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Original article

Root Architecture and Development of American Grape Rootstocks Grafted with Foxy Grapes (*Vitis labrusca* L.) Cultivars

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Abstract

One of the important factors affecting rootstock performance in grafted grapevine production is root structure and its ability for different soil. In the present study, foxy grape varieties registered for the first time in the Black Sea Region in Turkey by the selection, and several American grape rootstocks were bench grafted. In this study; it is aimed to examine the root architecture of foxy grape grafted saplings for their root architecture and the development of rootstocks. In the experiment 'Rizessi', 'Çeliksu', 'Ülkemiz' and 'Rizellim' foxy grape cultivars grafted on 140Ru, SO4 and 110R rootstocks. WinRhizo root analysis program (Regent Instrument Inc. Canada, ver.2013) was used to determine rootstocks' architecture and development of grafted vine saplings. Roots prepared for scanning were placed on the scanning part of the device and transferred to the computer context. Root length and mean root diameter are two of the essential features that reveal the root architecture of rootstocks. In the study, root length (cm), root surface area (cm2), root diameter (mm), root volume (cm3), root tip number (piece), root branching number (piece), and root intersection number (piece) were determined. Total root length was determined between 330.05 - 595.40 cm ('Rizellim'/SO4 and 'Çeliksu'/140Ru) and mean root diameter of 2.04 - 3.13 mm ('Çeliksu'/140Ru and 'Rizessi'/110R). Negative relationships were found between root length and mean root diameter. Among the rootstocks, the highest root surface area was 399.67 cm2, root volume was 29.32 m3, the number of root tips was 1605.75, the number of root forks was 5421.89, and the number of root crossing was 671.61 on 110R rootstock. In all combinations obtained as a result of the study, it was determined that the rootstocks showed good root development and were in harmony with the new foxy grape cultivars.

Keywords: WinRhizo, American vine rootstocks, Foxy grape, Root architecture.

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INTRODUCTION

Vitis species is one of the most economically important fruit species in Turkey and worldwide, with its use as table, drying, and wine grapes (Ali et al., 2010). The majority of vineyards in the world consist of *Vitis vinifera* varieties (Ferreira et al., 2014). Turkey ranks fifth in the world in terms of grape production. Although we have excellent grape production worldwide, the Black Sea Region is in the last place in Turkey. The reason for this is that the annual rainfall and humidity of the region are very high. The increase in fungal diseases, especially in the coastal region with increasing humidity, restricts the cultivation of *Vitis vinifera* L. varieties. Therefore, varieties of *Vitis labrusca* species adapted to this region are grown (Çelik, 2004). These varieties constitute approximately 40% of the grapes produced in America and are used to produce products such as red wine, grape juice, jam, vinegar, and jelly (Rombaldi et al., 2004). This species is a hybrid of *V. labrusca* and *V. vinifera* and is classified as *Vitis labrusca* L. Bailey. These varieties of American origin have adapted to different climates, from humid weather to dry weather, and different varieties have been bred (Creasy and Creasy, 2018). Commonly used varieties are Bordeaux, Isabella, Concord, and Niagara (Toaldo et al., 2013), and 'Rizellim', 'Çeliksu', 'Ülkemiz', 'Rizessi' and 'Rizpem' cultivars were registered in Turkey in 2016 by selection. (Steel et al., 2018).

With the arrival of the *Phylloxera* pest (*Daktulosphaira vitifoliae* Fitch) in the 1800s, the vineyards began to be damaged. Therefore, vine cultivation has begun using American vines resistant to *phylloxera* as rootstock (Pouget, 1990). The primary purpose of using these rootstocks is resistance to phylloxera. However, not only for this, but it is also used for nematodes, regulating water and nutrient uptake (McCarthy et al., 1997; Walker et al., 2000), or soil conditions that limit cultivation, such as soil pH (Keller, 2015). The way to control the growth and development of plants in different climatic and soil conditions is to inoculate. Grafting is an ancient method of growing fruits such as grapes. Grafting is done to control vegetative reproduction, change varieties quickly, shorten the period of fruiting, limit vegetative growth, and provide tolerance against biotic and abiotic stress conditions (Mudge et al., 2009).

