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Carbon Concentration in Tree Components of Mature *Pinus brutia* Ten. Forests in the Marmara Transition Zone

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Abstract

Aim of study: This study was carried out to determine the carbon concentration of the tree components (needles, wood, bark, root) and the weighted carbon concentrations of the above-ground and total tree mass.

Area of study: Current study was carried out in natural *Pinus brutia* forests in the Marmara Transition Zone, southern side of Sakarya river.

Material and methods: The samplings were made in 10 stands in the mature stage (dbh = 20.0-51.9 cm) that were different in terms of habitat characteristics. Needle, wood, bark, and root samples were taken from three dominant trees in each sample plot. Carbon was analysed in the laboratory in samples of tree components. The data obtained were evaluated by analysis of variance and Duncan multiple comparison test.

Main results: Significant differences were determined between carbon concentration of tree components ($p<0.001$). The lowest carbon concentration (50.25%) was found in root and the highest (54.90%) in the bark. The weighted carbon concentration was calculated as 52.07% for the above-ground and 51.77% for the total tree biomass.

Highlights: The results obtained can be used for the calculation of carbon stocks stored in both whole and in different components of trees in *Pinus brutia* forests.

Keywords: Calabrian Pine, Weighted Carbon Concentration, Site Properties

Marmara Geçiş Bölgesi'ndeki Ağaçlık Çağındaki *Pinus brutia* Ten. Ormanlarında Ağaç Bileşenlerinin Karbon Yoğunlukları

Öz

Çalışmanın amacı: Bu çalışma kızılçamda ağaç bileşenlerinin (ibre, odun, kabuk, kök) karbon oranlarını ve toprak üstü ve toplam ağaç kütlesine ait ağırlıklı karbon oranlarını belirlemek için yapılmıştır.

Çalışma alanı: Çalışma Marmara Geçiş Bölgesi'nde, Sakarya nehrinin güney kesimlerindeki doğal kızılçam ormanlarında yürütülmüştür.

Materyal ve yöntem: Örneklemeler ince ve orta ağaçlık çağında ($d_{1,3}$=20.0-51.9 cm) bulunan ve yetişme ortamı özellikleri bakımından farklılık gösteren toplam 10 alanda yapılmıştır. Her örnekleme alanında baskın durumda olan üç ağaçtan ibre, odun, kabuk ve kök örnekleri alınmıştır. Laboratuvarda ağaç bileşenlerine ait örneklerde karbon analizi yapılmıştır. Elde edilen veriler varyans analizi ve Duncan çoklu karşılaştırma testi ile değerlendirilmiştir.

Temel sonuçlar: Ağaç bileşenlerinin karbon oranları arasında önemli farklılıklar belirlenmiştir ($p<0.001$). Karbon yoğunluğu ağaç bileşenleri arasında en düşük kökte (%50.25), en yüksek ise kabukta (%54.90) bulunmuştur. Doğal kızılçam ormanları için ağırlıklı karbon oranı toprak üstü ağaç kütlesi için %52.07, toplam ağaç kütlesi için ise %51.77 olarak hesaplanmıştır.

Araştırma vurguları: Elde edilen sonuçlar, kızılçam ormanlarında gerek ağaçlarda gerekse ağaçların farklı bileşenlerinde depolanan karbon stoklarının hesaplanmasında kullanılabilir.

Anahtar Kelimeler: Kızılçam, Ağırlıklı Karbon Oranı, Yetişme Ortamı Özelliği

Introduction

CO_2 is a crucial greenhouse gas in the atmosphere for global climate change. Forest land is one of the largest carbon sinks in the terrestrial ecosystems. Therefore, increasing forest area by afforestation is regarded as one of the critical tools to reduce CO_2 in the atmosphere. Accordingly, it is necessary to determine the factors affecting carbon sequestration in forest ecosystems, such as the

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structure of forest and tree species to monitor carbon balance in forests and make the necessary calculations for a robust carbon inventory (Lamlom & Savidge, 2003; Malmsheimer et al., 2011). Most countries prepare their greenhouse inventory report based on forest inventory, which is based on tree stem volume, and biomass factors to convert stem volume to tree biomass. Carbon fraction is generally assumed as 0.50 for whole tree biomass carbon. However, using the carbon fraction of 0.5 may lead to over- or under-estimation. (Herrero et al., 2011).

