Research Article

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Morphological Evaluation of Pear cvs. Santa Maria, Williams, and Deveci Grafted onto Clonal and Seedling Rootstocks*

Santa Maria, Williams ve Deveci Armut Çeşitlerinin Farklı Klonal ve Çöğür Anaçları Üzerindeki Morfolojik Değerlendirilmesi

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Abstract: This research was conducted to determine the effects of quince clonal rootstocks [Quince BA29 (BA29) and Quince A (QA)], pear clonal rootstocks [FOX9, FOX11, OHxF333, OHxF87 and FAROLD40] and European pear seedling rootstocks on the morphological characteristics of 'Santa Maria', 'Williams', and 'Deveci' pear cultivars in Bafra (Samsun) ecological conditions in the research years of 2021 and 2022. Morphological characteristics, such as rootstock diameter (mm), trunk diameter (mm), trunk cross-sectional area (cm²), tree height (cm), crown dimensions (width, length, height and volume), leaf stalk length (cm), leaf stalk thickness (mm), leaf dimensions (width, length, area), annual shoot length (cm), node numbers and internode length (cm) were examined in the study. Results of the study revealed significant variation in the case of research years on most morphological attributes; generally, the values were higher in the research year 2022 than in 2021. It has been determined that the effect of rootstocks on all the morphological characteristics was significant except for leaf stalk thickness. The highest morphological values were obtained from OHxF333, FOX11, and FAROLD40 compared to the other rootstocks, and the lowest values were recorded in FOX9, OHxF87, and seedling rootstocks, respectively. Considering the cultivars' effect on the evaluated morphological traits, the highest leaf characteristics, and internode length in the annual shoots were acquired from the 'Santa Maria' cultivar, but all other attributes were higher in the 'Deveci' cultivar. The ' Williams ' cultivar recorded almost all the lowest morphological values. The highest trunk cross-sectional area was determined in the 'Deveci'/OHxF333 (38.63 cm²) and the lowest in the 'Williams'/FOX9 (4.95 cm²). The longest annual shoots were determined in the 'Deveci'/FOX11 (43.05 cm) and the shortest in the 'Williams'/Seedling (16.11 cm). The highest leaf area was observed from the 'Santa Maria'/BA29 (21.11 cm²) and 'Santa Maria'/FOX11 (20.95 cm²) combinations. According to the results of the research, it was determined that OHxF333 rootstock among the evaluated rootstocks performed morphologically better than the others. FOX9 and OHxF87 pear clone rootstocks showed very poor performance compared to other rootstocks.

Keywords: Pome fruits, rootstock, vegetative growth, *Pyrus communis*

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Öz: Bu araştırma farklı ayva klon [Quince BA29 (BA29) ve Quince A (QA)], armut klon [FOX9, FOX11, OHxF333, OHxF87 ve FAROLD40] ile Avrupa armudunun çöğür anaçları üzerine aşılı 'Santa Maria', 'Williams' ve 'Deveci' armut çeşitlerinin, morfolojik özelliklerini belirlemek amacıyla 2021 ve 2022 araştırma yıllarında Bafra (Samsun) ekolojik koşullarında yapılmıştır. Araştırmada morfolojik özellik olarak anaç çapı (mm), gövde çapı (mm), gövde kesit alanı (cm²), ağaç boyu (cm), taç boyutları (en, boy, yükseklik ve hacim), yaprak sapı uzunluğu (cm), yaprak sapı kalınlığı (mm), yaprak boyutları (en, boy, alan), yıllık sürgün uzunluğu (cm), boğum sayısı (adet) ve boğumlar arası mesafe (cm) incelenmiştir. Sonuçlara bakıldığında, morfolojik özelliklerin çoğunda araştırma yılları arasında önemli farklılıklar olduğu ortaya çıkmış, genellikle 2022 araştırma yılında 2021'den daha yüksek değerler elde edilmiştir. Anaçların yaprak sapı kalınlığı dışındaki tüm morfolojik özellikler üzerindeki etkisinin önemli olduğu belirlenmiştir. Diğer anaçlara göre en yüksek morfolojik değerler OHxF333, FOX11 ve FAROLD40 anaçlarından elde edilirken, en düşük değerler ise sırasıyla FOX9, OHxF87 ve çöğür anaçlarında kaydedilmiştir. Çeşitlerin değerlendirilen morfolojik özellikler üzerindeki etkisi göz önüne alındığında, en yüksek yaprak özellikleri ve yıllık sürgünlerde boğum arası mesafe 'Santa Maria' çeşidinden elde edilirken, diğer tüm özelliklerin 'Deveci' çeşidinde daha yüksek olduğu kaydedilmiştir. En düşük morfolojik değerlerin neredeyse tamamı 'Williams' çeşidinde kaydedilmiştir. En yüksek gövde kesit alanı 'Deveci'/OHxF333 (38.63 cm²), en düşük ise 'Williams'/FOX9 (4.95 cm²) kombinasyonunda belirlenmiştir. En uzun yıllık sürgünler 'Deveci'/FOX11 (43.05 cm) en kısa ise 'Williams'/Çöğür (16.11 cm) kombinasyonunda belirlenmiştir. En yüksek yaprak alanı 'Santa Maria'/BA29 (21.11 cm²) ve 'Santa Maria'/FOX11 (20.95 cm²) kombinasyonundan elde edilmiştir. Araştırma sonuçlarına göre değerlendirilen anaçlar arasından OHxF333 anacının morfolojik olarak diğerlerinden daha iyi performans gösterdiği belirlenmiştir. FOX9 ve OHxF87 armut klon anaçları ise diğer anaçlara göre çok zayıf performans göstermiştir.