The solid and high number of roots in vine rootstocks increase the seedling yield and the success rate under stress conditions (Geier et al., 2008). The root system is the part that provides the connection between the soil and the vine and is the organ where the water and nutrients needed by the vines are stored (Keller, 2015; Creasy and Creasy, 2018). The excellent development of the rootstock part in the vines means that it will develop well in the shoots. The strong root structure of rootstocks facilitates the uptake of water and mineral substances from the soil and increases the seedlings' quality. While a strongly developed rootstock provides better development of shoots (Fleishman et al., 2019), it also increases mineral substance uptake from the soil (Hanana et al., 2015) and hydraulic conductivity (Alsina et al., 2011).

There is much less information about the root structure and systems of plants than about shoots. Because taking root samples and analyzes are time-consuming, tiring, and labor-intensive (Box Jr, 1996). However, manual measurements made on the roots are used (Köse et al., 2016; Yağcı & Zenginoğlu, 2019), and some errors may occur in these roots. In recent years, new systems have started to be used with the development of computer hardware and software to determine root systems and architecture. The WinRhizo system reveals the root architecture (Bouma et al., 2000; Wang and Zhang, 2009; Peiro et al., 2020). This system obtains 2D and 3D images of morphological features such as total root length, mean root diameter, and root surface area (Dumont et al., 2014). Root architecture is generally related to the length and density of the roots, which covers the length of the root zone, determines the contact surface of the root with the soil, and increases the uptake of water and nutrients (Comas et al., 2013). Root architecture changes according to the ecological conditions in which the plant grows, and it is known that this is important for adaptation and yield. Especially in this process of global warming and climate change, growing vines in different ecological conditions and ensuring sustainability has become a severe factor to viticulture (Yıldırım et al., 2018).

This study is aimed to determine the root architecture of 140Ru, SO4, and 110R rootstocks grafted with different *Vitis labrusca* L. cultivars with WinRhizo and determine the root development in the grafted vine saplings obtained.

MATERIAL and METHOD

The study was carried out in Samsun Ondokuz Mayıs University Faculty of Agriculture Research and Application area in 2019. Grafted vine saplings obtained by grafting 'Rizessi', 'Çeliksu', 'Ülkemiz' and 'Rizellim' cultivars and 140Ru, SO4, and 110R rootstocks were used. The experiment was established as four varieties, three rootstocks, and three replications. At the end of the vegetation period, the vine saplings removed from the nursery plots were selected from those best represented the combinations. Measurements were made on the root parts of 9 saplings from each combination by taking three saplings per replication. The removed root parts were carefully washed and dried. WinRhizo root analysis program (ver. 2013, Regent Instruments, QC, Canada) was used to examine root architecture and determine root development. Roots prepared for scanning were placed on acetate paper. The scanning process was transferred to the computer environment on the scanner (Epson Expression 10000XL, Epson America Inc., Long Beach, CA, USA) part of the device.

Parameters analyzed with the WinRhizo program in American grape rootstocks are total root length (cm), root surface area (cm^2), root volume (cm^3), average root diameter (mm), root tip (type) number (piece), root branching (fork) number of roots (pieces), the number of root crossings (pieces) was determined, and root fresh and dry weights (g) were taken.

The obtained data were subjected to analysis of variance. “JMP-8” statistical package program was used in the evaluation of the data, and whether the difference between cultivar, rootstock, and cultivar/rootstock combinations was significant was determined by the LSD ($p<0.05$) test.

RESULTS and DISCUSSION

Determination of root length and root diameter are two of the most important features when defining roots in revealing root architecture. WinRhizo is a device that performs and facilitates these measurements (Bouma et al., 2000). Total root length values of American vine rootstocks grafted with different fragrant grape varieties are given in Figure 1. There was no statistical difference in the effects of cultivar/rootstock combination, cultivar, and rootstock on total root length. Total root length is 330.05 - 595.40 cm in cultivar/rootstock combination ('Rizellim'/SO4 and 'Çeliksu'/140Ru), in rootstocks 400.59 - 499.80 cm (SO4 and 140Ru), in cultivars 417.93 - 507.53 cm ('Ülkemiz' and 'Çeliksu') ranges were obtained. While statistically significant differences were found in the effects of rootstocks on the mean root diameter, the differences in the cultivar and variety/rootstock combinations were statistically insignificant. At rootstock level, 110R (2.95 mm) was statistically in the first important group; SO4 (2.55 mm) and 140Ru (2.32 mm) were in the second important group. The mean root diameter was determined between 2.04 mm ('Çeliksu'/140Ru) - 3.13 mm ('Rizessi'/110R) in cultivar/rootstock combinations, and 2.32 mm ('Çeliksu') - 2.84 mm ('Ülkemiz') in cultivars (Figure 2). Examining the development status of root architecture in drought conditions, Yıldırım et al. (2018) determined the total root length between 269 cm (41B) and 331 cm (110R) under well-irrigated conditions. The root lengths obtained as a result of the study were higher than those of the researchers. In the study conducted with 1103P and Pinot Noir cultivars, root diameter was not affected by cultivar/rootstock combinations (Gautier et al., 2021). In the results obtained, no statistical difference was found in cultivar/rootstock combinations.

