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The Overall Effect of Research Years, Rootstocks, and Cultivars on the Morphological Characteristics of Pear Trees

Armut Ağaçlarının Morfolojik Özellikleri Üzerine Araştırma Yıllarının, Anaçların ve Çeşitlerin Genel Etkisi

Zaki Ahmad FAIZI[1], Ahmet ÖZTÜRK[2]

[1]Department of Horticulture, Faculty of Agriculture, Ondukuz Mayis University, Kurupelit, Samsun · **zaky.faizi1369@gmail.com** · ORCID > 0000-0002-1429-6493

[2]Department of Horticulture, Faculty of Agriculture, Ondukuz Mayis University, Kurupelit, Samsun · **ozturka@omu.edu.tr** · ORCID > 0000-0002-8800-1248

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Sorumlu Yazar/Corresponding Author: Ahmet ÖZTÜRK

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THE OVERALL EFFECT OF RESEARCH YEARS, ROOTSTOCKS, AND CULTIVARS ON THE MORPHOLOGICAL CHARACTERISTICS OF PEAR TREES

ABSTRACT

This research was conducted to determine the combined effect of 3 factors, including rootstocks, cultivars, and research years, on the morphological characteristics in Samsun/Türkiye ecological conditions in 2021 and 2022 years. Eight rootstocks consisting of quince BA29 (BA29), quince A (QA), FOX9, FOX11, OHxF333, OHxF87, FAROLD40, and European pear seedlings were used in the study, while the 3 standard pear cultivars were 'Santa Maria', 'Williams', and 'Deveci'. The study results revealed the significance of the combined factors on all leaf characteristics of European pear. The rootstock diameter, scion diameter, tree height, and trunk cross-sectional area showed insignificant variations. It was determined that the canopy characteristics of the 'Williams'/FAROLD40 and 'Williams'/OHxF333 scion/rootstock combinations in 2022 were higher than other combinations, while the same combination was obtained with lower values in the case of other morphological characteristics. Generally, all the morphological attributes were obtained higher in the rootstocks/cultivars combination in 2022. In conclusion, the genetic capacity of rootstocks, cultivars, and variations of the climate situations in two consequent research years, resulted in variations in the morphological attributes of pear trees.

Keywords: European Pear, Rootstock, Vegetative Growth, *Pyrus communis*.

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ARMUT AĞAÇLARININ MORFOLOJİK ÖZELLİKLERİ ÜZERİNE ARAŞTIRMA YILLARININ, ANAÇLARIN VE ÇEŞİTLERİN GENEL ETKİSİ

ÖZ

Bu araştırma, 2021 ve 2022 araştırma yıllarında Samsun/Türkiye ekolojik koşullarında armut ağaçlarının morfolojik özellikleri üzerine anaç, çeşit ve araştırma yılları olmak üzere 3 faktörün birleşik etkisini belirlemek amacıyla yapılmıştır. Araştırmada BA29 (BA29), Ayva A (QA), FOX9, FOX11, OHxF333, OHxF87, FAROLD40 ve Avrupa armut çöğürü olmak üzere sekiz anaç; 'Santa Maria', 'Williams' ve 'Deveci' olmak üzere 3 standart armut çeşidi kullanılmıştır. Çalışma sonuçları, birleşik faktörlerin Avrupa armudunun tüm yaprak özellikleri üzerindeki önemini ortaya koymuştur. Anaç çapı, kalem çapı, ağaç boyu ve gövde kesit alanı ba-

kımından ise önemsiz farklılıklar göstermiştir. 2022 araştırma yılında 'Williams'/FAROLD40 ve 'Williams'/OHxF333 kombinasyonlarında taç özelliklerinin diğer kombinasyonlardan daha yüksek olduğu, diğer morfolojik özelliklerde ise aynı kombinasyonlarda daha düşük değerler elde edildiği belirlenmiştir. Genel olarak 2022 araştırma yılında anaç/çeşit kombinasyonunda tüm morfolojik özellikler daha yüksek elde edilmiştir. Sonuç olarak, anaçların ve çeşitlerin genetik kapasitesi ile birbirini takip eden iki araştırma yılındaki iklim koşullarındaki değişiklikler armut ağaçlarının morfolojik özelliklerinde farklılıklara neden olmuştur.

Anahtar Kelimeler: Avrupa Armudu, Anaç, Vejetatif Gelişme, *Pyrus communis.*

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1. INTRODUCTION

Pear (*Pyrus communis* L.) is one of the most common and well-known pome fruits in terms of fruit-growing techniques (Orman, 2005). Pears require 200-300 chilling hours in subtropical regions, while temperate areas at low to high latitudes (between 600-2700 m above sea level) need 500-1500 chilling hours (Kumar et al., 2023). Late spring frosts can limit cultivation and optimum production because its flowers are damaged at -2.2°C, and small fruits are damaged at 1.1°C (Kurt et al., 2022a). Along with pear rootstocks, quince dwarf rootstocks are desired to establish modernized pear orchards (Bolat and Ikinci, 2019; Kurt et al., 2022b). Rootstocks are widely used in fruit cultivation for various reasons, including their climate adaptation, soil qualities, impact on quality and yield, and tolerance to biotic stresses (Corso and Bonghi, 2014). According to research by Pasa et al. (2015) and Hepaksoy (2019), optimal planting density, proper rootstock choice, and adequate ecology contribute significantly to fruit trees' perfect vegetative and generative performances. The *Pyrus* genus mostly includes species of mid-sized trees, some shrubs, and various woody plants. The *Pyrus* genus trees have straight stems that are deeply rooted in the soil. The leaves are simple, alternately orientated, and vary in length from 2 to 12 cm and width from 3 to 5 cm. The petioles are stipulate and have whole or serrated limb margins. Even though most species are deciduous, a few Southeast Asian species have evergreen leaves. Some species have silvery, thick tomentose leaves, while others have glossy green foliage (Simionca et al., 2023). The vigor of pear trees is an outcome of heritability, biological versatility, adaptation, or favorable responses within the ecological conditions of the study area. For highly-density planting pear orchards and the availability of the cultural resources, dwarf trees are ideal. Nevertheless, trees with vigorous growth are ideal if the aim is to produce pears in drought conditions with less management resources, wood production, as ornaments for providing shade and shelter, construction, and furniture (Ozturk and Faizi, 2023; Simionca et al., 2023). Some selections of wild pears

