content is changed (Stamm 1964). Indeed, Bektas and Güler (2001) found that the shrinkages under drying of many woods are greatest in the tangential direction, smaller in the radial direction and very small longitudinally. It is known that there is a number of factors affecting the dimensional stability of wood. These factors include drying conditions, material solubility, leaching, and time.

Among these factors ecological factors affecting the development of plants under conditions of natural habitat, climatic, biotic and edaphic factors stand out because of large variability and big difference. The climatic factor is the most important of them (Ayaşligil 1989).

The effect of external factors in the development process of the trees is effective on wood structures. These factors are temperature, light intensity, amount of water, food, photoperiod, climatic conditions and geographical conditions (Ayaşligil 1989; Doğu 2002). Especially in these factors the effects of temperature and humidity come to the forefront.

The variations in the wood properties of the same species are due to different growth factors, such as growth and ecological conditions. In addition, altitude, soil and climate are also very effective factors. Besides, tree age, sample size, ring properties (e.g. ring width, ring orientation), and the test procedure may also affect the test results (Abasali et al. 2012).

Also, shrinkage is a physical property of wood that significantly affects its usability in products. Small shrinkage values are an advantage in use for some wood species (Ugrenovic 1950).

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Volume change is not equal in all directions. The greatest dimensional change occurs in a direction tangential to the growth rings and longitudinal (along the grain) shrinkage is so slight as to be usually neglected (Walker et al. 1993).

Shrinking and swelling can result in wood warping, checking, and splitting, which in turn can lead to decreased utility of wood products, such as loosening of tool handles, gaps in flooring, or other performance problems. Therefore, it is important that the dimensional stability be understood and considered when a wood product is exposed to large moisture fluctuations in service (Glass, Zelinka 2010).

Finally, the aim of this research was to determine the effect of climate factors on the dimensional stability of Calabrian pine wood. In addition, we assessed the relationship between wood sorption (shrinkage and swelling) and the density of Calabrian pine.

MATERIALS AND METHODS

Some properties of climate zones in test areas. Calabrian pine logs were collected from five different regions of the Mediterranean climate in Turkey according to Turkish Standards (TS) 4176 (1984), as shown in Table 1. As it is known, the Aegean climate is accepted as a subdivision of the Mediterranean climate. Test samples were taken from sections of the tree trunks according to the directions shown in Fig. 1.

Determination of some anatomical and physical properties of Calabrian pine. First, specimens with the dimensions of 3 × 3 × 1.5 cm and 3 × 3 × 10 cm were prepared from 1-m sections of the trunks taken from 2–4-m parts of the trees. These specimens were used to determine shrinkages (β) and swellings (α) in the tangential (t), radial (r), and longitudinal (l) directions based on DIN 52 184 (1979). Then, the amounts of shrinkages and swellings of the specimens were determined by the conventional equation included in the relevant, aforementioned standards.

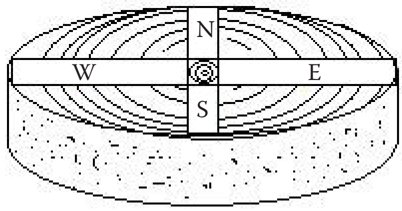

Fig. 1. Obtaining sections of the test samples from the tree trunk according to the directions

Some of the factors shown in Table 5 were calculated by the conventional equations, as described below.

In the determination of oven-dry densities, specimens with the dimensions of 2 × 2 × 3 cm were prepared from 15-cm parts taken from the logs, as described in TS 2470 (1976).

The fibre saturation point (FSP) of Calabrian pine wood was calculated by the following Equation 1:

$$\text{FSP } (\%) = \beta v/R \times 100 \qquad (1)$$

where:
βv – volumetric shrinkage (%),
R – bulk density of the Calabrian pine wood ($kg\cdot m^{-3}$).

The heartwood ratio (HWR) of Calabrian pine wood was determined by Equation 2:

Table 1. Some characteristic features of the test areas according to climate zones

Climate region	Climate characteristics of test areas				
	Mediterranean			Aegean	
	Eastern	Central	Western	Southern	Northern
Climatic type	MMC	TCM	MMCH	MAC	MAC
MR ($kg\cdot m^{-2}$)	708	744	1,220	701	738
MRH (%)	58	61	65	76	72
MT (°C)	16.5	13	15	18	15
Altitude (m)	800	800	700	350	400
Slope (%)	45	30	25	30	45
Exposure	south	south	south	north	south
Soil type	CL	CL	CL	CL	CL