The differences between the cultivar/rootstock combination and the effects of cultivars on the root surface area of the roots obtained from the grafted vine saplings were statistically insignificant, while the differences between the effects of the rootstocks were significant (5%). In the effects of rootstocks on root surface area, 110R (399.67 cm^3) was in the first important group, 140Ru (352.86 cm^3) was in both importance groups, SO4 (294.95 cm^3) was in the second important group. Root surface area at cultivar level was determined between 322.57 cm^3 ('Rizellim') and 367.51 cm^3 ('Çeliksu'), and in cultivar/rootstock combinations it was determined between 263.01 cm^3 ('Ülkemiz'/SO4) and 476.02 cm^3 ('Rizessi'/110R) ranges (Figure 3). Besides root length, root surface area is an important indicator for potential water and nutrient uptake from the soil (Himmelbauer, 2004). While there was no statistical difference between the effects of cultivar/rootstock combination and cultivars on root volume in the grafted vine saplings obtained, a significant difference was determined between the effects of rootstocks. Root volume values were obtained between 17.63 cm^3 ('Rizessi'/140Ru) and 35.03 cm^3 ('Rizessi'/110R) cultivar/rootstock combination, and between 21.04 cm^3 ('Çeliksu') and 24.51 cm^3 ('Ülkemiz') cultivars. In the effect of rootstocks on root volume, the highest value was determined as 29.32 cm^3, and the lowest value was determined as 18.92 cm^3 (Figure 4).

While there was no statistical difference in the effect of cultivar/rootstock combination on the number of root tips (type), significant differences were determined in the effect of cultivars and rootstocks. While 110R (1605.75 units) and 140Ru (1499.92 units) were statistically included in the first significant group, SO4 (1110.94 units) was in the second important group. The highest value was obtained in 'Ülkemiz' (1550.63 units) and the lowest value in 'Rizellim' (1178.85 units) cultivars. The number of root tips in the cultivar/rootstock combination ranged from 769.11 ('Rizellim'/SO4) to 1877 ('Ülkemiz'/110R) (Figure 5). In the study in which 1103P and Pinot Noir varieties were grafted on each other and themselves, the number of root tips was higher in the 1103P rootstock, and the number of root tips was affected by the rootstock (Gautier et al., 2021). The root tip results obtained were similar to the researchers' results, and the root tip numbers were affected by the rootstocks. No statistically significant differences were found in the effects of cultivar/rootstock combination and cultivars on the number of forks. The differences in the effects of rootstocks are statistically significant. The number of root branching was between 2546.22 and 6150.22 ('Rizellim'/SO4 and 'Ülkemiz'/110R, respectively) in cultivar/rootstock combinations 3996.63 and 5150.70 ('Rizellim' and 'Çeliksu', respectively) in cultivars. The highest number of root branching in rootstocks was obtained in 110R rootstock with 5421.89 units, followed by 140Ru with 5079.78 and SO4 rootstock with 3564.42 (Figure 6). While there was no statistical difference between the effects of cultivar/rootstock combination and cultivars on the number of root crossings, significant differences were determined between the effects of rootstocks. The number of root crossings varied between 249.11 - 764.33 in cultivar/rootstock combination ('Rizellim'/SO4 and 'Çeliksu'/110R, respectively) and between 477.85 - 651.66 in cultivars ('Rizellim' and 'Çeliksu', respectively). In rootstocks, 110R was in the first place with 671.61, 140Ru was in the second place with 628.69, and SO4 was in third place with 421.83 (Figure 7). In the study in which the root architecture of commonly used vine rootstocks and clones were evaluated with WinRhizo software, the mean root diameter of the 110R plant was similar in three different culture media. In other rootstocks, differences in root architecture values were determined. The highest values of total root length, area, volume, root tip, and root branching numbers were obtained from 110R rootstock under all conditions (Peiro et al., 2020). The highest values were determined in 110R rootstock in general, and similar results were obtained with the researchers.