species have a recognized ornamental value due to rapid growth, the varied range of shapes and sizes, rusticity, low demands on the soil, ability to thrive in different climates, having attractive foliage and flowers (Yamada et al., 2015). Huge canopy spread results in substantial costs for management procedures like pruning. Therefore, cultivars of pears like 'Hardy', 'Flemish Beauty', 'Anjou', and 'Comice' with less vegetative growth are perfect for reducing such expenditures (Kul et al., 2022). The using of the vigorous rootstocks and cultivars is one of the leading low yield causes in pear orchards (Pasa et al., 2017). For control the pear cultivars' vegetative growth potential, both *Pyrus* and *Cydonia* species are used as rootstock (Iglesias and Asin, 2011; North et al., 2015). However, *Pyrus* species as rootstock shows more vigorous growth than *Cydonia* (Kul et al., 2022). This research was conducted to determine the combined effects of 8 rootstocks (BA29, QA, FOX9, FOX11, OHxF333, OHxF87, FAROLD40, and European pear seedling), 3 cultivars ('Santa Maria', 'Williams', and 'Deveci') and 2 consecutive research years (2021 and 2022) on the morphological characteristics under the ecological conditions of Bafra district of Samsun province of Türkiye.

2. MATERIAL AND METHOD

2.1. Materials

In the study 'Santa Maria', 'Williams' and 'Deveci' cultivars were grafted on eight different rootstocks, including two Quince clonal rootstocks (BA29 and QA), five pear clonal rootstocks (FOX9, FOX11, OHxF333, OHxF87, and FAROLD40), and European pear seedling rootstocks were used as plant materials in the 2021 and 2022 years.

2.1.1. Experiment Area Properties

The soil of the orchard in which the study was performed included 2.73-10% clay (low), 13.21-20% silt (medium), 6.5-20% sand (moderate), pH 7.5 (slightly alkaline), 0.2-0.3 dS m^{-1} salt (no salt), 0.3-0.5 organic matter (low), 3-6% $CaCO_3$ (low), 0.03-0.06% N (low), 5-10 ppm P (moderate), with a soil depth of more than 1 meter. The climate situations of the study area, including temperature (max, min, and average in °C), relative humidity (%), and monthly total precipitation (mm) values, are presented in Table 1.

Table 1. Temperature, relative humidity, and monthly total precipitation of the study area in 2021 and 2022.

Months	Temperature (°C)			Relative Humidity (%)			Precipitation (mm)
	Max.	Min.	Avg.	Max.	Min.	Avg.	
				2021			
Jan.	13.1	6.5	9.2	90.8	35.0	63.7	68.0
Feb.	11.7	4.6	7.8	91.0	38.6	64.5	23.2
Mar.	11.4	4.0	7.1	85.5	48.2	73.3	90.8
Apr.	16.5	8.0	11.5	87.4	54.6	77.7	59.2
May	21.2	12.3	16.4	83.5	54.5	69.6	70.0
Jun	24.9	16.9	20.7	88.7	59.3	74.3	80.4
Jul.	28.9	21.3	25.0	83.0	59.0	71.4	6.0
Aug.	27.7	20.4	23.8	83.2	65.7	72.3	86.4
Sep.	22.0	15.2	18.1	83.0	51.3	70.0	117.8
Oct.	19.0	12.2	15.0	85.0	55.0	76.1	110.4
Nov.	16.5	9.3	12.2	87.6	57.3	72.9	68.6
Dec.	13.8	8.1	10.6	88.7	45.3	65.4	52.6
Mean	**18.9**	**11.6**	**14.8**	**86.5**	**52.0**	**70.9**	**69.5**
				2022			
Jan.	8.1	3.0	5.4	93.9	62.1	81.0	164.2
Feb.	12.1	5.4	8.2	95.1	63.3	82.2	61.0
Mar.	8.6	1.6	4.5	97.0	45.2	72.1	115.4
Apr.	21.2	7.5	13.3	92.4	46.7	71.3	39.8
May	25.5	9.3	16.8	95.8	44.0	70.9	44.8
Jun	32.4	16.2	22.8	95.9	44.1	74.0	73.4
Jul.	33.8	16.7	24.3	93.9	40.9	69.4	4.6
Aug.	35.5	19.7	26.4	96.2	45.5	75.1	5.2
Sep.	31.2	15.0	21.9	95.6	40.8	71.8	29.4
Oct.	24.9	11.2	16.5	97.1	52.6	80.4	69.6
Nov.	22.2	8.3	13.9	95.5	49.1	78.4	71.2
Dec.	15.8	8.3	13.8	93.2	62.8	80.6	51.8
Mean	**22.6**	**10.2**	**15.7**	**95.1**	**49.8**	**75.6**	**60.9**

2.2. Methods

The experiment was done in the pear orchard at the Bafra agricultural research field of Ondokuz Mayis University, situated in the Bafra district of the province of Samsun. The orchard was established in 2018 with 1-year-old saplings at a spacing of 1.5 x 3.5 m for quince rootstocks and 3.0 x 3.5 m for pear rootstocks. The plants were irrigated using drip irrigation from May 15 to September 15. Using 15-30-15 + ME fertilizer at the start of the summer and 20-20-20 NPK fertilizer in the fall, drip irrigation was used for fertilization. A rotavator was frequently used to eliminate weeds from between the rows while the earth was mulched on the row.

2.1.1. Morphological Observations

Morphological attributes including rootstock diameter (mm), cultivar diameter (mm), tree height (cm), canopy width (cm), canopy length (cm), canopy height (cm), canopy volume (m^3), trunk cross-sectional area (cm^2), leaf width (cm), leaf length (cm), leaf stalk length (cm), leaf stalk thickness (mm), leaf area (cm^2) and annual shoot length (cm) were evaluated according to previous researches (Ozturk and Ozturk, 2014; Kurt et al., 2022a).

2.1.2. Statistical Analysis

Factorial randomized complete block design (FRCBD) was used as the design of our study. Three factors of data, including cultivars (3 cultivars), rootstocks (8 rootstocks), and years (2 years), were combined and used for analysis. Three replications and 5 plants in each repetition were used in the research. The obtained data were analyzed in the statistical package program of IBM SPSS 21.0. Means differences were determined according to Duncan Multiple Comparison Test with 95% of confidence and 5% ($\alpha = 0.05$) probability error due to unknown situations.