MMC – Mediterranean near mountain climate (Semi-arid), TCM – transition zone of terrestrial climate from Mediterranean region (Semi-arid), MMCH – Mediterranean mountain climate (Humid), MAC – Mediterranean (Aegean type) climatic type (Semi-arid), MR – mean rainfall, MRH – mean relative humidity, MT – mean temperature, Soil type – soil depth is 0–90 cm, CL – Clay-loam

Table 2. The statistical analyses of shrinkage values according to climatic regions

D	Mediterranean			Aegean		P
	Eastern	Central	Western	Southern	Northern	
β_r	3.9 (25.1)^a	4.9 (0.93)^c	4.4 (18.9)^b	4.5 (20.6)^b	5.3 (21.1)^d	***
β_t	5.9 (15.6)^a	7.0 (16.0)^c	7.4 (17.2)^d	6.7 (17.2)^b	6.7 (14.3)^{bc}	***
β_t/β_r	1.5 (32.49)^b	1.4 (0.29)^{cd}	1.7 (0.75)^a	1.5 (0.36)^{bc}	1.3 (0.38)^d	***
β_l	0.5 (0.46)^{abc}	0.6 (73.3)^{bc}	0.6 (43.3)^a	0.5 (56.0)^{ab}	0.7 (61.4)^c	*
β_v	10.3 (12.0)^a	12.6 (3.2)^{bc}	12.3 (14.2)^{bc}	11.6 (2.04)^b	12.8 (17.5)^c	**

D – measured directions, β_r – radial shrinkage, β_t – tangential shrinkage, β_l – longitudinal shrinkage, β_v – volumetric shrinkage, values in parentheses are coefficient of variation (%), means with the same capital letter are not significantly different in Duncan's mean separation test, P – probability level in ANOVA, $^{***}P < 0.001$,$^{**}P < 0.01$

$$HWR (\%) = (Vhw - Vdwv) \times 100 \quad (2),$$

where:
Vhw – heartwood volume (cm^3),
Vdwv – the volume of debarked wood (cm^3).

Annual ring widths, diameters of pits, number of rays per mm^2, lengths of the fibres, and thicknesses of the cell walls were measured using microscope slides in the laboratory.

RESULTS AND DISCUSSION

Table 2 provides the mean values of shrinkage and swelling properties of Calabrian pine wood for different climate zones.

The data in Table 2 show that the measured values of the volumetric shrinkage of Calabrian pine from the North Aegean region were greater than those of other regions, with the lowest values obtained for the Eastern Mediterranean region. Based on the differences between the wood samples shown in Tables 1 and 5, the age of the tree is a major determining factor of wood properties. Thus, a more meaningful comparison of the dimensional stability of woods from four of the climatic regions (all but the North Aegean region) can be obtained because they are close in age. As such, the significant values according to the analytical results for the above-mentioned climatic regions are as follows. The rainfall and relative humidity of the Eastern Mediterranean region are lower, but the temperature is higher than that of the other regions. The results in Table 2 confirmed the conclusions of Guitard and Gachet (2004). Because these authors reported that the tangential shrinkage of early wood is very often greater than the radial shrinkage in softwoods.

It can be summarized from these results that the shrinkages of the Calabrian pine wood growing in the terrestrial climates near the Mediterranean with less rainfall and lower amounts of moisture are close to the shrinkage values of the trees growing in more rainy regions. Table 2 shows that the ratio of tangential to radial shrinkage (β_t/β_r) ranged from 1.41 to 1.69 for the different regions. In this study, the best ratio was obtained in the northern Aegean region. As it is known, when this value is closer to 1, the dimensional stability of the material is higher, indicating that the quality of the material is higher (Göker et al. 2000). Table 3 shows the results of statistical analyses of the swelling values of Calabrian pine wood, i.e. ANOVA and Tukey's mean separation test.

In general, the swelling tests of wood materials were considered a little more than the second degree based on the shrinkage experiments. Based

Table 3. Statistical analyses of swelling values according to climatic regions

D	Mediterranean			Aegean		P
	Eastern	Central	Western	Southern	Northern	
α_r	4.1(1.01)^a	4.6(1.22)^b	4.2(1.12)^a	4.7(1.46)^b	5.4(1.35)^c	***
α_t	6.8(1.34)^a	7.7(1.44)^b	7.9(3.67)^b	7.7(1.50)^b	8.0(1.34)^b	***
α_t/α_r	1.7(0.42)^b	1.7(0.51)^b	1.9(0.69)^a	1.6(0.35)^b	1.5(0.26)^c	***
α_l	0.3(1.16)^a	0.4(0.30)^{ab}	0.3(0.21)^a	0.3(0.23)^a	0.5(0.38)^{bc}	*
α_v	11.1(0.99)^a	12.8(038)^{bc}	12.8(2.34)^{bc}	12.7(2.72)^{bc}	13.9(2.77)^c	**