The correlation levels between the determination of root architecture and the results obtained are given in Table 1. While significant positive relationships were determined between root length and root volume, root tip number, root branching number, and root intersection number, negative relationships were determined with mean root diameter. Positive relationships were found between mean root volume and root volume.

Conclusions

As a result of the research, when all root elements were evaluated together, 110R rootstock stood out as the rootstock with the best values. As a result of the study, the total root length was determined between 330.05 - 595.40 cm ('Rizellim'/SO4 and 'Çeliksu'/140Ru) and the mean root diameter was 2.04 - 3.13 mm ('Çeliksu'/140Ru and 'Rizessi'/110R)'. Negative relationships were found between root length and mean root diameter. Among the rootstocks, 110R rootstock had the highest root surface area of 399.67 cm^2, root volume 29.32 m^3, root tip number 1605.75, root branching number 5421.89, and root intersection number 671.61. Although there were statistical differences between the rootstocks used, there was no difference between the combinations. It was determined that the roots performed well in rootstocks grafted with different varieties, and these rootstocks could be used.

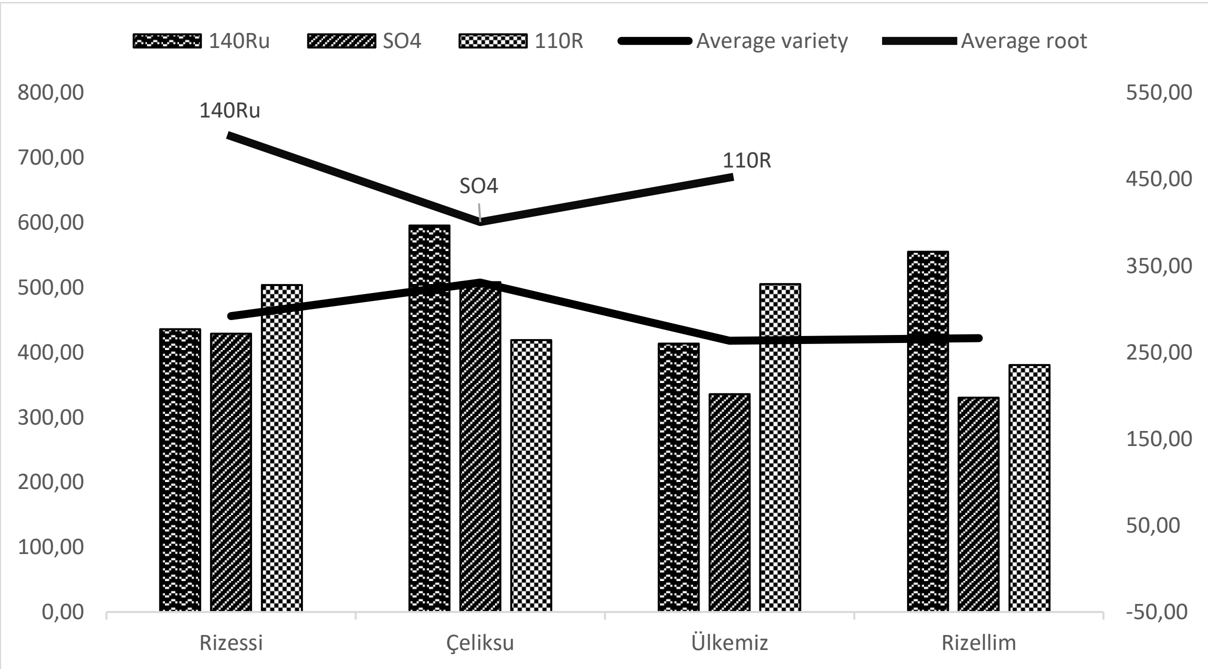

Figure 1. Total root length (cm) in American grapevine rootstocks grafted with different foxy grape varieties.