3. RESULTS AND DISCUSSION

3.1. Leaf Characteristics

The combined effect of the research years, rootstocks, and cultivars on the leaf stalk length (LSL), leaf stalk thickness (LST), leaf length (LL), leaf width (LW), and leaf area (LA) of pear cultivars grafted on different quince and pear rootstocks are given in Table 2. Leaf characteristics were all obtained as statistically significant ($p<0.05$). The LSL was recorded between 1.75-4.54 cm. The highest (4.54 cm) LSL in the 'Deveci'/FAROLD40 combination in 2022 and the lowest (1.75 cm) LSL in the 'Williams'/seedling combination in 2021. The LST varied from 1.49 mm ('Santa Mari'/FAROLD40 in 2021) to 0.65 mm ('Santa Mari'/FAROLD40 in 2022). The LA was obtained between 7.60-25.91 cm^2. The highest LL was determined in the 'Santa Maria'/FOX9 (7.62 cm) in 2022 and the lowest in the 'Williams'/Seedling (3.88 cm) in 2021. The highest LW was observed from 'Santa Maria'/OHxF333 (7.42 cm) in 2022 and the lowest in the 'Deveci'/Seedling (2.31 cm) in 2021. The highest LA in the 'Santa Maria'/OHxF333 combination in 2022 (25.91 cm^2) and the lowest LA in the 'Williams'/Seedling combination in 2021 (7.60 cm^2) (Table 2).

The leaf stalk length of 'Deveci' pear was significantly affected by rootstocks (Ozturk and Ozturk, 2014). They recorded the LSL of 'Deveci' between 33.5-44.3 mm, the highest LSL on BA29 (44.3 mm) and the lowest on pear seedlings (33.5 mm). Coban and Ozturk (2020) determined that rootstocks, cultivars, and their interactions had a significant effect on the LSL; they acquired LSL between 22.5-37.6 mm in the rootstocks and 29.3-35.7 mm in the cultivars. Our study findings partially differ from the findings of previous researchers. Differences could be due to the specific growing conditions, rootstocks, and cultivars.

Leaf stalk thickness was significantly affected by rootstock, cultivar, and their interactions, as reported by Ozturk and Ozturk (2014), the LST of 'Deveci' pear was reported from 0.58-0.76 mm, the highest (0.76 mm) was in BA29 rootstock, while the lowest (0.58 mm) in the EMC rootstock. Similarly significant effect of pear rootstocks, cultivars, and rootstock x cultivar combinations on LST was

reported by Coban and Ozturk (2020). Also Coban and Ozturk (2020) found LST between 0.97-1.27 mm in rootstocks and 1.06-1.16 mm in the cultivars; they noted the highest in the FOX11 (1.27 mm), while the lowest was in the seedling (0.97 mm) and OHxF333 (1.04 mm) rootstocks. Our research findings revealed no significant results among the cultivars, rootstocks, and their combined effect, except for research years.

Table 2. Combined effects of different rootstocks, cultivars, and research years on the leaf characteristics of European pear

Years	Rootstocks	Cultivars	LSL (cm) †	LST (mm)	LL (cm)	LW (cm)	LA (cm^2)
2021	BA29	Santa Maria	3.44 e-l	1.05 a-h	6.36 f-j	4.44 bcd	20.54 d-h*
		Williams	2.65 qrs	1.05 a-h	5.42 pqr	3.60 i-o	13.98 n-s
		Deveci	3.94 b-e	0.88 d-h	6.07 h-n	3.07 qr	13.45 p-u
	Quince A	Santa Maria	3.27 h-n	1.02 a-h	6.10 g-n	3.92 e-i	17.39 h-m
		Williams	2.51 rst	1.02 a-h	5.37 pqr	3.35 k-q	13.05 p-u
		Deveci	3.23 i-p	1.46 ab	5.42 pqr	2.45 st	9.65 vwx
	FOX9	Santa Maria	3.48 e-l	0.71 e-h	5.87 j-p	3.47 j-q	14.72 m-q
		Williams	2.30 st	1.10 a-h	4.94 rs	3.44 j-q	12.28 q-v
		Deveci	3.00 l-r	0.84 d-h	5.58 n-q	2.58 st	10.36 u-x
	FOX11	Santa Maria	3.88 b-f	1.11 a-h	6.29 g-k	4.05 d-h	18.42 hij
		Williams	2.76 n-s	0.76 e-h	5.35 pqr	3.63 i-n	14.13 n-r
		Deveci	3.59 d-k	0.70 gh	6.02 i-o	2.53 st	10.93 s-w
	OHxF333	Santa Maria	3.42 e-l	1.04 a-h	5.63 m-q	3.72 g-l	15.27 k-q
		Williams	3.70 c-j	1.13 a-h	6.50 d-i	3.90 e-i	18.52 hij
		Deveci	3.76 c-i	0.91 c-h	6.33 f-k	3.08 qr	13.84 o-t
	OHxF87	Santa Maria	2.57 q-t	1.32 a-d	6.24 g-k	3.75 g-k	18.05 h-l
		Williams	2.12 tu	1.00 a-h	4.56 s	3.14 pq	10.49 u-x
		Deveci	2.59 q-t	0.92 b-h	5.46 o-r	2.68 st	10.87 s-w
	FAROLD40	Santa Maria	3.38 f-l	1.49 a	5.68 l-q	2.62 st	10.75 t-w
		Williams	3.29 h-m	1.01 a-h	5.59 n-q	3.57 i-o	14.42 m-r
		Deveci	3.43 e-l	0.87 d-h	5.76 k-o	2.76 rs	11.43 r-v
	Seedling	Santa Maria	4.07 a-d	1.02 a-h	6.62 d-h	3.85 g-j	18.34 h-k
		Williams	1.75 u	0.92 b-h	3.88 t	2.66 st	7.60 x
		Deveci	2.38 st	0.80 d-h	4.89 rs	2.31 t	8.21 wx
2022	BA29	Santa Maria	3.88 b-f	1.28 a-e	7.00 b-e	4.29 b-e	21.67 c-g
		Williams	2.54 rst	1.02 a-h	5.63 m-q	3.55 i-p	14.37 m-r
		Deveci	4.22 abc	1.12 a-h	6.52 e-i	3.21 opq	15.08 l-q
	Quince A	Santa Maria	4.05 bcd	1.08 a-h	7.37 ab	4.49 abc	24.11 abc
		Williams	2.71 p-s	1.10 a-h	5.39 pqr	3.26 m-q	12.70 p-v
		Deveci	4.37 ab	0.93 b-h	6.60 e-i	3.23 n-q	15.23 k-q
	FOX9	Santa Maria	3.78 c-h	1.16 a-h	7.62 a	4.65 ab	25.52 ab
		Williams	2.76 n-s	1.04 a-h	5.22 qr	3.32 l-q	12.54 q-v
		Deveci	3.52 e-l	1.28 a-e	7.40 ab	3.69 h-l	19.92 e-i
	FOX11	Santa Maria	3.40 e-l	0.99 a-h	7.16 a-d	4.56 ab	23.48 a-d
		Williams	2.08 tu	1.25 a-g	6.35 f-j	3.71 g-l	16.96 i-o
		Deveci	3.62 d-j	1.10 a-h	6.99 b-e	3.65 h-m	18.44 hij
	OHxF333	Santa Maria	3.33 g-l	1.45 abc	7.42 ab	4.86 a	25.91 a
		Williams	2.81 m-s	1.14 a-h	6.17 g-m	3.53 i-p	15.79 j-p
		Deveci	3.79 c-h	1.05 a-h	7.23 abc	3.80 g-j	19.79 f-i
	OHxF87	Santa Maria	3.20 j-p	1.11 a-h	6.35 f-j	4.11 c-g	18.86 g-j
		Williams	2.30 st	1.16 a-h	6.48 e-i	3.67 h-m	17.14 j-n
		Deveci	2.81 m-s	1.20 a-h	6.46 e-i	3.14 pq	14.76 m-q
	FAROLD40	Santa Maria	3.25 i-o	0.65 h	7.17 a-d	4.27 b-f	22.32 b-e
		Williams	2.74 o-s	1.35 a-d	6.69 c-g	3.90 e-i	18.79 g-j
		Deveci	4.54 a	1.13 a-h	7.35 ab	3.58 i-o	18.94 g-j
	Seedling	Santa Maria	3.07 k-q	1.27 a-e	7.22 abc	4.36 bcd	22.81 b-e
		Williams	2.67 qrs	1.26 a-g	6.48 e-i	3.73 g-l	17.40 h-m
		Deveci	3.83 c-g	1.16 a-h	6.89 b-f	3.58 i-o	17.92 h-l
Significance (P< 0.05)			**0.001**	**0.006**	**0.001**	**0.001**	**0.001**
Mean standard errors			**0.158**	**0.155**	**0.174**	**0.123**	**0.947**