D – measured directions; α_r – radial swelling, α_t – tangential swelling, α_l – longitudinal swelling, α_v – volumetric swelling, values in parentheses are standard deviations; P – probability level in ANOVA; $^{***}P < 0.001$,$^{**}P < 0.01$; means with the same small letters are not significantly different in Duncan's mean separation test

Table 4. Statistical analyses of shrinkage and swelling values according to directions

Measured properties	Direction of the test specimen				P
	east	west	south	north	
Shrinkage					
β_r mean[A] (%)	4.9 (1.04)[a]	4.5 (1.07)[b]	4.7 (1.14)[b]	4.5 (1.12)[b]	*
β_t	5.0 (1.56)[a]	4.4 (1.18)[b]	4.6 (1.25)[b]	4.6 (1.29)[b]	*
β_l	0.6 (0.42)	0.6 (0.44)	0.5 (0.28)	0.5 (0.35)	n.s.
Swelling					
α_r, mean[A] (%)	7.0 (0.88)	6.8 (1.05)	6.8 (1.19)	6.8 (1.15)	n.s.
α_t	7.9 (1.33)	7.5 (1.30)	7.6 (1.29)	7.6 (1.86)	n.s.
α_l	0.3 (0.24)	0.4 (0.37)	0.3 (0.28)	0.3 (0.28)	n.s.

β_r – radial shrinkage, β_t – tangential shrinkage, β_l – longitudinal shrinkage, β_v – volumetric shrinkage, α_r – radial swelling, α_t – tangential swelling, α_l – longitudinal swelling, α_v – volumetric swelling, [A]value is the average of the test region; values in parentheses are standard deviations, P – probability level in ANOVA; $^*P < 0.05$, n.s. – non-significant, means with the same letters are not significantly different in Duncan's mean separation test

on the results in Table 3, it can be observed that the lowest value of α_t/α_r was 1.5% in the northern Aegean region and that the highest value was 1.9% in the western Mediterranean region. Also, the amount of volumetric swelling in woods from the eastern Mediterranean region was found to be smaller than those from the other regions. However, the results of the statistical analyses shown in Table 3 indicated that there was a non-significant relationship between the direction and the region for radial and tangential shrinkages and swellings.

Table 4 provides the results of the analyses and the mean values of the shrinkages and swellings of Calabrian pine wood according to directions in which the test samples were taken from the tree.

ANOVA in Table 4 showed that the directions had significant effects on the mean values of radial and tangential shrinkages ($P < 0.05$). The lowest mean values of radial and tangential shrinkage were measured in the western direction of the test samples (Fig. 1). Again, the highest mean values were obtained from the eastern direction.

Also, Table 4 provides the results of ANOVA for radial, tangential, and longitudinal swellings of the wood specimens that were tested according to directions. The lowest radial swelling values of 6.8% were observed in the western, southern, and northern directions of the specimens. However, the lowest tangential swelling values of 7.5% were obtained in the western direction. Again, Table 4 shows that the radial and tangential swelling values were non-significant according to direction. So, ecological and climatic factors have a non-significant impact on swelling values with regard to direction.

Table 5 presents the experimental results of the statistical analysis for some of the factors that influence the dimensional stability of wood.

According to the results of the statistical analysis data obtained to determine the effect of climatic differences (regions) on the amounts of shrinkage

Table 5. Some factors affecting the dimensional stability in Calabrian pine wood

	Mediterranean			Aegean		P
	Eastern	Central	Western	Southern	Northern	
ODD (g·cm^{-3})	0.507[a]	0.524[bc]	0.526[c]	0.517[b]	0.525[c]	***
DOP (μm)	16.05[a]	14.14[c]	15.13[b]	15.92[a]	15.46[ab]	***
NRP (mm^2)	24.63[a]	21.81[b]	23.46[ab]	22.86[ab]	18.26[c]	***
ARW (mm)	2.85[a]	1.71[c]	2.31[b]	2.95[a]	1.66[c]	***
FL (mm)	4.26[ab]	4.60[bc]	4.53[bc]	4.02[a]	4.70[c]	***
CWT (μm)	6.77[a]	6.45[b]	6.45[b]	6.22[c]	7.20[d]	***
FSP (%)	25.8	22.8	28.6	27.3	27.6	–
HWR (%)	8.33	6.77	5.25	4.16	13.33	–
ASP (year)	72	89	81	61	131	–