Anahtar Kelimeler: Yumuşak çekirdekli, anaç, vejetatif büyüme, *Pyrus communis*

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INTRODUCTION

Pyrus spp. are the most grown and consumed pome fruits worldwide after apples. *Pyrus communis* L. species is the most common and well-known in terms of fruit-growing techniques (Orman, 2005). Pears are more resistant to heat and drought but less resistant to cold than apples. Subtropical pears only require 200-300 chilling hours, whereas temperate pears can be produced from low to high latitudes between 600-2700 m above sea level with 500-1500 chilling hours (Kumar et al., 2023). Late frosts in the spring season limit its cultivation because its flowers are damaged at -2.2°C, and small fruits are damaged at 1.1 °C. However, trees can resist minimum temperatures up to -30°C in the dormant season (Kurt et al., 2022a) and maximum temperatures up to 45°C in the active growing season (Kumar et al., 2023). To establish modern pear orchards, besides pear rootstocks, quince dwarf rootstocks are desired (Bolat and İkinci, 2019; Kurt et al., 2022b). Reasons for the widespread use and breeding of rootstock in fruit cultivation are their adaptation to climatic conditions, soil properties, impact on quality, effect on yield, manage the cultural practices, and tolerance to biotic and abiotic stressors (Corso and Bonghi, 2014). The ideal vegetative and generative performances of fruit trees are highly related to suitable planting density, correct rootstock/scion selection, and appropriate ecology (Pasa et al., 2015; Hepaksoy, 2019). The *Pyrus* genus primarily covers woody plants, mainly medium-sized trees, and a few shrub species. The tree's stem of the *Pyrus* genus is straight and tightly embedded in the ground. In general, the petioles are stipulate and have entire or serrated limb margins, and the leaves are simple, alternately oriented, and range in length from 2 to 12 cm and width from 3 to 5 cm. While most species are deciduous, one or two Southeast Asian species exhibit sempervirescent leaves. Some species have glossy green leaves, while others have silvery, densely tomentose leaves (Simionca et al., 2023). Pear tree vigor results from heritability, biological versatility, adaptation, or favorable responses within the ecological conditions under assessment. Tree vigor status should depend on the cultivation aims and climatic situations of the cultivation area. For example, for highly density planting and availability of cultural resources, trees which are dwarf and growth weaker are ideal, but if the aim is to produce pear in dry conditions with less managemental resources, wood production, as ornamental for providing shade and shelter, construction, and furniture the trees with vigorous growth are ideal (Ozturk and Faizi, 2023; Simionca et al., 2023). Some selections of wild species of pears have a recognized ornamental value because, in addition to the rapid growth of the trees, the varied range of shapes and sizes, rusticity, low demands on the soil, or ability to thrive in different ecological conditions, they have attractive foliage, with glossy green leaves, flowers, and fruits that are particularly decorative (Yamada et al., 2015). Pear cultivars with high canopy spread cause high expenses of managemental practices like pruning. So, pear cultivars with less vegetative growth, such as 'Hardy', 'Flemish Beauty', 'Anjou' and 'Comice' are ideal for minimizing such costs (Kul et al., 2022). Using vigorous rootstocks and cultivars is the main factor in decreasing yield in pear orchards (Pasa et al., 2017). For pear cultivars, both *Pyrus* and *Cydonia* species are used as rootstocks (Iglesias and Asin, 2011; North et al., 2015). However, *Pyrus* species as rootstock shows strong vegetative growth and vigorous rootstocks provide excessive shoot and canopy development, which can reduce light usage by pear trees (Kul et al., 2022). This research was conducted to determine the effects of Quince BA29, Quince A, FOX9, FOX11, OHxF333, OHxF87, FAROLD40, and European pear seedling rootstocks on the morphological characteristics of 'Santa Maria', 'Williams', and 'Deveci' pear cultivars which have an essential place in pear cultivation of Türkiye in Bafra (Samsun) ecological conditions in the research years of 2021 and 2022.

MATERIAL AND METHOD

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 local European pear seedling rootstocks were used as plant materials in the research years of 2021 and 2022.

Features of the Experiment Area

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 illustrated in Table 1.

Table 1. Temperature, relative humidity, and monthly total precipitation of the study area in 2021 and 2022.
Çizelge 1. Çalışma alanının 2021 ve 2022 yıllarında sıcaklığı, bağıl nemi ve aylık toplam yağış miktarı.

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

Methods

The study was conducted in the pear orchard, which was established in 2018 with 1-year-old saplings at a spacing of 3.5 m by 1.5 m in the case of quince rootstocks and 3.0 m by 3.5 m in the case of pear rootstocks at the Bafra agricultural research center of Ondokuz Mayis University which is located at Samsun province of Türkiye. The plants were supported by metal poles each at a height of 3.5 m, with four rows of galvanized wires on the horizontal arms positioned 50 cm above the ground. Between 15 May and 15 September, drip irrigation was used to irrigate the plants. Fertilization was done through drip irrigation using 15-30-15 + ME fertilizer at the start of the summer and 20-20-20 NPK fertilizer in the fall. Weeds between the rows were routinely removed using a rotavator while the ground was mulched on the row.

Morphological Observations

Rootstock diameter (mm), cultivar diameter (mm), the height of the tree (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), petiole length (cm), petiole thickness (mm), leaf area (cm^2), annual shoot length (cm) were determined according to previous researches (Öztürk and Öztürk, 2014; Kurt et al., 2022a).