*: Means with different letters in the same column are significant.
†: Leaf stalk length (LSL), Leaf stalk thickness (LST), Leaf length (LL), Leaf width (LW), Leaf area (LA).

The leaf length of the pear varied significantly in terms of rootstock and cultivars, as stated by Serttaş (2019) reported that the LL was between 59.0-65.2 mm in the case of different rootstocks. He acquired the highest (65.5 mm) LL from 'Santa Maria' and the lowest from 'Williams' and 'Abate Fetel' respectively, 61.7 mm and 61.5 mm. Ozturk and Ozturk (2014) was found to have the highest LL in the 'Deveci'/BA29 combination. Our results revealed the highest LL in the 'Santa Maria' on different rootstocks. Kılıc (2015) found LL between 32.00-60.18 mm in consideration of different genotypes of pear. Coban and Ozturk (2020) stated that rootstocks and cultivars significantly affected the LL in 'Deveci' and 'Williams' pear cultivars grafted on quince and pear clonal rootstocks. They noted that the LL was 6.67-6.88 cm in the rootstock averages and 6.42-7.23 in the cultivars. When our research findings are compared with previous studies, it is clarified that the LL is approximately parallel with them.

Ozturk and Ozturk (2014) determined the significant impact of the rootstocks on the leaf sizes of the 'Deveci' cultivar; they reported that LW was the highest in trees grafted on BA29 rootstock. Kılıc (2015) said that LW differed between pear genotypes in the 28.99-48.34 mm range. Similar to our findings, significant effects of cultivars, rootstocks, and rootstock x cultivar combinations were recorded by Çoban (2019) and Coban and Ozturk (2020) between 36-37 mm in cultivars and 35-38 mm in the rootstocks. Serttas and Ozturk (2020) reported the highest LW in 'Deveci' and 'Santa Maria' (3.75 cm and 3.44 cm) and the lowest (3.40 cm and 3.34 cm) in 'Abate Fetel' and 'Williams' cultivars. The variations in the results were due to genetic and environmental factors.

Leaf area is an important morphological characteristic in the determination of the canopy volume efficiency for an ideal quantity and quality production (Zhang et al., 2016). Additionally, they noted that the LA of 'Santa Maria' was 23.82 cm^2 while grafted on BA29. The LA is a significant factor for understanding the status of trees' evaporation, metabolism, photosynthesis, light reception, water, fertilizer utilization, blooming, setting of fruit, and productivity (Ozturk et al., 2019). The leaf area of the 'Deveci' grafted on BA29 was higher than that of the other rootstocks, according to earlier studies that claimed that the rootstocks had a substantial impact on the LA (Ozturk and Ozturk, 2014). Engin (2011) obtained the LA between 15.72-23.78 cm^2 in 'Santa Maria'/QA, and 17.07-21.61 cm^2 in the 'Santa Maria'/OHxF333 combinations.

Leaf characteristics of pear trees were acquired as the following while considering different rootstocks and cultivars respectively, petiole length of 19.26 MC to 30.74 mm QA, 22.34 'Williams' to 28.50 mm 'Deveci'; petiole thickness of 0.71 MC to 0.80 mm BA29, 0.74 'Deveci' to 0.79 mm 'Abate Fetel'; leaf length of 37.41 MC to 47.93 mm QA, 35.56 'Williams' to 49.20 mm 'Santa Maria'; leaf

width of 21.06 MC to 29.41 mm QA, 23.98 'Abate Fetel' to 28.81 mm 'Santa Maria'; leaf area of 5.70 MC to 9.87 cm^2 QA, 6.24 'Williams' to 10.80 cm^2 'Santa Maria' (Kurt et al., 2022a).

