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Investigation of The Morphological Characteristics of Cones and Seeds of The Scots pine (*Pinus sylvestris* L.) in Natural Populations in Northwestern Türkiye

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Abstract

Aim of study: The aim of this study is to investigate the morphological characteristics of Scots pine cones and seeds in a variety of natural populations.

Area of study: The study was carried out in 12 different natural Scots pine populations in the Western Black Sea Region of Türkiye.

Material and method: A total of 600 cone and 1727 seed samples were collected from 12 natural Scots pine populations. Multivariate Analysis of Variance and post-hoc test were used to investigate differences in cone and seed characteristics including cone length (cl), cone diameter (cd), cl/cd ratio, seed length (sl), seed width (sw), sl/sw ratio, seed wing length (wl), seed wing width (ww) and wl/ww ratio between populations.

Main results: Cone and seed morphological characteristics of Scots pine individuals showed statistically significant differences between populations. The Dedemdağ (Tosya) population had the largest cones in terms of both diameter and length, while the Kızılkaya (Yenice) and Kartalkaya (Aladağ) populations had the smallest cones.

Research highlights: The protection of natural populations of Scots pine is very important, especially for the conservation of seed resources. This study provides important information about potential Scots pine populations in Northwestern Türkiye.

Keywords: Cone Length, Cone Diameter, Seed Length, Seed Width, Seed Wing

Türkiye'nin Kuzeybatısındaki Doğal Sarıçam (*Pinus sylvestris* L.) Popülasyonlarında Kozalak ve Tohumların Morfolojik Özelliklerinin Araştırılması

Öz

Çalışmanın amacı: Bu çalışmanın amacı Sarıçamın kozalak ve tohum morfolojik özelliklerinin çeşitli doğal popülasyonlarda incelenmesidir.

Çalışma alanı: Bu çalışma Türkiye'nin Batı Karadeniz Bölgesinde yer alan 12 farklı doğal Sarıçam popülasyonlarında gerçekleştirilmiştir.

Materyal ve yöntem: Toplamda 12 farklı popülasyondan 600 kozalak ve 1727 tohum örneği elde edilmiştir. Popülasyonlar arasında kozalak ve tohum özelliklerindeki (kozalak boyu, kozalak çapı, tohum uzunluğu, tohum genişliği, tohum kanat uzunluğu, tohum kanat genişliği ve bu karakterlerin en/boy oranları) farklılıkları araştırmak için Çok Değişkenli Varyans Analizi ve post-hoc testi kullanılmıştır.

Temel sonuçlar: Sarıçam bireylerinin kozalak ve tohum morfolojik karakterleri popülasyonlar arasında istatistiksel olarak anlamlı farklılıklara sahip bulunmuştur. Hem çap hem de boy olarak en büyük kozalaklar Dedemdağ (Tosya) popülasyonunda bulunmuştur. Bunun yanında, en küçük kozalaklar Kızılkaya (Yenice) ve Kartalkaya (Aladağ) popülasyonlarından elde edilmiştir.

Araştırma vurguları: Doğal sarıçam popülasyonlarının korunması özellikle tohum kaynaklarının muhafazası için oldukça önemlidir. Bu çalışma Batı Karadeniz bölgesindeki potansiyel sarıçam populasyonları hakkında önemli bilgiler sağlamaktadır.

Anahtar Kelimeler: Kozalak Boyu, Kozalak Çapı, Tohum Uzunluğu, Tohum Eni, Tohum Kanadı

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Introduction

Scots pine (*Pinus sylvestris* L.) is one of the most important coniferous species of pine from an ecological and economic point of view (Koprowski et al., 2012). It grows naturally in large areas including Siberia, the Caucasus, Europe and northern Asia, due to its resistance to hot summers, cold winters and its tolerance in terms of soil requirements (Giuggiola et al., 2010). This contentment also makes it a pioneer species in naturally or anthropogenically disturbed ecosystems (Mátyás et al., 2004). Scots pine, which grows at altitudes ranging from 0 to 2700 m, is one of the most important commercial native tree species in Türkiye (Carus, 2004). Coniferous and mixed coniferous-deciduous forests account for about 68% of Türkiye's forests in terms of distribution area and growing stock. And Scots pine, one of the country's most important conifers, covers about 6.3% (1.5 million ha) of the total forest area (GDF, 2022). In addition, the importance of Scots pine in the Turkish forestry is likely to increase, as it is a preferred species for afforestation, particularly for commercial and conservation purposes such as erosion control. It also plays an important role in Black Sea forestry, particularly in functions such as protecting water basins, providing a natural habitat for wildlife and providing recreational benefits through its aesthetic appearance. Scots pine prefers humid southern aspects of the Black Sea coastal mountains and humid northern aspects of the inner mountains. It generally grows at an altitude of 1200 to 1600 m in the western region of the Black Sea. (Turna & Güney, 2009; Şevik et al., 2010).