Statistical Analysis

Factorial randomized complete block design (FRCBD) was used as the design of our study. Three factors, including cultivars (3 cultivars), rootstocks (8 rootstocks), and research years (2 research years), were taken into evaluation. 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 by using GLM procedure. Means differences were determined according to Duncan's Multiple Comparison Test with 95% of confidence and 5% ($\alpha = 0.05$) probability error due to unknown situations.

RESULTS AND DISCUSSION

Leaf Characteristics

The effect of research years, rootstocks, cultivars, and rootstock x cultivar interactions 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. The LST in the case of rootstocks, cultivars, and rootstock x cultivar interactions was insignificant. However all other factors were determined as statistically significant. The main effect of research years on the leaf characteristics revealed higher values in 2022 than in the research year of 2021. In terms of rootstock averages, the higher values of leaf attributes were observed in the OHxF333, while the lowest in the OHxF87 rootstock. In the case of cultivars' averages, leaf attributes observed the highest in 'Santa Maria' cultivar and the lowest in the 'Williams' and 'Deveci' cultivars. Considering the rootstock x cultivar interactions, the LSL varied between 2.21-4.08 cm. The highest (4.08 cm) LSL was in 'Deveci'/BA29 and the lowest (2.21 cm) in 'Williams' grafted on BA29 and seedling rootstocks. The LST was observed between 0.90-1.24 mm. The LL varied between 5.08-6.92 cm, the highest LL (6.92 cm) was recorded in the 'Santa Maria'/seedling, and the lowest (5.08 cm) in 'Williams'/FOX9 combination. The LW observed between 2.84-4.37 cm, recorded the highest LW (4.37 cm) in the 'Santa Maria'/BA29, and the lowest (5.08 cm) in the 'Deveci'/QA combination. The LA was obtained in the range of 12.41-21.11 cm^2; the highest LA was recorded in the 'Santa Maria'/BA29 (21.11 cm^2), and the lowest in the 'Williams'/FOX9 (12.41 cm^2) combination (Table 2).

The leaf stalk length of 'Deveci' pear was significantly affected by rootstocks (Öztürk and Öztürk, 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). Çoban and Öztürk (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 growing conditions, rootstocks, and cultivars.

Leaf stalk thickness was significantly affected by rootstock, cultivar, and their interactions, as reported by Öztürk and Öztürk (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 Çoban (2019). She found LST between 0.97-1.27 mm in rootstocks and 1.06-1.16 mm in the cultivars; he 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.

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. Öztürk and Öztürk (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. Kılıç (2015) found LL between 32.00-60.18 mm in consideration of different genotypes of pear. Çoban and Öztürk (2020) stated that rootstocks and cultivars significantly affect 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.

Table 2. Leaf characteristics of European pear considering different rootstocks, cultivars, and research years.
Çizelge 2. Farklı anaçlar, çeşitler ve araştırma yılları bakımından Avrupa armudunun yaprak özellikleri.

Rootstocks	Cultivars	Leaf stalk length (cm)	Leaf stalk thickness (mm)	Leaf length (cm)	Leaf width (cm)	Leaf area (cm^2)
BA29	Santa Maria	3.66 abc	1.16 a	6.68 ab	4.37 a	21.11 a *
	Williams	2.60 g-j	1.04 a	5.53 c-f	3.58 d-h	14.17 de
	Deveci	4.08 a	1.00 a	6.30 a-d	3.14 f-i	14.27 de
Quince A	Santa Maria	3.66 abc	1.05 a	6.74 ab	4.21 abc	20.75 ab
	Williams	2.61 g-j	1.06 a	5.38 def	3.30 f-i	12.88 e
	Deveci	3.80 ab	1.20 a	6.01 a-f	2.84 i	12.44 e
FOX9	Santa Maria	3.63 abc	0.93 a	6.75 ab	4.06 a-d	20.12 abc
	Williams	2.53 hij	1.07 a	5.08 f	3.38 e-i	12.41 e
	Deveci	3.26 b-f	1.06 a	6.49 abd	3.13 f-i	15.14 cde
FOX11	Santa Maria	3.64 abc	1.05 a	6.73 ab	4.31 ab	20.95 a
	Williams	2.42 ij	1.01 a	5.85 d-f	3.67 c-g	15.55 b-e
	Deveci	3.60 abc	0.90 a	6.50 abc	3.09 ghi	14.69 de
OHxF333	Santa Maria	3.38 b-e	1.24 a	6.52 abc	4.29 ab	20.59 ab
	Williams	3.25 b-f	1.13 a	6.34 a-d	3.72 b-g	17.16 a-e
	Deveci	3.78 ab	0.98 a	6.78 ab	3.44 e-i	16.82 a-e
OHxF87	Santa Maria	2.89 e-i	1.22 a	6.30 a-d	3.93 a-e	18.46 a-d
	Williams	2.21 j	1.08 a	5.52 c-f	3.41 e-i	13.81 de
	Deveci	2.70 f-j	1.06 a	5.96 a-f	2.91 i	12.81 e
FAROLD40	Santa Maria	3.32 b-e	1.07 a	6.43 abc	3.45 e-i	16.53 a-e
	Williams	3.02 d-h	1.18 a	6.14 a-e	3.73 b-t	16.61 a-e
	Deveci	3.99 a	1.00 a	6.56 abc	3.17 f-i	15.19 cde
Seedling	Santa Maria	3.57 a-f	1.14 a	6.92 a	4.11 a-d	20.57 ab
	Williams	2.21 j	1.09 a	5.18 ef	3.20 f-i	12.50 e
	Deveci	3.10 c-g	0.98 a	5.89 a-f	2.94 hi	13.07 e
Significance		0.001	0.869	0.001	0.001	0.001
Years (Y)	2021	3.11 b	1.01 b	5.66 b	3.27 b	13.61 b
	2022	3.30 a	1.14 a	6.72 a	3.84 a	18.78 a
Significance		0.001	0.004	0.001	0.001	0.001
Rootstocks	BA29	3.45 a	1.07 a	6.17 ab	3.70 a	16.51 bc
	Quince A	3.36 ab	1.10 a	6.04 cd	3.45 b	15.35 cd
	FOX9	3.14 cd	1.02 a	6.11 cd	3.52 b	15.89 bcd
	FOX11	3.22 bc	0.99 a	6.36 ab	3.69 a	17.06 b
	OHxF333	3.47 a	1.12 a	6.55 a	3.81 a	18.19 a
	OHxF87	2.60 e	1.12 a	5.93 d	3.42 b	15.03 d
	FAROLD40	3.44 a	1.08 a	6.38 ab	3.45 b	16.11 bcd
	Seedling	2.96 d	1.07 a	6.00 cd	3.41 b	15.38 cd
Significance		0.001	0.790	0.001	0.001	0.001
Cultivars	Santa Maria	3.47 a	1.11 a	6.63 a	4.09 a	19.89 a
	Williams	2.61 b	1.08 a	5.63 c	3.50 b	14.38 b
	Deveci	3.54 a	1.02 a	6.31 b	3.08 c	14.30 b
Significance		0.001	0.290	0.001	0.001	0.001