3.2. Rootstock and Scion Diameter, Tree Length, and Trunk Cross-Sectional Area

The combined effects of three factors (research years, rootstocks, cultivars) on rootstock diameter (RD), scion diameter (SD), tree length (TL), and trunk cross-sectional area (TCSA) of pear trees are illustrated in Table 3. All the attributes mentioned above were found to be statistically insignificant. The RD obtained between 22.89-78.62 mm, SD varied from 19.0-76.16 mm, TL observed between 123.22-302.0 cm, and TCSA ranged from 2.88-45.70 cm^2 (Table 3).

In our study, we observed the lower rootstock diameter than the scion diameter in the case of all quince rootstocks and pear cultivars combinations (Figure 1, Figure 2 and Figure 3), while the cultivars grafted on the seedling rootstocks, higher rootstock diameter, was obviously observed than the scion diameter. Francescatto et al. (2010) reported the lowest rootstock diameter in EMC rootstock in the 'Packhams'/EMC combination, while the cultivar was grafted on 7 different rootstocks. Similarly, Ozturk and Ozturk (2014) reported that the highest RD was in the BA29 and the lowest in the MC rootstock. Likewise, a significant impact of rootstocks on RD was obtained by Giacobbo et al. (2010), Machado et al. (2016), and Rahman et al. (2017). Cetinbas et al. (2018) stated that the effect of rootstocks and cultivars on rootstock diameter was significant, while considering the cultivars effect, RD was obtained higher in 'Deveci' than 'Santa Maria'. In terms of rootstocks, they found higher values in the OHxF333, BA29, OHxF69, and QC rootstocks than the other evaluated ones. The RD of the 'Deveci' cultivar grafted on BA29, MC, and seedling rootstocks changed in various research years and rootstocks. The researcher reported the lowest values in the MC than other rootstocks (Ozturk, 2021).

Scion diameter values that we obtained are compatible with the studies previously performed (Ozturk and Ozturk, 2014; Machado et al., 2016; Mete, 2019; Ozturk, 2021). It was emphasized in similar studies that the effects of rootstocks on the SD were significant; the SD of the cultivars on vigorous rootstocks was observed higher than on the dwarfing rootstocks (Sugar and Basile, 2011; Dondini and Sansavini, 2012; Askari-Khorosgani et al., 2019).

Table 3. Combined effects of different rootstocks, cultivars, and research years on the rootstock diameter, scion diameter, tree length, and trunk cross-sectional area of European pear

Years	Rootstocks	Cultivars	RD (mm) †	SD (mm)	TL (cm)	TCSA (cm²)
2021	BA29	Santa Maria	42.73 a	39.89 a	249.39 a	12.50 a*
		Williams	34.71 a	32.34 a	202.86 a	4.41 a
		Deveci	53.27 a	52.04 a	236.94 a	21.56 a
	Quince A	Santa Maria	42.35 a	42.33 a	247.87 a	14.26 a
		Williams	27.54 a	26.02 a	154.39 a	5.34 a
		Deveci	47.96 a	49.82 a	246.92 a	19.57 a
	FOX9	Santa Maria	24.13 a	21.24 a	138.37 a	3.55 a
		Williams	22.89 a	19.00 a	123.22 a	2.88 a
		Deveci	27.78 a	25.17 a	150.78 a	4.98 a
	FOX11	Santa Maria	48.13 a	45.33 a	266.87 a	16.19 a
		Williams	53.86 a	48.69 a	272.31 a	18.66 a
		Deveci	54.75 a	51.46 a	262.46 a	21.90 a
	OHxF333	Santa Maria	45.87 a	40.13 a	218.97 a	12.71 a
		Williams	48.72 a	46.97 a	277.97 a	18.92 a
		Deveci	62.47 a	60.67 a	289.14 a	29.66 a
	OHxF87	Santa Maria	31.22 a	27.02 a	183.82 a	5.73 a
		Williams	34.74 a	27.23 a	179.19 a	5.85 a
		Deveci	28.91 a	22.24 a	146.51 a	3.89 a
	FAROLD40	Santa Maria	46.28 a	43.44 a	227.45 a	14.82 a
		Williams	53.44 a	47.65 a	286.40 a	17.82 a
		Deveci	58.46 a	52.26 a	293.04 a	21.82 a
	Seedling	Santa Maria	47.83 a	37.83 a	277.54 a	11.27 a
		Williams	40.11 a	31.50 a	203.04 a	7.93 a
		Deveci	47.76 a	39.21 a	217.72 a	12.36 a
2022	BA29	Santa Maria	48.10 a	44.90 a	236.05 a	15.87 a
		Williams	35.03 a	35.75 a	204.00 a	10.37 a
		Deveci	56.63 a	56.16 a	242.85 a	24.89 a
	Quince A	Santa Maria	52.37 a	50.51 a	284.72 a	20.36 a
		Williams	28.89 a	27.97 a	158.26 a	6.16 a
		Deveci	60.33 a	59.34 a	261.50 a	27.73 a
	FOX9	Santa Maria	34.61 a	31.27 a	186.17 a	7.78 a
		Williams	30.20 a	29.88 a	182.13 a	7.01 a
		Deveci	39.40 a	34.24 a	181.11 a	9.37 a
	FOX11	Santa Maria	52.02 a	49.37 a	240.52 a	19.26 a
		Williams	61.91 a	55.89 a	282.06 a	24.53 a
		Deveci	77.14 a	74.59 a	296.54 a	43.79 a
	OHxF333	Santa Maria	55.04 a	52.17 a	230.64 a	21.39 a
		Williams	66.68 a	67.25 a	302.00 a	35.50 a
		Deveci	77.79 a	76.16 a	299.27 a	45.70 a
	OHxF87	Santa Maria	37.03 a	32.83 a	185.76 a	8.58 a
		Williams	42.36 a	37.13 a	202.49 a	10.94 a
		Deveci	38.08 a	33.49 a	164.28 a	8.86 a
	FAROLD40	Santa Maria	53.99 a	51.19 a	264.00 a	20.57 a
		Williams	63.87 a	58.48 a	273.38 a	26.87 a
		Deveci	78.62 a	72.37 a	298.99 a	41.32 a
	Seedling	Santa Maria	59.46 a	48.22 a	243.38 a	18.29 a
		Williams	48.67 a	44.37 a	212.08 a	15.74 a
		Deveci	58.23 a	52.94 a	209.50 a	22.66 a
Significance (P< 0.05)			**0.644**	**0.638**	**0.772**	**0.289**
Mean standard errors			**3.412**	**3.368**	**16.565**	**2.685**

*: Means with similar letters in the same column are insignificantly different.
†: Rootstock diameter (RD), Scion diameter (SD), Tree length (TL), Trunk cross-sectional area (TCSA).