The ability of forest ecosystems to adapt to changing environmental conditions is one of the main challenges to their survival. In addition, the adaptability of plants is of great importance for the continuity of ecosystems. To analyze how morphological and genetic diversity relates to changing environmental and climatic conditions is an important task to control ecological stability as plants are threatened by environmental stress (Turna, 2003; Ayan et al., 2005; Turna & Güney, 2009; Seki, 2023). Thus, the potential natural range of plants under possible global warming scenarios can be analyzed and alternative plant species can be identified for many regions.

Considering that Türkiye has a very heterogeneous structure in terms of topographic and ecological conditions (Ekim & Güner, 2000), it is a fact that Scots pine shows morphological and genetic variation under different conditions (Turna, 2003; Ergül Bozkurt et al., 2021). Therefore, investigating the morphological responses of Scots pine under different topographic and climatic conditions allows us to develop recipes for afforestation activities to be carried out in different localities and possible climate change scenarios. Studies on reproductive phenological patterns in particular are among the studies that best reflect the responses and adaptations of trees to changing climatic conditions and help understand these relationships (Köbölkuti & Höhn, 2018).

Scots pine cone and seed morphology are some of the most important variables that are influenced by ecological conditions such as topography (Turna & Güney, 2009). There have been some studies investigating the morphological differences and growth variation of Scots pines growing in different regions of Türkiye in relation to environmental conditions (Turna, 2003; Turna & Güney, 2009; Ergül Bozkurt et al., 2021) and examining the morphological cone and seed characteristics of Scots pine among clonal seed orchard populations (Bilir et al., 2008; Şevik & Topaçoğlu, 2015). However, much work remains to be done for the natural populations in the western Black Sea region of Türkiye, which is an important area of distribution for the Scots pine. In this study, cone and seed morphological characteristics of 12 different natural populations in the Western Black Sea Region were examined and the differences between the populations were studied.

Material and Methods

In this study, some natural Scots pine populations were examined in the Western Black Sea region, one of the most important natural ranges of Scots pine. For this purpose, 12 different Forest Chiefdoms were selected from the regions of Kastamonu,

Zonguldak and Karabük. The mean altitude of the sampled populations ranged from 1070 m to 1750 m. The investigated populations are shown on the map in Figure 1, and information on the populations is given in Table 1.

Figure 1. Locations of the investigated Scots pine populations

Table 1. Information on the populations studied

Population	Regional Directorate of Forestry	Forest Enterprise	Forest Chiefdom	Average altitude of the investigated populations (m)
P1	Kastamonu	Devrekani	Devrekani	1310
P2		Taşköprü	Dikmen	1500
P3			Düzdağ	1250
P4			Kırkçam	1290
P5			Koçanlı	1440
P6			Sarıkaya	1430
P7		Tosya	Dedemdağ	1470
P8			Çaldağ	1510
P9		Karadere	Tepeharman	1580
P10	Zonguldak	Karabük	Keltepe	1070
P11		Yenice	Kızılkaya	1260
P12	Bolu	Aladağ	Kartalkaya	1750

To reflect the variation in the study area for each population, at least five trees were randomly selected from different populations and a total of at least 30 cone samples were collected from these trees. As recommended by Turna & Güney (2009), a minimum distance of 150 m was maintained between the selected trees. Care was also taken to ensure that the last year's mature cones collected from the upper part of the crowns were healthy. A total of 600 cone samples, at least 30 from each population, were collected as part of the study. For the examination of seed characteristics, 2-3 seed samples were taken from each cone, giving a total of 1727 seed samples.

The study investigated 9 morphological characteristics including cone length (cl), cone diameter (cd), cl/cd ratio, seed length (sl), seed width (sw), sl/sw ratio, seed wing length (wl), seed wing width (ww) and wl/ww ratio. The cl, cd, sl, sw, wl and ww were measured using Digimizer v.5.6.0. (Medcalc Software Ltd.) to an accuracy of 0.1 mm. The cl/cd, sl/sw and wl/ww ratios were then calculated.