ODD – oven-dry density, DOP –diameter of pit, NRP – number of rays per 1 mm^2, ARW – average annual ring width, FL – average fibre length, CWT – average cell wall thickness, FPS – fibre saturation point, HWR – heartwood ratio, ASP – average age of sample trees, P – probability level in ANOVA; $^{***}P < 0.001$,$^{**}P < 0.01$; means with the same letters are not significantly different in Duncan's mean separation test

Table 6. Equations derived from regression analyses for volumetric (shrinkage and swelling) and some wood properties

	Climatic regions	Equations	R^2
Shrinkage	Eastern Mediterranean	$Y = -6.6 + 23.3x_1 - 0.7x_2 + 0.1x_3 + 0.4x_4 + 0.3x_5 - 0.2x_6 + 0.1x_7$	0.28
	Central Mediterranean	$Y = 0.49 + 23.1x_1 - 0.2x_2 + 0.03x_3 + 0.2x_4 - 0.3x_5 + 1.4x_6 + 0.1x_7$	0.25
	Western Mediterranean	$Y = 14.9 - 18.5x_1 + 1.1x_2 + 0.02x_3 - 0.24x_4 - 0.03x_5 - 0.2x_6 - 0.05x_7$	0.21
	Southern Aegean	$Y = 7.1 + 20.1x_1 - 0.3x_2 + 0.1x_3 - 0.02x_4 - 0.23x_5 - 0.04x_6 + 0.003x_7$	0.31
	Northern Aegean	$Y = -6.5 + 38.6x_1 - 0.04x_2 - 0.1x_3 - 0.2x_4 + 0.05x_5 + 0.06x_6 + 0.03x_7$	0.10
Swelling	Eastern Mediterranean	$Y = 3.4 + 8.4x_1 - 0.9x_2 + 0.1x_3 + 0.6x_4 - 0.3x_5 - 0.1x_6 + 0.1x_7$	0.15
	Central Mediterranean	$Y = -17.4 + 46.2x_1 - 0.9x_2 - 0.2x_3 + 0.6x_4 + 0.6x_5 - 1.2x_6 + 0.12x_7$	0.35
	Western Mediterranean	$Y = -39.8 + 27.8x_1 + 2.6x_2 + 0.1x_3 + 0.5x_4 + 1.4x_5 - 0.8x_6 + 0.04x_7$	0.20
	Southern Aegean	$Y = -12.0 + 50.5x_1 + 0.4x_2 - 0.2x_3 + 0.3x_4 - 0.4x_5 + 0.6x_6 + 0.04x_7$	0.42
	Northern Aegean	$Y = -2.2 + 24.7x_1 + 0.4x_2 - 0.1x_3 + 0.3x_4 + 0.1x_5 + 0.2x_6 - 0.1x_7$	0.35

x_1 – oven-dry density (ODD), x_2 – cell wall thickness (CWT), x_3 – heartwood ratio (HWR), x_4 – fibre length (FL), x_5 – diameter of pit (DOP), x_6 – annual ring width (ARW), x_7 – number of rays per mm^2 (NRP), R^2 – coefficient of determination

and swelling of Calabrian pine, Table 5 indicates that the values of oven-dry density, diameter of pit, number of rays per mm^2, annual ring width, fibre length, and the thickness of the cells walls were significantly different. The lowest values of shrinkage and swelling were obtained from the eastern Mediterranean region. Also the fibre saturation point value (25.8%) of this region is smaller than in the other regions except the central Mediterranean. This fact was due to the loss of bound water in the presence of liquid water. Table 5 also indicates that the heartwood ratio and average ages of the sample trees probably contributed to these differences.

Indeed, tangential shrinkage in the direction parallel to the growth rings is always a little greater than the shrinkage in the radial direction and in the direction perpendicular to the growth rings; this is so because radial shrinkage is partially restrained by the rays. Thus, the lack of movement of ray cells towards the pith to the bark in the radial direction has a positive effect on the βt/βr ratio in wood. The t/r ratio increment of woods shows that these species present a higher anisotropic behaviour. This situation affected the values in Tables 2 and 3, which explains why there is an inverse relationship between the number of ray cells per mm^2 and the amounts of the shrinkages and swellings.

So, it can be said that there is a relationship between climatic factors and the shrinkage and swelling values determined for *Pinus brutia*. Also, it was evident that the shrinkage of the wood was relatively independent of directions and climatic conditions, but it decreased as the age of the trees increased in the northern Aegean region. Regression analyses were conducted in all regions, and the results are documented in Table 6.