More than 160 countries have committed to reduce their greenhouse gas emissions in line with the Kyoto Protocol to alleviate the climate change effects on society (Colombo et al., 2005). As a result of this policy, a standard inventory method was needed including various sectors, namely AFOLU-IPCC Guidelines for National Greenhouse Gas Inventories for Agriculture, Forestry and Other Land Use (IPCC, 2006).

The guideline provides detailed information on carbon sequestration in forest ecosystems on a country scale. According to the guideline, carbon pools should be determined for tree categories, including live below- and above-ground biomass, dead organic matter, and soil. Furthermore, the guidelines provide some default constants by climate zones, forest types, and tree species to be used in calculating carbon stocks for countries that have no species-specific biomass and carbon constants. However, using a specific constant is recommended if available for more robust carbon inventory in the guidelines. As a matter of fact, studies show that carbon concentrations in carbon reservoirs vary depending on environmental factors, tree species, and tree components (Laiho & Laine, 1997; Lamlom & Savidge, 2003; Bert & Danjon, 2006; Thomas & Malczewski, 2007).

Calabrian pine (*Pinus brutia* Ten.) spreads across Palestine, Jordan, Syria, Iraq, Lebanon, Türkiye, Greece, and Italy (Yaltırık & Akkemik, 2011). It is widely distributed in the Aegean, Mediterranean and Marmara Regions in Türkiye, while it also exists in small spots alongside the Black Sea coastline (Anşin, 1988). Türkiye's forest asset is 22.9 million hectares, and Calabrian pine accounts for 22.7% of the country's forests, with an area of 5.2 million hectares (GDF, 2022). Calabrian pine should be studied for carbon calculations as it has the widest distribution area of all coniferous tree species and also it is one of the priority species in industrial plantations. There is a study conducted in the Calabrian pine forests in the Mediterranean Region (Adana) to determine on above-ground plant biomass, carbon concentrations and carbon stocks (Durkaya et al., 2015). The study conducted by Durkaya et al. (2015) was carried out in the broad-leaved and coniferous forest ecozone of the Mediterranean mountain zone and Mediterranean coastal strip zone, according to Serengil's (2018) classification. In addition, Aka Sağlıker & Darıcı (2006) also calculated the carbon stock for various tree species in the Mediterranean Region. Kahriman et al. (2016) carried out a study on the yield of pure *Pinus brutia* forests in the vicinity of Antalya and Mersin. Besides, another research on aboveground biomass and carbon stocks of young *Pinus brutia* forests in Türkiye was carried out by Sakici et al. (2018). However, our study differs from the previous ones as it was conducted in the broad-leaved, coniferous, and mixed forest ecozone in a transition zone to Northern Anatolia.

The purpose of this study was to determine the carbon concentrations of tree components and the weighted carbon concentrations of above-ground tree biomass and total tree biomass in Calabrian pine forests.

Materials and Methods

Study Area

The study was carried out in the natural Calabrian pine forests in Sakarya Valley located in the Marmara Transition Zone (Atalay, 2002).

The habitat characteristics and coordinates of the sampling plots are presented in Table 1, which shows that the sampling plots are located at an elevation of 430-928 m., inclination of 36-61%, northern aspects and mostly upper slopes and middle slopes.

The data of the Sarıcakaya meteorology station (2013-2020) that was the closest one was used to determine the climate features of the sampling plots. The annual precipitation in the sampling plots is 465-734 mm, mean annual temperature is 12.4-14.9ºC, mean annual high temperature is 19.7-22.2ºC (GDM, 2021). According to Erinç's method, the climate in the sampling plots ranges from semi-arid (Im=21.0) to semi-humid (Im=37.3) (Özyuvacı, 1999).