The minimum, maximum, mean and standard deviation of the cone and seed

characteristics of the Scots pines were calculated separately for each population and overall. Then, a multivariate analysis of variance (MANOVA) with population as a factor and Tukey's post-hoc test at the significance level of 0.05 were used to assess the significance of differences between populations for cone and seed characteristics. All the analyses mentioned in this section have been carried out in the R, version 4.1.2 (R Core Team, 2024).

Results and Discussion

The number of samples, minimum, maximum, mean and standard deviation values for cone characteristics including cl, cd and cl/cd for each population and as an average of all populations are given in Table 2. For all populations studied (overall), cl ranged from 27.5 mm to 68.5 mm with a mean of 48.2 mm, cd ranged from 13.8 mm to 33.9 mm with a mean of 23.7 mm, and cl/cd ranged from 1.44 to 2.64 with a mean of 2.05.

As shown in Table 2, there are differences between the populations in terms of the characteristics of the cones. To determine whether these changes were statistically significant between populations, MANOVA and post-hoc were used. The results are given in Figure 2 using a graphical visualization. The lowest cl values were found in populations P11, P12 and P5 (homogeneous groups), and the highest cl value was found in population P7. Similarly, the lowest cd values were found in populations P11, P12, P2, P5 and P4 (homogeneous groups), and the highest cl values were found in populations P7, P10, P9, P3, P1 and P6 (homogeneous groups). Finally, the homogeneous groups with the lowest cl/cd ratio were the P6 and P1 populations, while the groups with the highest ratio were the P4, P8 and P2 populations. For cl, cd and cl/cd characters, the highest variation was found in populations P9 (SD=7.8 mm), P10 (SD=4.2 mm) and P4 (SD=0.23), respectively, while the lowest variation was found in populations P6 (SD=4.3 mm), P4 (SD=1.6 mm) and P11 (SD=0.13), respectively (Table 2).

Table 2. Descriptive statistics of cone characters

Cone characteristics	Number of sample	Minimum	Maximum	Mean	Standard deviation
P1 (Devrekani)					
cl (mm)		35.7	58.9	50.8	5.1
cd (mm)	30	21.4	33.9	26.4	2.9
cl/cd		1.54	2.39	1.94	0.23
P2 (Dikmen)					
cl (mm)		33.7	62.6	49.3	6.9
cd (mm)	30	17.7	25.0	21.8	1.8
cl/cd		1.67	2.56	2.26	0.22
P3 (Düzdağ)					
cl (mm)		38.3	68.5	53.8	5.6
cd (mm)	48	22.2	31.2	26.6	2.3
cl/cd		1.63	2.30	2.02	0.15
P4 (Kırkçam)					
cl (mm)		37.8	57.9	46.8	5.3
cd (mm)	30	19.7	27.2	22.1	1.6
cl/cd		1.56	2.64	2.13	0.23
P5 (Koçanlı)					
cl (mm)		27.5	54.9	44.5	6.2
cd (mm)	30	18.3	26.0	22.0	1.8
cl/cd		1.50	2.37	2.02	0.22
P6 (Sarıkaya)					
cl (mm)		39.8	54.1	46.6	4.3
cd (mm)	30	22.4	30.1	26.0	2.2
cl/cd		1.44	2.07	1.80	0.22
P7 (Dedemdağ)					
cl (mm)		44.0	66.6	56.4	5.2
cd (mm)	30	20.8	33.7	28.0	2.9
cl/cd		1.62	2.55	2.03	0.20
P8 (Çaldağ)					
cl (mm)		36.9	63.7	50.4	5.4
cd (mm)	99	18.7	29.1	23.7	2.1
cl/cd		1.60	2.53	2.13	0.17
P9 (Tepeharman)					
cl (mm)		40.0	65.7	52.5	7.8
cd (mm)	30	19.5	33.4	26.6	4.0
cl/cd		1.70	2.30	1.98	0.15
P10 (Keltepe)					
cl (mm)		39.5	67.1	53.9	5.8
cd (mm)	52	17.3	33.9	27.0	4.2
cl/cd		1.49	2.47	2.02	0.21
P11 (Kızılkaya)					
cl (mm)		27.9	54.0	42.4	6.1
cd (mm)	68	13.8	25.7	20.4	2.6
cl/cd		1.68	2.32	2.09	0.13
P12 (Kartalkaya)					
cl (mm)		29.6	64.8	42.9	6.7
cd (mm)	123	16.1	27.3	21.1	2.6
cl/cd		1.50	2.55	2.03	0.22
Overall					
cl (mm)		27.5	68.5	48.2	7.5
cd (mm)	600	13.8	33.9	23.7	3.7
cl/cd		1.44	2.64	2.05	0.21