*: Means with different letters in the same column are significant differences at P<0.05 based on the DMRT test.

Öztürk and Öztürk (2014), were determined the significant impact of rootstocks on the leaf sizes of the 'Deveci' cultivar; they reported that LW was the highest in trees grafted on BA29 rootstock. Kılıç (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

and Öztürk (2020) between 36-37 mm in cultivars and 35-38 mm in the rootstocks. Serttaş and Öztürk (2020) reported the highest LW in 'Deveci' and 'Santa Maria' (3.75 cm and 3.44 cm) and the lowest in 'Abate Fetel' and 'Williams' cultivars (3.40 cm and 3.34 cm), respectively. The variations in the results were due to genetic and environmental factors.

Leaf area is an important morphological attribute in the determination of 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, and 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 (Öztürk and Öztürk, 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 attributes 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 cm2 QA, 6.24 'Williams' to 10.80 cm^2 'Santa Maria' (Kurt et al., 2022a).

Rootstock and Scion Diameter, Tree height, and Trunk Cross-Sectional Area

The impact of the research years, rootstocks, cultivars, and rootstocks x cultivars combined effect on rootstock diameter (RD), scion diameter (SD), tree height (TH), and trunk cross-sectional area (TCSA) of pear trees are illustrated in Table 3. All the aforementioned attributes were found to be statistically significant. Considering the research years, higher values recorded in the research year of 2022 than in 2021, RD obtained between 42.75-52.35 mm, SD varied from 38.73-49.02 mm, TH observed between 223.05-235.07 cm, and TCSA was ranged from 12.86-20.56 cm^2. In the case of rootstocks, the highest values recorded in the OHxF333 and the lowest values recorded in the FOX9 rootstock, RD was 29.83-59.43 mm, SD varied between 26.80-57.22 mm, TH observed between 160.30-273.88 cm, and TCSA was ranged between 5.93-27.31 cm^2. Cultivar averages revealed the highest values in the 'Deveci' cultivar and the lowest in the 'Williams' cultivar; RD obtained between 43.35-54.22 mm, SD varied from 39.76-50.76 mm, TL observed between 219.74-237.35 cm, and TCSA varied between 13.68-22.50 cm^2. In the combined effect of rootstock x cultivar, the highest values were acquired from the 'Deveci'/OHxF333 and 'Deveci'/FAROLD40 combinations. While the lowest values were recorded in the 'Williams'/FOX9 combination. RD acquired 26.55-70.13 mm, SD varied between 24.44-68.41 mm, TH observed between 152.68-296.02 cm, and TCSA obtained 4.95-37.68 cm^2 (Table 3).

Francescatto et al. (2010) reported the lowest rootstock diameter in the EMC rootstock in the 'Packhams'/EMC combination, while the cultivar was grafted on 7 different rootstocks. Similarly, Öztürk and Öztürk (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). Çetinbaş 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 (Öztürk, 2021).

Scion diameter values that we obtained are compatible with the studies previously performed (Öztürk and Öztürk, 2014; Machado et al., 2016; Mete, 2019; Öztürk, 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. Rootstock and scion diameter, tree length, and trunk cross-sectional area of European pear considering different rootstocks, cultivars, and research years.
Çizelge 3. Farklı anaçlar, çeşitler ve araştırma yılları bakımından Avrupa armudunun anaç ve kalem çapı, ağaç boyu ve gövde kesit alanı.