Table 1. Some site characteristics of sample plots

Sample plot	Coordinates (UTM)			Altitude (m)	Inclination (%)	Aspect (°)	Slope position (%)	Climate type
	GZ	Latitude	Longitude					
1	36T	0324362	4430563	928	44	NW (290)	US (2)	Semi-humid
2	36T	0324428	4431709	741	46	N (350)	US (16)	Semi-humid
3	36T	0324569	4431803	691	40	N (355)	US (2)	Semi-humid
4	36T	0324890	4431942	697	36	NW (320)	US (2)	Semi-humid
5	36T	0325292	4431814	719	46	N (355)	MS (30)	Semi-humid
6	36T	0324990	4431602	842	55	N (350)	MS (35)	Semi-humid
7	36T	0324890	4431942	832	58	N (350)	US (1)	Semi-humid
8	36T	0326659	4432284	615	59	N (5)	MS (51)	Semi-humid
9	36T	0326452	4432474	532	61	N (345)	MS (69)	Semi-humid
10	36T	0324627	4432544	430	52	N (350)	LS (81)	Semi-arid

GZ: grid zone, N: north, NE: northeast, E: east, SE: southeast, S: south, SW: southwest, W: west, NW: northwest, US: upper slope, MS: middle slope, LS: lower slope

The bedrock in the study area consists of ophiolite, sandstone, chlorite schist and sericite schist, while the soils were classified as cambisols and textures included sandy loam, sandy clay loam, clay loam and loamy clay (Çelik, 2006).

Pinus brutia is the dominant species in the study area. Some of the other common plant species in the area include *Quercus pubescens*, *Quercus cerris*, *Quercus infectoria*, *Juniperus oxycedrus*, *Juniperus foetidissima*, *Juniperus excelsa*, *Acer campestre*, *Ficus carica*, *Pyrus eleagrifolia*, *Pistacia terebinthus*, *Ephedra major*, *Cistus creticus*, *Jasminum fruticans*, *Clematis vitalba*, *Genista* sp., *Paliurus spina-christii*, *Colutea cilicica*, *Rhamnus thymifolius*, *Rhus coriaria*, *Rosa canina*, *Lonicera etrusca*, *Berberis crataegina* and *Tamarix smyrensis* (Çelik, 2006).

Sampling Method and Laboratory Analyses

Samples were collected from 10 plots across the pure Calabrian pine stands at the mature stage (dbh=20.0-51.9 cm) with ages 40-60 and height 10-15 m approximately, representing different habitat characteristics. The sampling plots were 20×20=400 m^2 in size. The inclination of the sampling plots was determined with a clinometer, the elevation was determined with an altimeter and the aspect was determined with a compass. The slope position was determined by considering the slope length between the crest line and the foot slope as 100 units, while the average distance from the upper edge of the slope was calculated as the percentage of slope length. Sampling was performed in November. In each sampling plot, needle, wood, bark, and root samples were collected from three individual trees located on the dominant layer. Needle samples were taken with scissors at a height of around 7 meters from the ground. Some sample trees had needles up to four-year-old, with very few quantities, while almost all trees had three years old. Therefore, needle samples were collected from four sides of the canopy in equal quantities considering needle age, including current year needles (C), C+1 year, and C+2-year-old Wood and bark samples were collected with increment borer at the breast height of sampled trees. Then a cross-section was bored at the bottom of the sampled trees with a pickaxe and root samples with a diameter of ≤ 5 cm were taken from those bored cross-sections. Wood and branches were reported to contain similar carbon concentrations (Durkaya et al. 2015). Thus, the branches were not sampled because it is time-consuming and labor-intensive work. Considering that the tree branch is woody material, the carbon concentration of the branches was assumed to be the same as stem in this study. The collected samples were washed to rinse away soil and transported to the laboratory with the other samples.

The samples (10 plots × 3 replications × 4 components = 120 samples) belonging to tree components (needle, wood, bark, and root) were dried at a temperature of 65 ºC until they reached constant weight and grained for carbon analysis. LECO CNH TruSpec analyser (Leco Corporation, St. Joseph, MI, USA) was used to analyse the carbon concentration of the samples.

Evaluation

Data evaluation was made by dividing the sample plots into two elevation groups as <700 m and >700 m, two slope position groups as upper and middle slope, two inclination groups as <50% and >50%. As there was one sampling plot at the lower slope, lower slope was not included in the evaluation of slope position. For the calculation of weighted carbon concentration, the ratio of tree components to the above-ground and total tree biomass was calculated using the biomass equation proposed by Orhan (2013) (Table 2). The biomass of wood was calculated by summing up the stem wood and the wood of branches larger than 4 cm and smaller than 4 cm while the biomass of bark was calculated by summing stem bark and bark of branches larger than 4 cm and smaller than 4 cm. For the calculation of total tree biomass, r/s ratio was considered as 0.20 (IPCC, 2006).