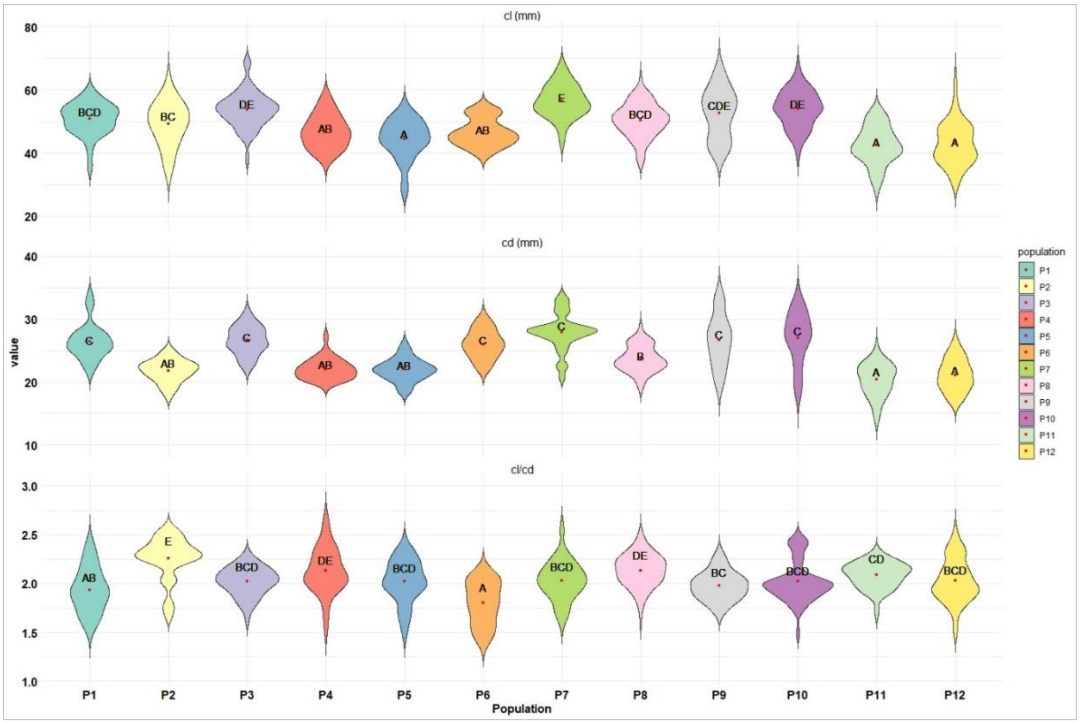

Figure 2. Graphs showing homogeneous groups according to post-hoc results for cone characters. Superscript letters of A, B, C, D and E are homogeneous subsets of post-hoc test results ($p<0.05$)

The number of samples, minimum, maximum, mean and standard deviation values for seed characters including sl, sw and sl/sw for each population and as an average of all populations are given in Table 3, while these descriptive statistics of wing characteristics are given in Table 4. A total of 1727 seed samples obtained from 600 sample cones were used in the study for measurement and calculation of sl, sw, sl/sw, wl, ww and wl/ww characteristics. For all populations studied (overall), sl ranged from 3.4 mm to 7.1 mm with a mean of 5.0 mm, sw ranged from 1.7 mm to 4.2 mm with a mean of 2.9 mm, and sl/sw ranged from 1.03 to 3.06 with a mean of 1.78 (Table 3). Besides, wl ranged from 10.5 mm to 30.2 mm with a mean of 19.4 mm, ww ranged from 2.8 mm to 9.8 mm with a mean of 5.8 mm, and wl/ww ranged from 1.65 to 6.21 with a mean of 3.43 (Table 4).

As shown in Table 3 and Table 4, there are differences between the populations in terms of the characteristics of the seed and wing characteristics, respectively. The results of the MANOVA and post-hoc tests are presented in Figure 3 and Figure 4, respectively, for the seed and wing characteristics, using a graphical visualization.