Rootstocks	Cultivars	Rootstock diameter (mm)	Scion diameter (mm)	Tree height (cm)	Trunk cross-sectional area (cm^2)
BA29	Santa Maria	45.42 ef	42.40 def	242.72 c-g	14.18 f-i *
	Williams	34.87 ghi	34.05 fgh	203.43 hij	7.39 hij
	Deveci	54.95 cde	54.10 bc	239.90 d-h	23.23 de
Quince A	Santa Maria	47.36 def	46.42 cde	266.30 a-d	17.31 efg
	Williams	28.22 hi	27.00 h	156.33 k	5.75 ij
	Deveci	54.15 cde	54.58 bc	254.21 b-e	23.65 cde
FOX9	Santa Maria	29.37 hi	26.26 h	162.27 k	5.67 ij
	Williams	26.55 i	24.44 h	152.68 k	4.95 j
	Deveci	33.59 hi	29.71 gh	165.95 k	7.17 hij
FOX11	Santa Maria	50.08 cde	47.35 cde	253.69 b-e	17.72 efg
	Williams	57.88 bcd	52.29 bcd	277.18 a-d	21.59 def
	Deveci	65.94 bc	63.03 ab	279.50 abc	32.85 ab
OHxF333	Santa Maria	50.45 cde	46.15 cde	224.80 e-i	17.05 efg
	Williams	57.70 bcd	57.11 bc	289.99 ab	27.21 bcd
	Deveci	70.13 a	68.41 a	294.20 a	37.68 a
OHxF87	Santa Maria	34.13 hi	29.92 gh	184.79 jk	7.16 hij
	Williams	38.55 fgh	32.18 gh	190.84 ijk	8.40 hij
	Deveci	33.50 hi	27.87 gh	155.39 k	6.37 hij
FAROLD40	Santa Maria	50.13 cde	47.32 cde	245.72 c-f	17.70 efg
	Williams	58.66 bc	53.06 bcd	279.89 abc	22.35 def
	Deveci	68.54 a	62.32 ab	296.02 a	31.57 abc
Seedling	Santa Maria	53.65 cde	43.03 def	260.46 a-e	14.78 e-h
	Williams	44.39 efg	37.94 efg	207.56 g-j	11.83 g-j
	Deveci	53.00 cde	46.07 cde	213.61 f-j	17.51 efg
Significance		0.001	0.001	0.001	0.001
Years (Y)	2021	42.75 b	38.73 b	223.05 b	12.86 b
	2022	52.35 a	49.02 a	235.07 a	20.56 a
Significance		0.001	0.001	0.014	0.001
Rootstocks	BA29	45.08 c	43.51 b	228.68 b	14.93 c
	Quince A	43.24 c	42.67 b	225.61 b	15.57 c
	FOX9	29.83 e	26.80 c	160.30 c	5.93 d
	FOX11	57.97 a	54.22 a	270.13 a	24.05 b
	OHxF333	59.43 a	57.22 a	269.66 a	27.31 a
	OHxF87	35.39 d	29.99 c	177.01 c	7.31 d
	FAROLD40	59.11 a	54.23 a	273.88 a	23.87 b
	Seedling	50.34 b	42.35 b	227.21 b	14.71 c
Significance		0.001	0.001	0.001	0.001
Cultivars	Santa Maria	45.07 b	41.10 b	230.09 ab	13.95 b
	Williams	43.35 b	39.76 b	219.74 b	13.68 b
	Deveci	54.22 a	50.76 a	237.35 a	22.50 a
Significance		0.001	0.001	0.013	0.001

*: Means with different letters in the same column are significant differences at P<0.05 based on the DMRT test.

Tree height was reported by the rootstocks and cultivars (Giacobbo et al., 2010; Lepsis and Duredze, 2011; Dondini and Sansavini, 2012). The highest TH of 'Abate Fetel' and 'Conference' cultivars were observed on pear seedlings rather than on the BA29 and MA rootstocks (Castro and Rodriguez, 2002). In our study, we observed the highest TH 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 TH was acquired 159 cm in 'Williams' pear cultivar and 225 cm in the 'Deveci' cultivar while grafted on QA rootstock (Akçay 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' TH by 60% compared to pear seedling rootstock (*Pyrus calleryana*). The highest TH of the 'Deveci' cultivar was recorded on the BA29 rootstock and the lowest on the MC rootstock (Öztürk, 2021).

Our research revealed that the trunk cross-sectional area differs in terms of research years, cultivars, and rootstocks. Similar findings were reported by (Iglesias and Asin, 2011; Sugar and Basile, 2011; Lepsis and Drudze, 2011; Öztürk and Öztürk, 2014; Saracoglu and Cebe, 2018; Mete, 2019; Öztürk, 2021; Küçüker and Ağlar, 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 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).

Canopy Characteristics

Canopy characteristics of European pear considering different rootstocks, cultivars, research years, and the rootstocks x cultivars combined effect is given in Table 4. Except for the canopy width in the case of cultivars which was observed as insignificant, all other effects were found statistically significant. In terms of the research years, it was determined that canopy volume (CV) in 2022 was higher (1.56 m^3) than in 2021 (0.94 m^3). The CV regarding rootstock averages varied between 0.21-2.08 m^3, the highest (2.08 m^3) CV observed in the OHxF333, and the lowest (0.21 m^3) in the FOX9 rootstock. Regarding cultivar averages, CV varied between 1.14-1.41 m^3, the highest (1.41 m^3) CV was in the 'Deveci', and the lowest (1.14 m^3) in the 'Santa Maria' cultivar. The CV observed between 0.12-2.66 m^3 in the combined effect of rootstock x cultivar; the highest (2.66 m^3) CV was in the 'Williams' and the 'Deveci' cvs. on the OHxF333 rootstock, and the lowest (0.12 m^3) in the 'Williams'/ FOX9 combinations (Table 4).

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 'BP 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 Öztürk and Öztürk (2014), the 'Deveci' pear cultivar's CV was larger on the BA29 rootstock than it was on the MC rootstock. According to Öztürk (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 (Küçüker and Ağlar, 2021).

Table 4. Canopy attributes of European pear considering different rootstocks, cultivars, and research years.
Çizelge 4. Farklı anaçlar, çeşitler ve araştırma yılları bakımından Avrupa armudunun taç özellikleri.