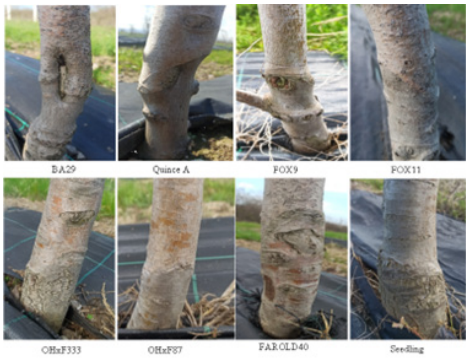

Figure 1. Diameter illustration of the 'Santa Maria' pear cultivar on eight different rootstocks in 2022

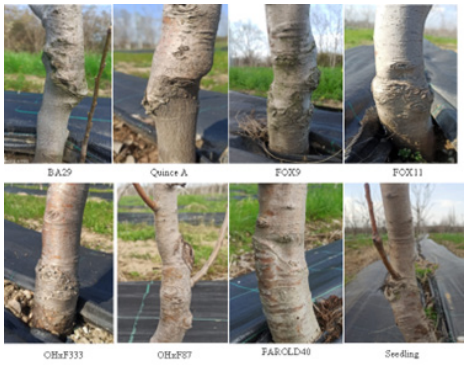

Figure 2. Diameter illustration of 'Williams' pear cultivar on eight different rootstocks in 2022.

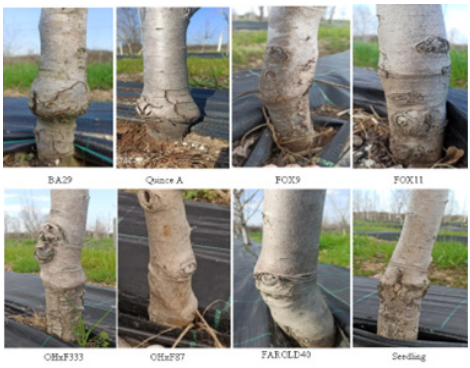

Figure 3. Diameter illustration of 'Deveci' pear cultivar on eight different rootstocks in 2022.

Tree length was reported by the rootstocks and cultivars (Giacobbo et al., 2010; Lepsis and Duredze, 2011; Dondini and Sansavini, 2012). The highest TL of 'Abate Fetel' and 'Conference' cultivars were observed on pear seedlings than on the BA29 and MA rootstocks (Castro and Rodriguez, 2002). In our study, we observed the highest TL in the FAROLD40, FOX11, and OHxF333 rootstocks, respectively. This difference with the previously mentioned study could be due to the slow growth of seedling rootstocks at the early ages as compared to clonal rootstocks of pear. In the case of quince clonal rootstocks, there were no statistically significant differences between them (BA29 and QA), with similar results among QA, QC, Sydo, BA29, Pyrus communis seedlings rootstocks reported by Kviklys and Kvikliene (2004). The TL was acquired 159 cm in 'Williams' pear cultivar and 225 cm in 'Deveci' cultivar while grafted on QA rootstock (Akcay et al., 2009). Similar differences among the cultivars were observed in our study. Considering the performance of 'Seleta' cultivar on quince rootstocks (Adams, EMC, and Portugal) and Pyrus calleryana pear seedlings, Giacobbo et al. (2018) stated that all quince rootstocks reduced the cultivars' TL by 60% compared to pear seedling rootstock (Pyrus calleryana). The highest TL of the 'Deveci' cultivar was recorded on the BA29 rootstock and the lowest on the MC rootstock (Ozturk, 2021). There were significant differences in TL considering different research years. It can be said that differences were due to the age of the trees (Gercekcioglu et al., 2014). Our research revealed that the trunk cross-sectional area differs regarding research years, cultivars, and rootstocks. Similar findings were reported by (Iglesias and Asin, 2011; Sugar and Basile, 2011; Leipsis and Drudze, 2011; Ozturk and Ozturk, 2014; Mete, 2019; Ozturk, 2021; Kücüker and Aglar, 2021; Jovanovic et al. 2022).

In a study that evaluated the effect of different rootstocks and cultivars on morphological characteristics, the findings respected to the rootstocks reported as the following: rootstock diameter of 30.20 mm MC to 38.98 BA29; stem diameter of 25.98 MC to 33.30 BA29 mm; tree length of 153.93 MC to 184.18 cm BA29; trunk cross-sectional area of 6.88 MC to 10.71 cm^2 BA29; canopy volume of 0.20 QA to 0.29 m^3 BA29. While in the case of cultivars respectively reported 25.18 mm 'Williams' to 41.75 'Deveci'; 21.58 'Santa Maria' to 33.39 mm 'Deveci'; 142.73 'Williams' to 191.34 cm 'Santa Maria'; 4.79 'Williams' to 11.56 cm^2 'Deveci'; 0.12 'Williams' to 0.36 m^3 'Santa Maria' by Kurt et al. (2022a).

3.3. Canopy Characteristics

Canopy characteristics of European pear, considering the combined effects of three different factors are given in Table 4. The canopy width (CW) and canopy volume (CV) were observed as significant, while canopy length (CL) and canopy height (CH) were acquired as statistically insignificant. The CW was in the 35.22-199.0 cm range, the highest (199.0 cm) CW observed in the 'Williams'/OHxF333 interaction in the research year of 2022, and the lowest (35.22 cm) in the 'Williams'/

FOX9 combination in the research year of 2021 (Table 4). The CV varied between 0.05-4.19 m^3, the highest (4.19 m^3) CV observed in the 'Williams'/OHxF333 combination in the research year of 2022, and the lowest (0.05 m^3) in the 'Williams'/FOX9 combination in the research year of 2021 (Table 4).