Table 6 indicates the relationship between volumetric shrinkage-swelling and some wood properties according to linear regression analyses. Table 6 depicts that the strongest relationship between

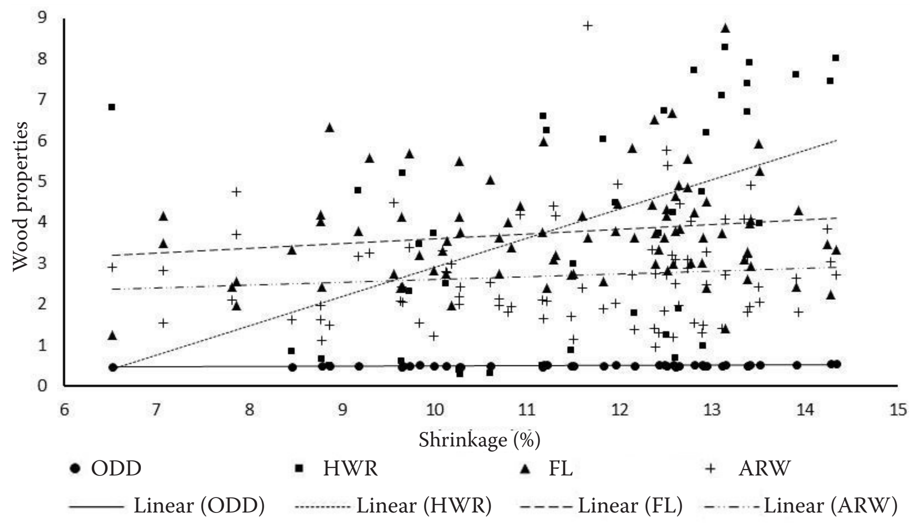

Fig. 2. The relation between volumetric shrinkage and some wood properties for the southern Aegean region

volumetric shrinkage and wood properties was obtained from the southern Aegean region and that the weakest relationship was calculated for the northern Aegean. At the same, Table 6 shows that the strongest relationship between volumetric swelling and wood properties was determined for the southern Aegean region and that the weakest relationship was measured for the eastern Mediterranean region. These corrected the Wodzicki (2001). It is well known that various factors affect the properties of wood, including the percentage of porosity, water content, extractive substances, wood species, site, origin, age of tree, and ring structure. As an example, Fig. 2 shows that the southern Aegean region obtained the lowest sorption values among the various climatic regions. This figure shows the relationship between the values of volumetric shrinkage and some wood properties for Calabrian pine in the southern Aegean region as determined by linear regression analysis. Note that Fig. 2 shows that there was a positive linear relationship between shrinkage and some wood properties (ODD, HRW, ARW, FL), as evidenced by the coefficients of correlation (R_{ODD} = 0.57, R_{HRW} = 0.47, R_{ARW} = 0.10, R_{FL} = 0.17) and the coefficients of determination (R^2_{ODD} = 0.33, R^2_{HRW} = 0.22, R^2_{ARW} = 0.01, R^2_{FL} = 0.03) for volumetric shrinkage. However, Kord et al. (2010) reported that longitudinal shrinkage and swelling in some species tend to decrease as some properties of the wood increase.

CONCLUSIONS

It can be expressed that the Calabrian pine growing in areas that are cold in the winter and dry in the summer produce wood that has similar properties to the wood from pines growing in optimum climatic conditions.

That is, the Mediterranean climate, with summers that are especially hot and dry and winters that are mild and rainy, is preferred. Bolte et al. (2009) stated that forests respond differently to changing climate depending on individual site characteristics, such as various soil and microclimatic conditions.

Calabrian pine wood from the Eastern Mediterranean region had the lowest shrinkage and swelling values, i.e. 10.3 and 11.1%, respectively, among the five regions that were studied. This region had the lowest instances of shrinkage and swelling for both radial and tangential measures in the western direction.

Regression analysis showed that the volumetric shrinkage for all regions did not have a strong correlation with the wood properties. This result can be admissible for volumetric swelling. But Udoakpan (2013) reported that it may be possible to use density and grain orientation biometry to predict the anisotropic shrinkage of wood.

In light of the tests, analysis, and related information, it can be stated that the Calabrian pine species produces wood with optimal dimensional stability and can produce useable wood in climatic regions at altitudes of 800 m, annual average relative humidity of 60%, annual rainfall of 700 kg·cm^{-2}, and average temperature of 16°C. These conclusions were in good agreement with those produced by Arnold et al. (1999). Most aspects of the use of this species for the production of useable wood are compatible with existing environmental factors in the regions that were studied.

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