Rootstocks	Cultivars	Canopy width (cm)	Canopy length (cm)	Canopy height (cm)	Canopy volume (m^3)
BA29	Santa Maria	141.34 abc	126.79 b-e	198.38 d-h	1.58 b-e *
	Williams	112.73 b-e	101.52 efg	153.72 ijk	0.89 d-h
	Deveci	148.79 ab	133.17 a-e	202.96 d-g	1.81 a-d
Quince A	Santa Maria	144.47 abc	134.91 a-d	222.50 a-e	1.93 abc
	Williams	87.32 efg	69.06 hij	125.82 k	0.40 gh
	Deveci	140.70 abc	121.09 c-f	215.69 b-f	1.76 a-d
FOX9	Santa Maria	55.12 gh	52.26 j	138.80 jk	0.22 gh
	Williams	44.99 h	43.41 j	126.18 k	0.12 h
	Deveci	66.08 fgh	68.50 hij	129.67 k	0.30 gh
FOX11	Santa Maria	128.18 a-d	124.84 b-e	225.64 a-d	1.55 b-e
	Williams	139.31 abc	135.79 a-d	237.02 a-d	1.88 abc
	Deveci	131.40 abc	132.90 a-e	242.32 abc	1.86 a-d
OHxF333	Santa Maria	117.03 b-e	117.60 c-g	185.87 e-j	1.02 c-h
	Williams	149.26 ab	161.61 a	255.33 a	2.66 a
	Deveci	158.85 a	153.73 ab	251.66 ab	2.56 a
OHxF87	Santa Maria	67.40 fgh	60.76 ij	152.98 ijk	0.30 gh
	Williams	88.19 efg	85.97 ghi	162.77 h-k	0.56 fgh
	Deveci	54.97 gh	54.83 j	131.65 k	0.16 h
FAROLD40	Santa Maria	119.47 b-e	106.86 d-g	204.39 c-g	1.16 c-g
	Williams	149.56 ab	141.76 abc	250.94 ab	2.38 ab
	Deveci	134.09 abc	142.14 abc	259.19 a	1.89 abc
Seedling	Santa Maria	131.05 abc	109.98 c-g	200.52 d-h	1.38 c-f
	Williams	93.02 def	92.01 gh	178.31 f-i	0.66 e-h
	Deveci	110.82 cde	104.79 d-g	173.17 g-j	0.95 c-h
Significance		0.001	0.001	0.001	0.001
Years (Y)	2021	99.22 b	95.68 b	186.85 b	0.94 b
	2022	126.96 a	119.01 a	198.61 a	1.56 a
Significance		0.001	0.001	0.015	0.001
Rootstocks	BA29	134.29 ab	120.49 bc	185.02 b	1.43 bc
	Quince A	124.17 bc	108.35 cd	188.00 b	1.36 c
	FOX9	55.40 e	54.72 e	131.55 c	0.21 e
	FOX11	132.96 ab	131.18 b	234.99 a	1.76 ab
	OHxF333	141.71 a	144.31 a	230.96 a	2.08 a
	OHxF87	70.19 d	67.19 e	149.13 c	0.34 e
	FAROLD40	134.38 ab	130.25 b	238.17 a	1.81 a
	Seedling	111.63 c	102.26 d	184.00 b	1.00 d
Significance		0.001	0.001	0.001	0.001
Cultivars	Santa Maria	113.01 a	104.25 b	191.13 ab	1.14 b
	Williams	108.05 a	103.89 b	186.26 b	1.19 b
	Deveci	118.21 a	113.89 a	200.79 a	1.41 a
Significance		0.057	0.016	0.045	0.037

*: Means with different letters in the same column are significant differences at P<0.05 based on the DMRT test.

Shoot Characteristics

The rootstocks x cultivars' combined effect on the annual shoot length (ASL), node numbers in the annual shoots (NNAS), and internode length in the annual shoots (ILAS) characteristics are given in Table 5. In terms of combined rootstocks x cultivars, the ASL and ILAS were statistically significant, while the NNAS was not significant. The ASL varied between 16.11-43.05 cm. The longest ASL was determined in the

'Deveci'/FOX11 combination (43.05 cm), and the shortest (16.11 cm) in the 'Williams'/seedling combination. The NNAS was found between 9.78-16.87 pcs. The ILAS varied between 1.29-2.98 cm. The longest ILAS was determined in the 'Santa Maria'/BA29 combination (2.98 cm) and the shortest (1.29 cm) in the 'Williams'/seedling combination (Table 5).

Table 5. Shoot characteristics of European pear in terms of different rootstock x cultivar interaction.
Çizelge 5. Farklı anaç x çeşit interaksiyonu bakımından Avrupa armudunun sürgün özellikleri.