The lowest sl values were found in populations P10, P6 and P12 (homogeneous groups), and the highest sl value was found in population P3. Besides, the lowest sw values were found in populations P11 and P2 (homogeneous groups), and the highest sw value was found in population P6. Finally, the homogeneous groups with the lowest sl/sw ratio were the P6 and P10 populations, while the groups with the highest ratio were the P9, P3, P8, P11 and P2 populations (Figure 3).

The lowest wl values were found in populations P10 and P12 (homogeneous groups), and the highest wl values were found in population P3, P8 and P7 (homogeneous groups). Besides, the lowest ww values were found in populations P11, P12 and P2 (homogeneous groups), and the highest ww values were found in populations P7 and P3. Finally, the homogeneous groups with the highest wl/ww ratio were the P2 and P11 populations, while the lowest ratio was found in the P10 (Figure 4).

Table 3. Descriptive statistics of seed characteristics

Seed characteristics	Number of sample	Minimum	Maximum	Mean	Standard deviation
P1 (Devrekani)					
sl (mm)		3.8	6.4	5.2	0.5
sw (mm)	184	2.2	4.1	3.1	0.4
sl/sw		1.11	2.45	1.71	0.26
P2 (Dikmen)					
sl (mm)		4.1	6.0	4.9	0.4
sw (mm)	103	1.7	3.4	2.5	0.3
sl/sw		1.50	2.89	1.97	0.28
P3 (Düzdağ)					
sl (mm)		4.5	7.4	5.7	0.6
sw (mm)	193	1.8	4.2	3.0	0.4
sl/sw		1.15	3.06	1.92	0.26
P4 (Kırkçam)					
sl (mm)		3.7	6.5	4.9	0.5
sw (mm)	174	2.1	3.5	2.8	0.3
sl/sw		1.32	2.64	1.79	0.24
P5 (Koçanlı)					
sl (mm)		3.5	6.1	4.8	0.6
sw (mm)	146	2.0	4.1	2.8	0.4
sl/sw		1.24	2.50	1.75	0.24
P6 (Sarıkaya)					
sl (mm)		3.4	6.1	4.7	0.6
sw (mm)	162	2.1	4.0	3.2	0.4
sl/sw		1.03	2.45	1.45	0.24
P7 (Dedemdağ)					
sl (mm)		3.7	6.8	5.1	0.7
sw (mm)	90	2.2	4.0	3.0	0.4
sl/sw		1.20	2.42	1.71	0.27
P8 (Çaldağ)					
sl (mm)		4.2	6.4	5.4	0.5
sw (mm)	105	2.1	3.5	2.8	0.3
sl/sw		1.38	2.67	1.93	0.27
P9 (Tepeharman)					
sl (mm)		4.3	6.3	5.5	0.4
sw (mm)	100	2.3	3.3	2.9	0.2
sl/sw		1.53	2.42	1.91	0.17
P10 (Keltepe)					
sl (mm)		3.4	6.1	4.5	0.4
sw (mm)	120	2.5	3.5	3.0	0.2
sl/sw		1.03	2.04	1.52	0.16
P11 (Kızılkaya)					
sl (mm)		3.7	6.0	4.8	0.5
sw (mm)	125	2.1	2.9	2.5	0.2
sl/sw		1.45	2.59	1.96	0.22
P12 (Kartalkaya)					
sl (mm)		3.7	6.0	4.7	0.5
sw (mm)	225	2.1	3.2	2.6	0.2
sl/sw		1.33	2.23	1.78	0.18
Overall					
sl (mm)		3.4	7.1	5.0	0.6
sw (mm)	1727	1.7	4.2	2.9	0.4
sl/sw		1.03	3.06	1.78	0.28