Table 2. Equations used in biomass calculations (Orhan, 2013)

Component	Equation	R^2	SE
Stem wood	$B= -18.51581+(0.32992\times d^2)$	0.938	56.93
Stem bark	$LnB= 0.19391+(0.13508\times d)+(-0.00085\times d^2)$	0.858	0.42
Branch wood > 4 cm	$B= -44.51623+(3.14666\times d)$	0.781	16.29
Branch bark > 4 cm	$B= -22.90663+(8.83301\times \ln d)$	0.537	2.60
Branch wood < 4 cm	$B= 14.73115 + (-0.35158\times d) + (0.02024\times d^2)$	0.532	14.31
Branch bark < 4 cm	$B= 2.84845 + (0.00083\times d^2)$	0.051	2.19
Needles	$B= 2.57040 + (0.01997\times d^2)$	0.787	7.00

B: biomass (kg $tree^{-1}$), d: diameter at breast height (cm), SE: standard error

According to the calculations, the ratios of the needle, wood, and bark masses for above-ground biomass were 0.0485, 0.8366, and 0.1149, respectively. The ratios of needle, wood, bark, and root masses for the total tree biomass were 0.0404, 0.6972, 0.0957 and 0.1667, respectively.

Equation 1 was used to calculate the weighted carbon concentration of above-ground and total tree biomass (Erkan & Güner, 2018).

$$wcc = \sum\left(\frac{ccc_i \times cb_i}{100}\right) \quad (1)$$

Where wcc is weighted carbon concentration for the total biomass (%); ccc_i is carbon concentration of the tree component (%), i is i^{th}: tree component (%); cb_i is biomass ratio of tree component in above-ground or total tree biomass (%).

Normal distribution of the data set was controlled by Shapiro-Wilk tests, while homogeneity of the variances was evaluated by *Levene's test*. All data were normally distributed and homogeneous variance. Then the differences among tree components carbon concentration were evaluated by analysis of variance (ANOVA). Duncan's multiple-range test was used for comparison of the means. Results were accepted statistically significant at the α=0.05 level. SPSS statistical software was used (SPSS v.22.0®, 2015) for the statistical analyses.

Results and Discussion

Carbon Concentration of Tree Components

The descriptive statistics regarding the carbon concentration of tree components and results of the ANOVA are presented in Table 3. Statistically significant differences were found among the carbon concentrations of tree components ($p<0.001$). The lowest carbon concentration was found in roots (50.25%), while the highest one was found in barks (54.90%) (Table 3). Similar results were also reported in studies performed in Scots pine (Çömez, 2012; Erkan & Güner, 2018), black pine (Güner & Çömez, 2017), cedar (Karataş et al., 2017), *Abies nordmanniana* subsp. *equi-trojani* (Güner, 2019), and maritime pine (Bert & Danjon, 2006; Tolunay et al., 2017; Güner et al., 2019) species. In a study conducted on black pine, the carbon concentration of bark was found to be higher than that of other components, which was proposed to be associated with high concentrations of lignin and extractive substances in bark (Güner & Çömez, 2017). Because in coniferous species, the lignin concentration of wood can reach a maximum of 30% while it is up to 55% in the bark. Furthermore, the extractive substance concentration of bark is almost 3 times higher than that of wood (Dönmez & Dönmez, 2013). However, Durkaya et al. (2015) reported that the lowest carbon concentration among tree components was found in branches (50.8%) and barks (50.8%) of Calabrian pine trees while the carbon concentrations of wood and branches were very close, with means of 49.2% and 49.0%, respectively. The highest carbon concentration was found in needles of Calabrian pine, Scots pine, and black pine with 52.1%, 52.6%, and 52.3%, respectively (Durkaya et al., 2015). In studies conducted on *Abies nordmanniana* subsp. *bornmulleriana* (Durkaya et al., 2013a) and *Cedrus libani* (Durkaya et al., 2013b), the highest carbon concentration was found in needles, likely due to the synthesis of several organic compounds needed by the plant in leaves through photosynthesis (Graham et al., 2014). On the other hand, in addition to different species studied, differences between the seasons when sampling was performed in those studies, development stages of stands, and their habitat characteristics might also be the other factors leading to variation in carbon concentration of tree components, as reported by many researchers (Erkan & Güner, 2018; Güner, 2019) and stand's development stage (Çömez, 2012; Makineci et al., 2015; Güner & Çömez, 2017; Karataş et al., 2017). Moreover, Aka Sağlıker & Darıcı (2006) also found that the carbon concentration of needles was higher in Calabrian pine growing on conglomerate bedrock than in stem while the carbon concentration of stem was higher than in needles on marn bedrock, indicating that the habitat characteristics may affect the distribution of carbon compounds across different tree components. However, there is a need for further studies to clarify this matter.