Rootstocks	Cultivars	Annual shoot length (cm)	Node numbers in the annual shoots (pcs.)	Internode length in the annual shoots (cm)
BA29	Santa Maria	33.83 a-d	11.31 a	2.98 a *
	Williams	24.13 d-i	10.44 a	2.23 c-g
	Deveci	32.70 a-e	12.45 a	2.61 a-e
Quince A	Santa Maria	32.55 a-f	11.35 a	2.89 ab
	Williams	23.19 d-i	11.22 a	2.09 d-g
	Deveci	26.87 c-i	11.25 a	2.38 b-g
FOX9	Santa Maria	20.17 ghi	11.29 a	1.81 g
	Williams	18.53 hi	9.78 a	1.89 fg
	Deveci	26.28 c-i	10.64 a	2.49 a-f
FOX11	Santa Maria	35.91 abc	13.03 a	2.77 abc
	Williams	32.31 b-f	15.89 a	2.03 efg
	Deveci	43.05 a	16.87 a	2.54 a-e
OHxF333	Santa Maria	27.55 c-h	12.36 a	2.24 c-g
	Williams	21.34 f-i	11.22 a	1.91 fg
	Deveci	36.28 abc	13.96 a	2.60 a-e
OHxF87	Santa Maria	25.67 c-i	13.77 a	1.93 fg
	Williams	25.77 c-i	14.02 a	1.82 g
	Deveci	21.85 e-i	11.72 a	1.86 g
FAROLD40	Santa Maria	32.17 b-f	14.91 a	2.11 d-g
	Williams	30.71 b-g	15.15 a	2.04 efg
	Deveci	40.83 ab	16.25 a	2.49 a-f
Seedling	Santa Maria	27.23 c-i	10.29 a	2.65 a-d
	Williams	16.11 i	12.00 a	1.29 h
	Deveci	23.47 d-i	11.91 a	1.95 fg
Significance		0.001	0.140	0.001

*: Means with different letters in the same column are significant differences at P<0.05 based on the DMRT test.

Rootstocks' main effect on the ASL, NNAS, and ILAS characteristics is given in Figure 1. Regarding rootstocks' main effect, all attributes were acquired as statistically significant. The ASL ranged from 21.66-37.09 cm. The longest ASL was determined in the FOX11 rootstock (37.09 cm) and the shortest (21.66 cm) in the FOX9 rootstock. The NNAS was found between 10.57-15.44 pcs. The highest (15.44 pcs.) NNAS was in the FAROLD40 rootstock, while the lowest (10.57 pcs.) was in the FOX9 rootstock. The ILAS was recorded in the range of 1.87-2.60 cm. The longest (2.60 cm) ILAS was determined in the BA29 rootstock, and the shortest (1.87 cm) in the OHxF87 rootstock (Figure 1).

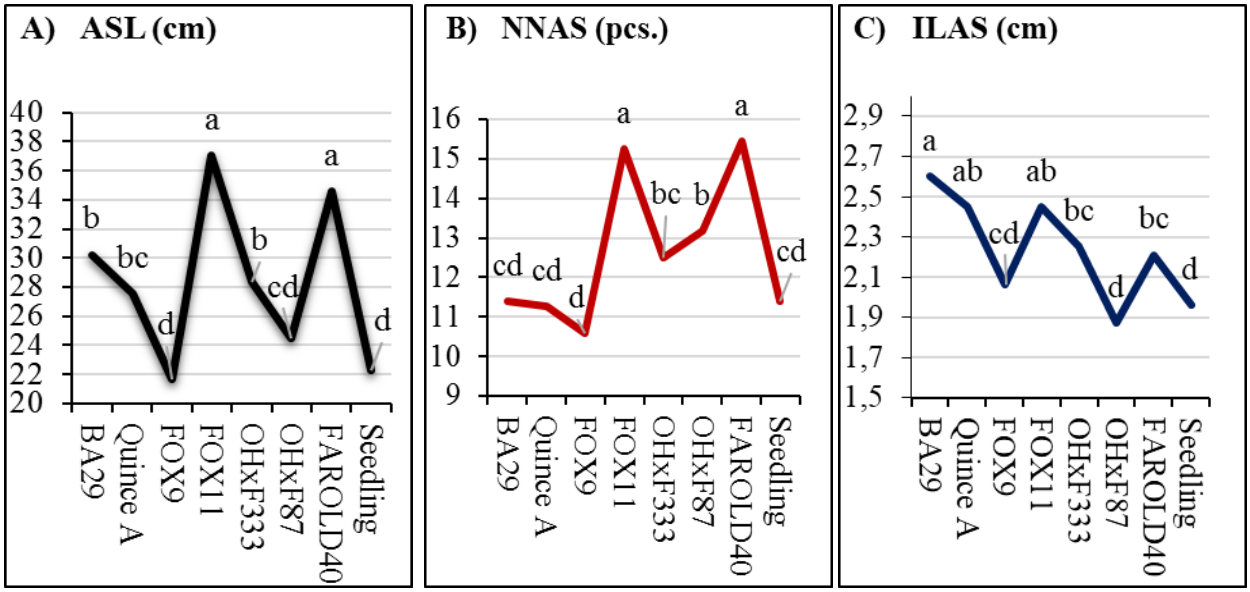

Figure 1. The rootstock's main effects on; **A)** annual shoot length (ASL), **B)** node numbers in the annual shoots (NNAS), and **C)** internode length in the annual shoots (ILAS).
Şekil 1. A) yıllık sürgün uzunluğu (ASL), B) yıllık sürgünlerdeki boğum sayıları (NNAS) ve C) yıllık sürgünlerdeki boğum arası uzunluğu (ILAS) üzerine anaçların etkisi.

Cultivar's main effects on the ASL, NNAS, and ILAS characteristics are illustrated in Figure 2. Considering cultivar main effects, the ASL and ILAS were obtained as statistically significant, while the NNAS was not significant. The ASL varied from 24.01 cm to 31.42 cm. The longest ASL was determined in the 'Deveci' cultivar (31.42 cm) and the shortest (24.01 cm) in the 'Williams' cultivar. The NNAS was found between 12.29-13.13 pcs. The ILAS was 1.91-2.42 cm. The longest (2.42 cm) ILAS was determined in the 'Santa Maria' cultivar, and the shortest (1.91 cm) in the 'Williams' cultivar (Figure 2).