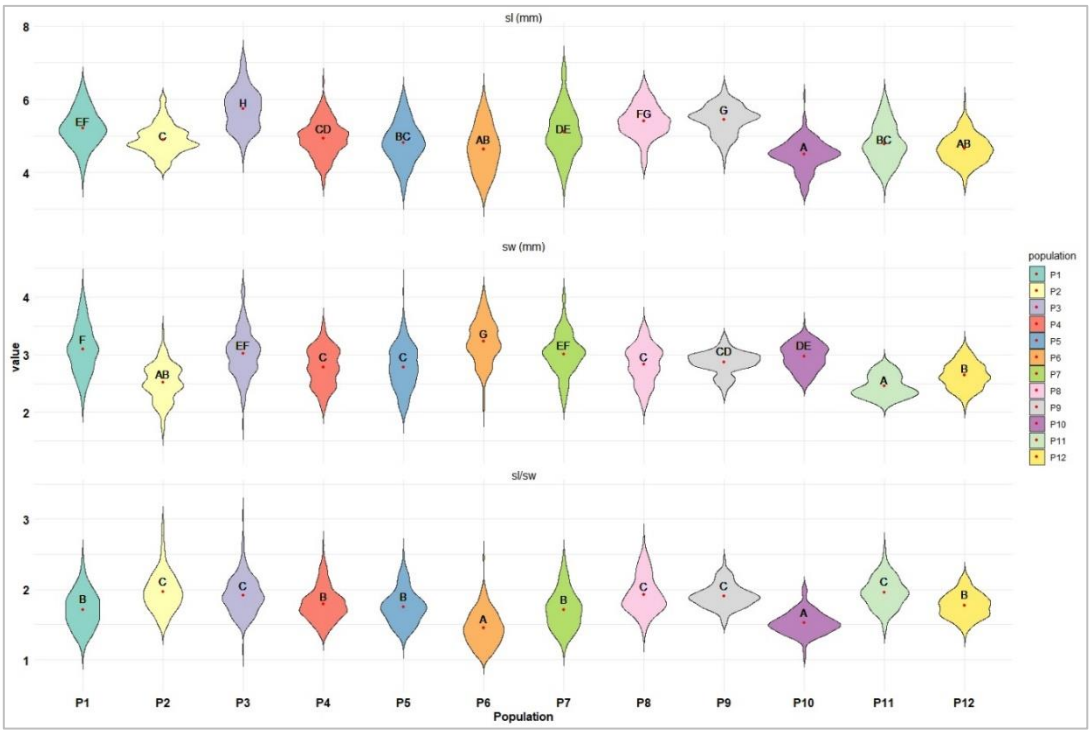

Figure 3. Graphs showing homogeneous groups according to post-hoc results for seed characters. Superscript letters of A, B, C, D, E, F, G and H are homogeneous subsets of post-hoc test results ($p<0.05$)

Table 4. Descriptive statistics of wing characters

Wing characteristics	Number of sample	Minimum	Maximum	Mean	Standard deviation
P1 (Devrekani)					
wl (mm)		14.8	24.7	20.5	1.9
ww (mm)	184	3.8	9.8	6.1	1.0
wl/ww		2.11	5.38	3.45	0.58
P2 (Dikmen)					
wl (mm)		15.4	21.8	19.4	1.2
ww (mm)	103	3.5	7.0	5.2	0.6
wl/ww		2.87	4.71	3.80	0.37
P3 (Düzdağ)					
wl (mm)		11.2	30.2	20.9	3.1
ww (mm)	193	4.2	9.7	6.6	0.9
wl/ww		1.65	5.04	3.22	0.54
P4 (Kırkçam)					
wl (mm)		10.5	23.0	19.2	2.0
ww (mm)	174	3.7	7.2	5.4	0.7
wl/ww		2.02	5.10	3.58	0.54
P5 (Koçanlı)					
wl (mm)		11.0	21.8	18.3	2.2
ww (mm)	146	3.8	7.1	5.5	0.7
wl/ww		2.30	5.38	3.36	0.57
P6 (Sarıkaya)					
wl (mm)		15.7	24.2	19.4	1.9
ww (mm)	162	4.5	7.7	6.2	0.7
wl/ww		2.30	4.79	3.15	0.43
P7 (Dedemdağ)					
wl (mm)		16.8	25.1	21.2	1.8
ww (mm)	90	4.5	8.8	6.4	0.8
wl/ww		2.41	4.71	3.35	0.49
P8 (Çaldağ)					
wl (mm)		17.0	25.0	21.0	1.7
ww (mm)	105	4.2	7.7	6.0	0.7
wl/ww		2.74	4.86	3.53	0.46
P9 (Tepeharman)					
wl (mm)		14.9	23.0	20.0	2.0
ww (mm)	100	4.1	6.6	5.6	0.6
wl/ww		2.73	4.70	3.58	0.42
P10 (Keltepe)					
wl (mm)		14.1	20.8	17.8	1.6
ww (mm)	120	4.5	7.4	6.2	0.5
wl/ww		2.25	4.00	2.90	0.37
P11 (Kızılkaya)					
wl (mm)		11.9	23.5	18.4	2.9
ww (mm)	125	2.8	7.3	4.9	0.9
wl/ww		2.40	6.21	3.82	0.74
P12 (Kartalkaya)					
wl (mm)		13.1	23.9	17.8	2.1
ww (mm)	225	3.5	6.8	5.1	0.7
wl/ww		2.59	5.23	3.57	0.50
Overall					
wl (mm)		10.5	30.2	19.4	2.4
ww (mm)	1727	2.8	9.8	5.8	0.9
wl/ww		1.65	6.21	3.43	0.57