In this study, the carbon concentration of stem wood which is the most important carbon stock among tree components was found to be 51.67% for Calabrian pine. In a study conducted in the Mediterranean Region, it was reported to be 51.5% (Durkaya et al., 2015). Aka Sağlıker & Darıcı (2006) found that carbon concentration in Calabrian pine stem was 46% on conglomerate and 50% on marn bedrock. The carbon concentration in needle found in that study (52.08%) was very close to that (52.1%) reported by Durkaya et al. (2015). Carbon concentrations in stem wood and needles found in these two studies conducted on natural Calabrian pine forests in the Black Sea and Mediterranean Regions were very similar. On the other hand, Aka Sağlıker & Darıcı (2006) found that carbon concentration was 47-49% in needles and 46-60% in stems in Calabrian pine trees, which were lower than those found in this study. Çalışkan & Makineci (2015) also found that carbon concentration varied across seeds of Calabrian pine collected from different populations. Different carbon concentrations found in the same tree species indicate that trees may have varying carbon concentrations depending on habitats. This shows that local coefficients should be used more commonly for precise carbon calculations.

Table 3. Some statistics for carbon concentration (%) in tree components (n=30) and mean weighted carbon concentration for aboveground and above+belowground biomass.

Tree Component	Mean	Min	Max	Std. Dev.
Root	50.25a	49.77	51.03	0.38
Wood	51.67b	51.30	52.05	0.25
Needles	52.08c	51.28	52.76	0.46
Bark	54.90d	54.33	55.22	0.29
Weighted mean (Aboveground)	52.07			
Weighted mean (Above- and belowground)	51.77			

Different letters show significant differences among the means at a level of α=0.05

Weighted Carbon Concentration

Weighted carbon concentration for Calabrian pine was found to be 52.07% in above-ground tree biomass and 51.77% in total tree biomass (Table 3). This value is very close to the one reported by Durkaya et al. (2015) for stem wood of Calabrian pine, which was 51.5%. In studies performed in Türkiye on different tree species, the weighted carbon concentration of total tree biomass was reported to be 51.96% (Tolunay, 2009), 52.46% (Çömez, 2012) and 52.37% (Erkan & Güner, 2018) in natural Scots pine forests; 52.15% (Güner, 2019) in natural *Abies nordmanniana* subsp. *equi-trojani* forests; 53.86% (Güner & Çömez, 2017) in black pine plantations; 51.27% (Karataş et al., 2017) in *Cedrus libani* plantations; 50.32% in *Pinus pinea* plantations (Tolunay et al., 2017); and 51.44% in maritime pine plantations (Güner et al., 2019). There is no study on weighted carbon concentrations in Calabrian pine. Therefore, Erkan & Aydın (2016) used 50% of plant biomass for carbon concentration while calculating the carbon accumulation in Calabrian pine plantations.

AFOLU (agriculture, forestry, and land use) guidelines recommend that carbon concentration should be taken as 51% for coniferous species in carbon inventory reports if there is no research on specific species (IPCC, 2006). On the other hand, the carbon concentration of the tree components other than stem wood is not taken into account in several carbon budget calculations for forestry sector. However, our findings in addition to the recent studies (Çömez, 2012; Güner & Çömez, 2017; Karataş et al., 2017; Tolunay et al., 2017) demonstrated that carbon concentrations of tree components were quite different. Hence, coefficients to be found by taking account of weighted carbon densities of tree components will provide a more precise calculation.