Table 4. Combined effects of different rootstocks, cultivars, and research years on the canopy attributes of European pear

Years	Rootstocks	Cultivars	CW (cm) †	CL (cm)	CH (cm)	CV (m^3)
2021	BA29	Santa Maria	136.35 d-j	122.72 a	201.78 a	1.47 d-l*
		Williams	113.09 g-n	96.97 a	149.88 a	0.93 i-r
		Deveci	140.46 d-j	123.57 a	200.29 a	1.56 d-k
	Quince A	Santa Maria	138.24 d-j	127.82 a	201.43 a	1.64 d-j
		Williams	88.30 m-q	71.34 a	123.43 a	0.41 l-r
		Deveci	115.85 g-n	103.14 a	210.38 a	1.11 h-r
	FOX9	Santa Maria	40.77 st	38.29 a	114.19 a	0.08 qr
		Williams	35.22 t	35.45 a	97.11 a	0.05 r
		Deveci	42.94 st	57.44 a	118.33 a	0.10 pqr
	FOX11	Santa Maria	125.40 d-m	126.13 a	248.67 a	1.57 d-k
		Williams	122.23 e-m	114.50 a	231.43 a	1.37 d-m
		Deveci	109.44 i-n	108.63 a	225.31 a	1.29 g-n
	OHxF333	Santa Maria	109.71 h-n	111.96 a	177.72 a	0.86 j-r
		Williams	99.53 j-p	117.22 a	241.17 a	1.12 h-r
		Deveci	138.06 d-j	130.83 a	251.61 a	1.95 d-i
	OHxF87	Santa Maria	57.12 q-t	54.30 a	148.97 a	0.19 o-r
		Williams	68.58 p-t	67.46 a	152.37 a	0.29 m-r
		Deveci	48.24 rst	49.61 a	124.72 a	0.11 pqr
	FAROLD40	Santa Maria	124.61 e-m	109.39 a	184.89 a	1.15 g-q
		Williams	113.47 g-n	120.99 a	256.94 a	1.34 d-m
		Deveci	112.34 g-n	119.66 a	258.49 a	1.30 g-n
	Seedling	Santa Maria	130.96 d-k	102.33 a	220.17 a	1.52 d-k
		Williams	77.96 n-s	89.35 a	174.54 a	0.44 l-r
		Deveci	92.31 k-q	97.21 a	170.55 a	0.64 j-r
2022	BA29	Santa Maria	146.33 c-i	130.86 a	194.98 a	1.69 d-j
		Williams	112.38 g-n	106.06 a	157.56 a	0.85 j-r
		Deveci	157.12 b-e	142.77 a	205.62 a	2.06 d-h
	Quince A	Santa Maria	150.70 b-h	142.01 a	243.57 a	2.22 c-g
		Williams	86.35 m-q	66.77 a	128.22 a	0.38 m-r
		Deveci	165.54 a-d	139.04 a	221.00 a	2.41 cde
	FOX9	Santa Maria	69.47 o-t	66.23 a	163.40 a	0.35 m-r
		Williams	54.75 q-t	51.38 a	155.25 a	0.18 o-r
		Deveci	89.22 l-q	79.56 a	141.00 a	0.50 l-r
	FOX11	Santa Maria	130.97 d-k	123.55 a	202.62 a	1.54 d-k
		Williams	156.39 b-f	157.08 a	242.61 a	2.38 c-f
		Deveci	153.36 b-g	157.17 a	259.33 a	2.43 cd
	OHxF333	Santa Maria	124.34 e-m	123.23 a	194.03 a	1.18 g-p
		Williams	199.00 a	206.00 a	269.50 a	4.19 a
		Deveci	179.63 abc	176.63 a	251.71 a	3.17 bc
	OHxF87	Santa Maria	77.68 n-s	67.21 a	156.98 a	0.40 l-r
		Williams	107.80 i-o	104.49 a	173.16 a	0.82 j-r
		Deveci	61.69 p-t	60.05 a	138.58 a	0.21 n-r
	FAROLD40	Santa Maria	114.33 g-n	104.33 a	223.89 a	1.17 g-q
		Williams	185.66 ab	162.52 a	244.93 a	3.41 ab
		Deveci	155.84 b-f	164.62 a	259.88 a	2.47 cd
	Seedling	Santa Maria	131.13 d-k	117.63 a	180.88 a	1.24 g-o
		Williams	108.08 i-o	94.67 a	182.08 a	0.88 i-r
		Deveci	129.33 d-l	112.36 a	175.79 a	1.26 g-n
Significance (P< 0.05)			**0.035**	**0.075**	**0.412**	**0.013**
Mean standard errors			**11.814**	**10.905**	**16.526**	**0.312**

*: Means with different letters in the same column are significant.
†: Canopy width (CW), Canopy length (CL), Canopy height (CH), Canopy volume (CV).

The findings of this study are consistent with earlier research; it was found that the research years, rootstocks, and cultivars had a significant impact on canopy volume (CV). (Stern and Doron, 2009; Hudina et al., 2014). Giocabbo (2010) stated that the rootstocks significantly affect the CV of cultivars. The CV of 'Deveci' grafted on QA was 0.20-0.76 m^3, and the 'Santa Maria' found 0.26-1.02 m^3 (Engin, 2011). According to Kaplan (2011), there was a statistically significant variation in CV across pear cultivars grafted on QA rootstock. He noted that 'B. Hardy' and 'B. P. Morettini' had the biggest and 'Williams' had the lowest CV. It was reported that the lowest CV of pear cv. 'Suvenirs' was observed while grafted on QA and QC rootstocks (Lepsis and Drudze, 2011). According to Ozturk and Ozturk (2014), the 'Deveci' pear cultivar's CV was larger on the BA29 rootstock than it was on the MC rootstock. According to Ozturk (2021), when comparing the performance of 'Deveci' pears on various rootstocks, BA29 had the largest (2.32 m^3) CV, and MC rootstock had the lowest (0.74 m^3) CV. The CV of 'Santa Maria' grafted on QA rootstock ranged between 0.71 and 2.0 m^3, and the 'Deveci' between 0.67 and 1.86 m^3 in the Tokat ecological conditions (Kücüker and Aglar, 2021).

3.4. Shoot Characteristics

The combined effects of three research factors on the annual shoot length (ASL), node numbers in the annual shoots (NNAS), and internode length in the annual shoots (ILAS) are given in Table 5. The ASL was statistically significant, but the NNAS and ILAS were insignificant. The ASL was in the 11.94-51.04 cm range. The longest (51.04 cm) ASL was determined in the 'Deveci'/FOX11 combination in 2022, and the shortest (11.94 cm) in the 'Williams'/seedling combination in 2021 (Table 5).