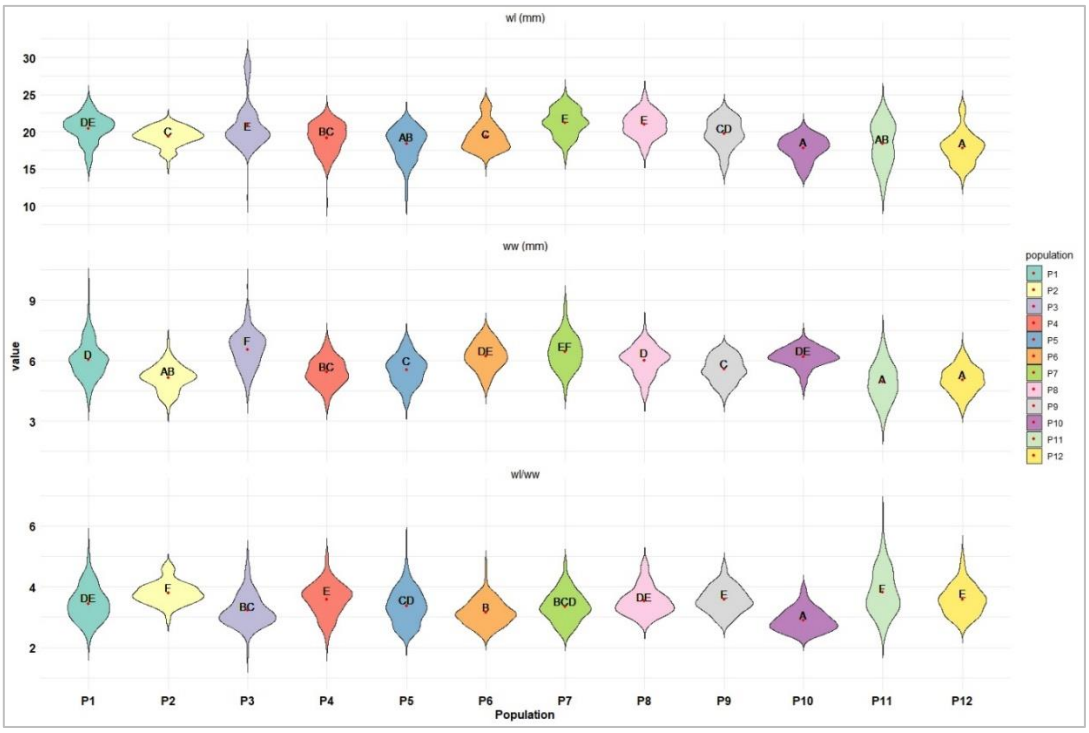

Figure 4. Graphs showing homogeneous groups according to post-hoc results for wing characteristics. Superscript letters of A, B, C, D, E and F are homogeneous subsets of post-hoc test results ($p<0.05$)

A number of studies have been carried out on the cone and seed morphology of the Scots pine, which is one of the most important conifer species for Türkiye. Although many studies have been conducted on the cone and seed morphology of Scots pine in natural populations and seed orchards, studies conducted on natural populations, such as this study, will be discussed in more detail in this discussion. Turna & Güney (2009) investigated the morphological characteristics of cones, seeds and wings in natural Scots pine populations at five different altitudes in Trabzon, northeastern Türkiye. As the average of all these five populations, cl was found to be between 25.1-61.3 mm with an average of 43.1 mm, cd was found to be between 13.3-29.8 mm with an average of 22.0 mm, sl was found to be between 3.4-6.9 mm with an average of 5.2 mm, sw was found to be between 2.3-3.7 mm with an average of 2.9, wl was found to be between 9.4-23.2 mm with an average of 16.6 mm and ww was found to be between 3.9-6.8 mm with an average of 5.7. As the current study, study of Turna & Güney (2009) underlined the ability of Scots pines to adapt to different ecological conditions and found that altitude had a major influence on this differentiation. Jasińska et al. (2014) investigated the phenotypic differentiation of Scots pine in southern Europe and southwestern Asia, using thirty-two natural populations. This study also included the Scots pine morphology assessment of 10 different populations from Türkiye. The mean±SD values of cl and cd of Scots pine trees in Türkiye as an average of 10 populations were found to be 47.35 mm and 25.97 mm, respectively. The mean values of cone morphologic characters for all populations examined in the current study (cl=48.2 mm, cd=23.7 mm) are similar to the mean values found by Jasińska et al (2014).