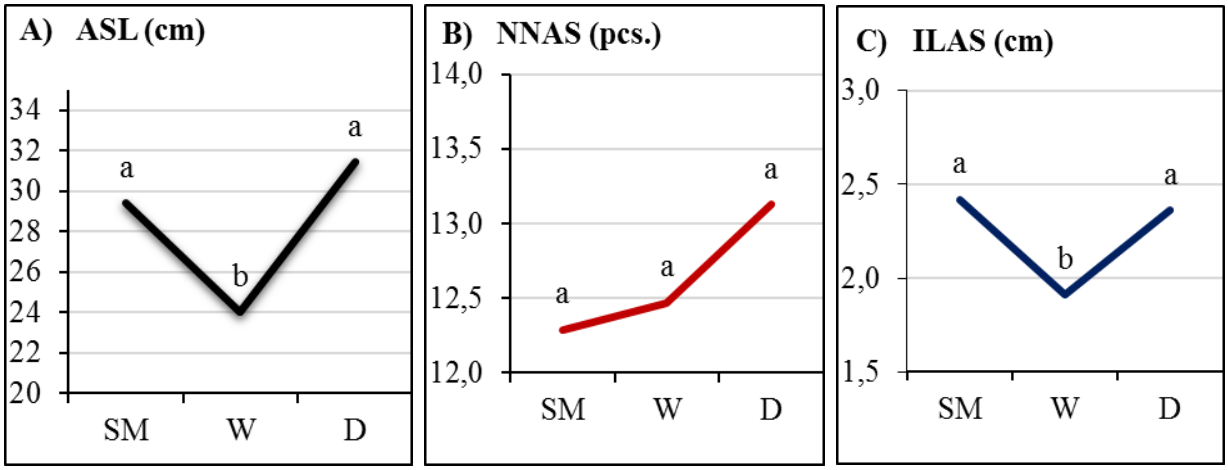

Figure 2. The cultivar's main effects on; **A)** annual shoot length (ASL), **B)** node numbers in the annual shoots (NNAS), and **C)** internode length in the annual shoots (ILAS). SM= 'Santa Maria', W= 'Williams', D= 'Deveci'.
*Şekil 2. **A)** yıllık sürgün uzunluğu (ASL), **B)** yıllık sürgünlerdeki boğum sayıları (NNAS) ve **C)** yıllık sürgünlerdeki boğum arası uzunluğu (ILAS) üzerine çeşitlerin etkisi.*

The research years' main effect on the ASL, NNAS, and ILAS characteristics is shown in Figure 3. Considering research years' main effect on the ASL, NNAS, and ILAS was not significant.

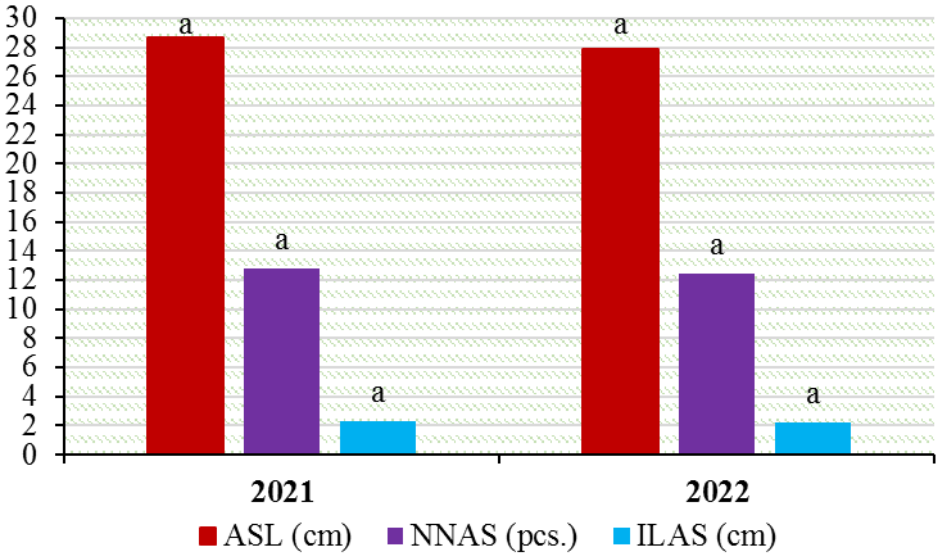

Figure 3. Research years' main effects on the annual shoot length (ASL), node numbers in the annual shoots (NNAS), and internode length in the annual shoots (ILAS).
Şekil 3. Yıllık sürgün uzunluğu (ASL), yıllık sürgünlerdeki boğum sayısı (NNAS) ve yıllık sürgünlerdeki boğum arası uzunluğu (ILAS) üzerine araştırma yılların etkisi.

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 (Osmanoğlu 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 the case of different rootstocks x cultivars combinations, the ASL recorded between 26.0-44.56 cm in the 'Deveci'/QA, 35.56-49.0 cm in the 'Santa Maria'/QA, 22.89-46.44 cm in the '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).

CONCLUSION

It was determined that pear cv. 'Williams' did not perform well in vegetative growth compared to other evaluated cultivars. It may result from incompatibility between the 'Williams' and rootstocks used in the study. The 'Deveci'cultivar performed better morphological growth than both 'Santa Maria' and 'Williams' cultivars. The genetic capacity of rootstocks, cultivars, and variations of the climatical conditions in two consequent research years, 2021 and 2022, resulted in the withstand 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

ZAF: Gathered the information, analyzed the data, and wrote the manuscript.
AÖ: conceptualized and designed the study and checked the final draft.

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