Effects of Environmental Drivers on Carbon Concentration

Carbon concentration of needles, wood and roots did not vary significantly depending on elevation, inclination and slope position ($p>0.05$), whereas carbon concentration of bark was found to be significantly lower at higher inclinations compared to those at lower inclinations ($p<0.05$) (Figure 1). The carbon concentration of bark was reported to range from 53% to 56% in *Pinus pinea*, which is one of the pine species in the Mediterranean Region, and it is very close to the value we found in our study (Correia et al., 2010). However, Durkaya et al. (2015) found much lower carbon concentration in bark of Calabrian pine in the Mediterranean Region of Türkiye than the one we found in our study. Land slope may have an impact on soil and some climate features as well as humidity economy of habitats. Thus, trees at higher inclinations may have different feeding pattern compared to those at lower inclinations. This might lead to some differences in the chemical properties of barks.

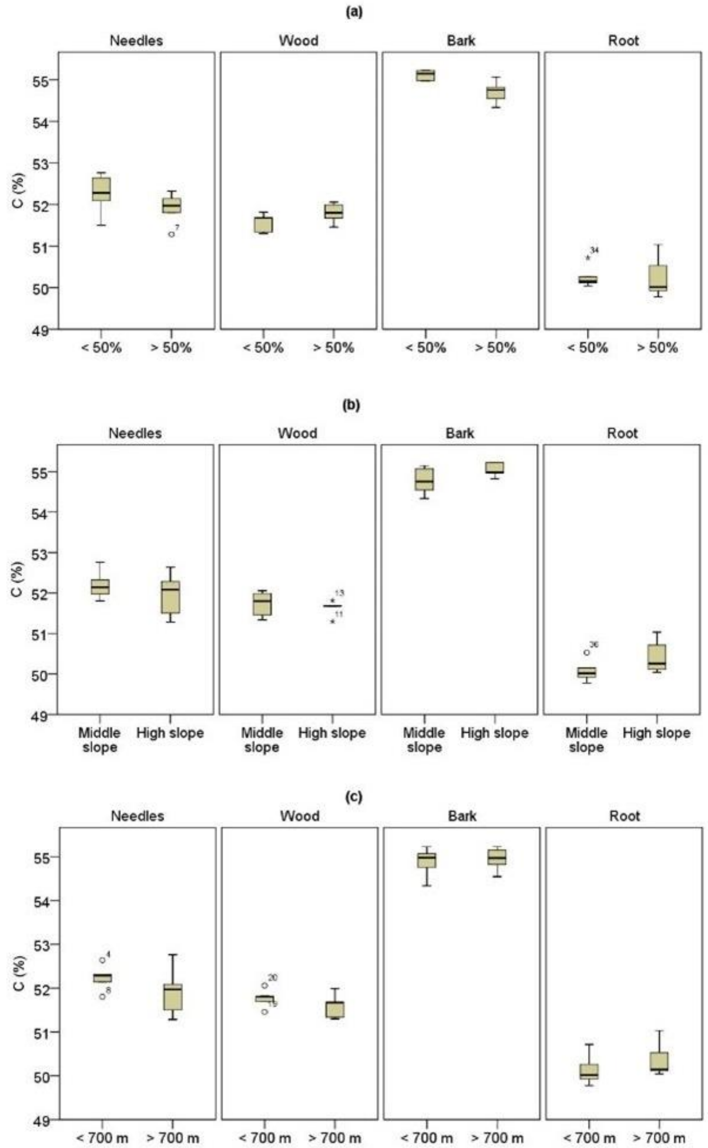

Figure 1. Changes in carbon concentration of tree components according to a) inclination groups, b) slope positions and c) elevation groups

Conclusions

In this study, it was determined that the carbon concentration of tree components in Calabrian pine forests showed significant differences and varied between 50.25% and 54.90%. Weighted carbon concentration was found as 52.07% for whole tree biomass and 51.77% for above-ground biomass. As a result, to make a more reliable carbon inventory for Calabrian pine ecosystems, carbon concentrations based on biomass components ratios of the tree and revealed in this study can be used.

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Ethics Committee Approval

N/A

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Author Contributions

Conceptualization: Ş.T.G., A.Ç.; Investigation: Ş.T.G., A.Ç.; Material and Methodology: Ş.T.G., A.Ç.; Supervision: Ş.T.G., A.Ç.; Visualization: Ş.T.G., A.Ç.; Writing-Original Draft: Ş.T.G., Writing-review & Editing: Ş.T.G., A.Ç.; Other: All authors have read and agreed to the published version of manuscript.

Conflict of Interest

The authors have no conflicts of interest to declare.

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