The ASL of pear cvs. 'Ankara', 'Akça', 'Williams', 'Santa Maria', and 'Deveci' in Bingöl ecological conditions were observed between 22.0-86.0 cm. The highest ASL was in 'Ankara', and the lowest was in the 'Santa Maria' cultivar (Osmanoglu et al., 2013). In the case of 'Abate Fetel' pear, the ASL was the highest on seedlings (82.0 cm) and the lowest on BA29 (4.6 cm) and MA (5.2 cm) rootstocks. In addition, they observed the highest (83.3 cm) ASL of the 'Conference' pear on the seedling and the shortest (2.6 cm) on the BA29 rootstock (Castro and Rodriguez, 2002). In case of different rootstocks x cultivars combinations, the ASL recorded between 26.0-44.56 cm in 'Deveci'/QA, 35.56-49.0 cm in 'Santa Maria'/QA, 22.89-46.44 cm in 'Deveci'/OHxF333, and 16.67-37.90 cm in the 'Santa Maria'/OHxF333 by Engin (2011). In the case of pear cv. 'Shahmiveh', the longest ASL was obtained from Konjoni and pear seedlings rootstocks, and the shortest from hawthorn seedling and QC rootstocks (Akbari et al., 2014). A study evaluated the effect of Champion, Melliforme, P. calleryana pear rootstock on the ASL of pear cv. 'Williams' by Pasa et al. (2020), it was found that the Champion had weaker growth than other rootstocks. In a study that evaluated the effect of different rootstocks and cultivars on

morphological characteristics, the annual shoot length of 26.88 (MC) to 45.09 cm (BA29), 31.99 'Deveci' to 42.79 cm 'Abate Fetel' were reported by Kurt et al. (2022a).

Table 5. Combined effects of different rootstocks, cultivars, and research years on the rootstock diameter, scion diameter, tree length, and trunk cross-sectional area of European pear.

Years	Rootstocks	Cultivars	ASL (cm) †	NNAS (pcs.)	ILAS (cm)
2021	BA29	Santa Maria	40.85 a-d*	11.96 a	3.43 a
		Williams	32.32 d-l	11.67 a	2.72 a
		Deveci	40.25 b-e	13.21 a	3.04 a
	Quince A	Santa Maria	34.36 c-i	11.37 a	3.03 a
		Williams	29.72 d-o	11.61 a	2.63 a
		Deveci	30.89 d-n	11.89 a	2.61 a
	FOX9	Santa Maria	18.93 o-u	10.67 a	1.79 a
		Williams	19.65 n-u	10.19 a	1.93 a
		Deveci	23.56 i-t	10.64 a	2.21 a
	FOX11	Santa Maria	38.21 c-f	13.31 a	2.89 a
		Williams	37.13 c-g	17.09 a	2.19 a
		Deveci	35.07 c-h	14.77 a	2.39 a
	OHxF333	Santa Maria	24.45 h-t	11.24 a	2.19 a
		Williams	21.15 l-u	10.35 a	2.05 a
		Deveci	31.73 d-l	14.51 a	2.18 a
	OHxF87	Santa Maria	28.44 f-p	17.09 a	1.69 a
		Williams	36.91 c-g	18.80 a	2.04 a
		Deveci	24.72 h-t	12.92 a	1.92 a
	FAROLD40	Santa Maria	20.07 m-u	12.81 a	1.60 a
		Williams	31.43 d-m	15.39 a	2.05 a
		Deveci	32.68 d-k	14.72 a	2.23 a
	Seedling	Santa Maria	26.59 g-s	9.90 a	2.69 a
		Williams	11.94 u	10.45 a	1.15 a
		Deveci	16.36 r-u	10.84 a	1.49 a
2022	BA29	Santa Maria	26.81 g-s	10.65 a	2.52 a
		Williams	15.94 stu	9.22 a	1.73 a
		Deveci	25.15 h-t	11.68 a	2.18 a
	Quince A	Santa Maria	30.75 d-n	11.32 a	2.74 a
		Williams	16.65 q-u	10.83 a	1.55 a
		Deveci	22.85 j-u	10.60 a	2.14 a
	FOX9	Santa Maria	21.40 k-u	11.92 a	1.84 a
		Williams	17.40 p-u	9.37 a	1.86 a
		Deveci	29.00 e-o	10.64 a	2.76 a
	FOX11	Santa Maria	33.61 c-j	12.75 a	2.65 a
		Williams	27.48 f-r	14.69 a	1.86 a
		Deveci	51.04 a	18.96 a	2.69 a
	OHxF333	Santa Maria	30.65 d-n	13.48 a	2.29 a
		Williams	21.53 k-u	12.09 a	1.78 a
		Deveci	40.83 a-d	13.41 a	3.01 a
	OHxF87	Santa Maria	22.89 j-u	10.45 a	2.17 a
		Williams	14.64 tu	9.24 a	1.59 a
		Deveci	18.99 o-u	10.52 a	1.79 a
	FAROLD40	Santa Maria	44.28 abc	17.01 a	2.62 a
		Williams	30.00 d-o	14.91 a	2.03 a
		Deveci	48.97 ab	17.77 a	2.74 a
	Seedling	Santa Maria	27.86 f-q	10.67 a	2.61 a
		Williams	20.28 m-u	13.56 a	1.42 a
		Deveci	30.57 d-n	12.97 a	2.40 a
Significance (P< 0.05)			**0.031**	**0.285**	**0.127**
Mean standard errors			**3.272**	**1.321**	**0.192**

*: Means with different letters in the same column are significant.
†: Annual shoot length (ASL), Node numbers in the annual shoots (NNAS), Internode length in the annual shoots (ILAS).

4. CONCLUSION

It was determined that the canopy characteristics of 'Williams' pear cultivar in combination with the FAROLD40 and OHxF333 in 2022 were higher than other combinations, while the same combination was obtained with lower values in the case of other morphological characteristics. Generally, all the morphological characteristics were obtained higher in the rootstocks and cultivars combination in 2022. In conclusion, the genetic capacity of rootstocks, cultivars, and variations of the climate situations in two consequent research years resulted in variations in the morphological attributes of pear trees.

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Conflict of Interest

The authors declare no conflicts of interest concerning this article's research, authorship, and/or publication.

Author Contributions

Design of Study: AÖ(%75), ZAF(%25)

Data Acquisition: AÖ(%30), ZAF(%70)

Data Analysis: AÖ(%50), ZAF(%50)

Writing Up: AÖ(%25), ZAF(%75)

Submission and Revision: AÖ(%85), ZAF(%15)

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