A study on the cone morphology of Carpathian Scots pine populations was carried out by Kökölkuti et al (2017). In this study carried out on 16 natural Scots pine populations distributed in Hungary, Slovakia and Romania, the average cd was found to be between 40 and 48 mm, the average cl between 34 and 43 mm, and the cl/cd ratio between 0.9 and 1.0. In the current study of

natural Scots pine populations in the Western Black Sea region of Türkiye, the cones were found to be longer (cl=48.2 mm) and thinner (cl=23.7 mm) than the cones of Scots pines in the Carpathian populations examined by Kökölkuti et al. (2017). Therefore, the cl/cd ratios (cone shapes) in the natural populations of Western Black Black Sea of Türkiye and Carpathian appear to be different.

Scots pine has been identified as a species with significant variation both within and between populations in this and previous studies (Urbaniak, 1997; Turna and Güney, 2009; Łabiszak et al., 2017). One of the possible reasons for this is due to water stress, as conifers in general respond to dry conditions (Yılmaz, 2015; Kopabayeva et al., 2017; Kahveci et al., 2018; Bozkurt et al., 2021). The results of this study show that the populations of Scots pine in the different topographies show differences in the characteristics of the cones and the seeds. The importance of the morphological adaptation of Scots pine is highlighted, especially considering that the populations studied are located at altitudes between 1070 m and 1750 m. Understanding these differences can increase the success of tree breeding programs.

The morphological variation of cones under different ecological conditions was investigated in this study and in many of the studies mentioned above. Nevertheless, cone size and weight can be influenced by tree age, general health of the trees, and the macro- and micro- habitat of the parent trees (Dangasuk & Panetsos, 2004). For this reason, more comprehensive studies examining the effects of variables such as tree age and health status, as well as geographical and ecological characteristics on morphological variation are needed. In addition, there are studies in the literature that have also examined the adaptation of Scots pine needle characteristics under different ecological conditions (Jankowski et al., 2017; Łabiszak et al., 2017; Ergül Bozkurt et al., 2021; Wrońska-Pilarek et al., 2023). Studies better reflects the environmental adaptations of the species studied by examining needle adaptations together with cone adaptations (Boratyńska et al., 2022).

Plants generally respond to changes in environmental conditions and stresses in terms of morphological and growth characteristics (Atar et al., 2024). This variation that plants show under certain environmental conditions is also an indication of the limits of tolerance for that particular environment (Yılmaz and Yılmaz, 2016). For this reason, studies investigating morphological variation, especially in areas of high topographic and climatic variation, are of great importance. Determining the range of the species in terms of morphological characteristics, predicting its responses to possible stress conditions and highlighting conservation priorities are directly related to these results. Although this and some previous studies have focused on the morphological variation of Scots pine, given the size of its distribution range, it is essential to continue to investigate the morphology of Scots pine in different populations.

Conclusion

Variation in cone and seed morphological characteristics was found in natural Scots pine populations in the Western Black Sea Region of Türkiye. The Dedemdağ population had the largest cones in terms of both length (56.4 mm) and diameter (28.0 mm), while the Kızılkaya (cl=42.4 mm, cd=20.4 mm) and Kartalkaya (cl=42.9 mm, cd=21.1 mm) populations had the smallest cones. The results of this study have important implications for forest research, management and practice, particularly the selection of seed sources and seed transfer zones. The adaptation and morphological differences of Scots pine populations growing in environments with different ecological characteristics will also help to understand their potential adaptations under possible climate change scenarios. Therefore, more studies are needed to investigate the morphological diversity of Scots pine in Türkiye, which has very different ecological regions, especially in terms of topographic and climatic features. Besides, the conservation of the natural populations of Scots pine which has wide distribution range

is of great importance, particularly because of its ability to adapt to different geographical and climatic conditions.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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