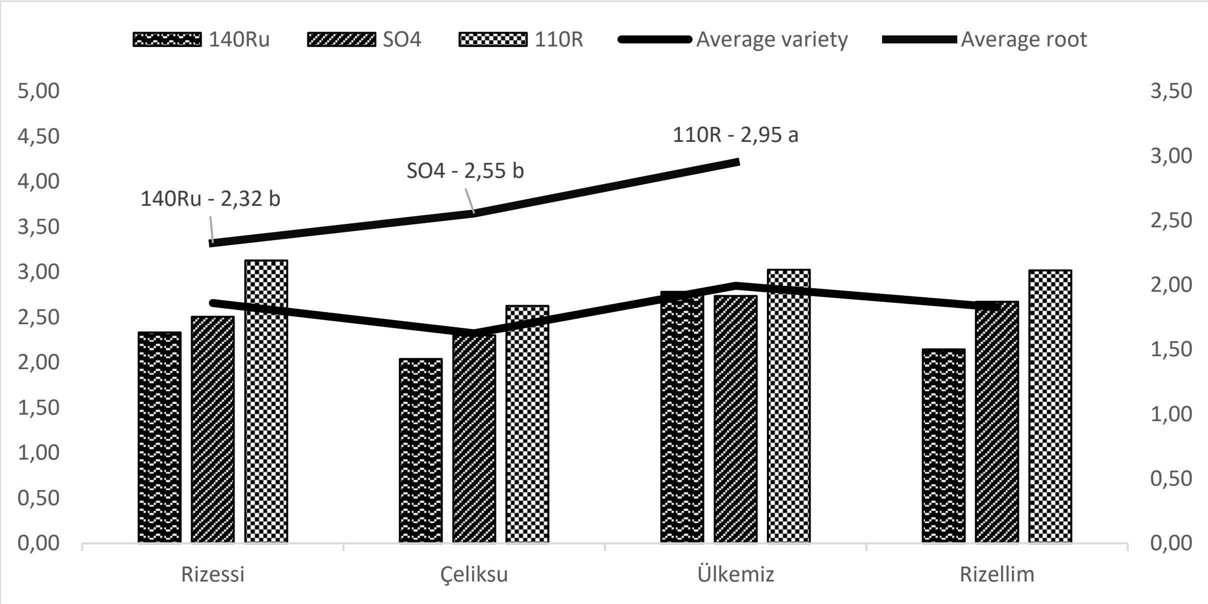

Figure 2. Total root diameter (mm) of American grapevine rootstocks grafted with different foxy grape varieties. Rootstock LSD: 0.32 $p<0.01$

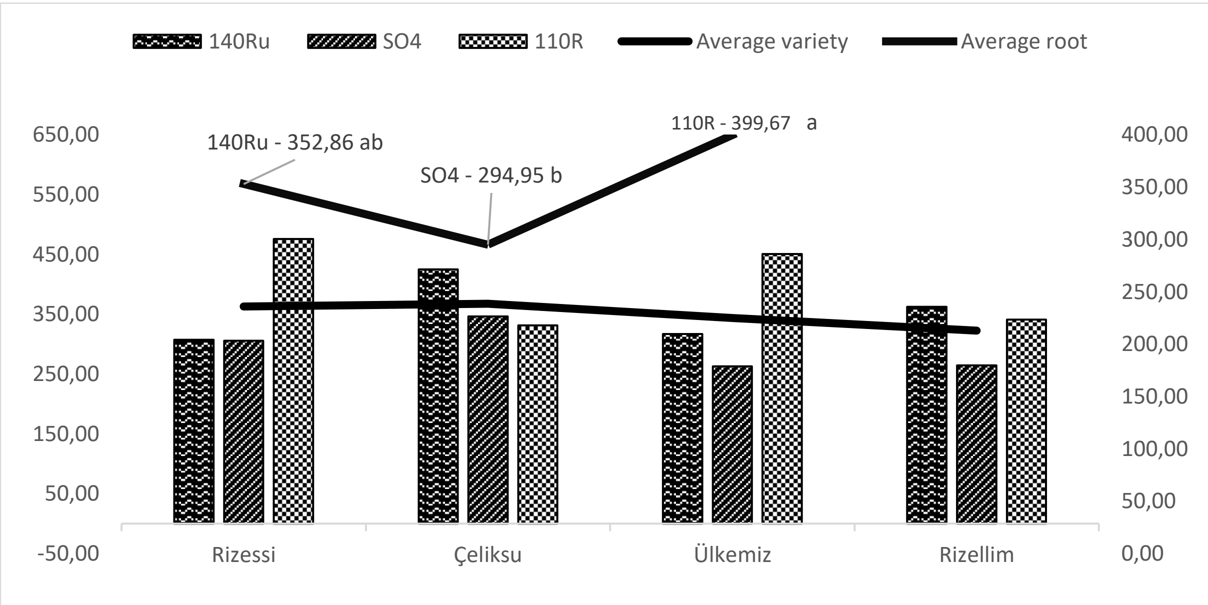

Figure 3. Root surface area (cm^2) of American grapevine rootstocks grafted with different fragrant grape varieties. Rootstock LSD: 61.03 $p<0.01$

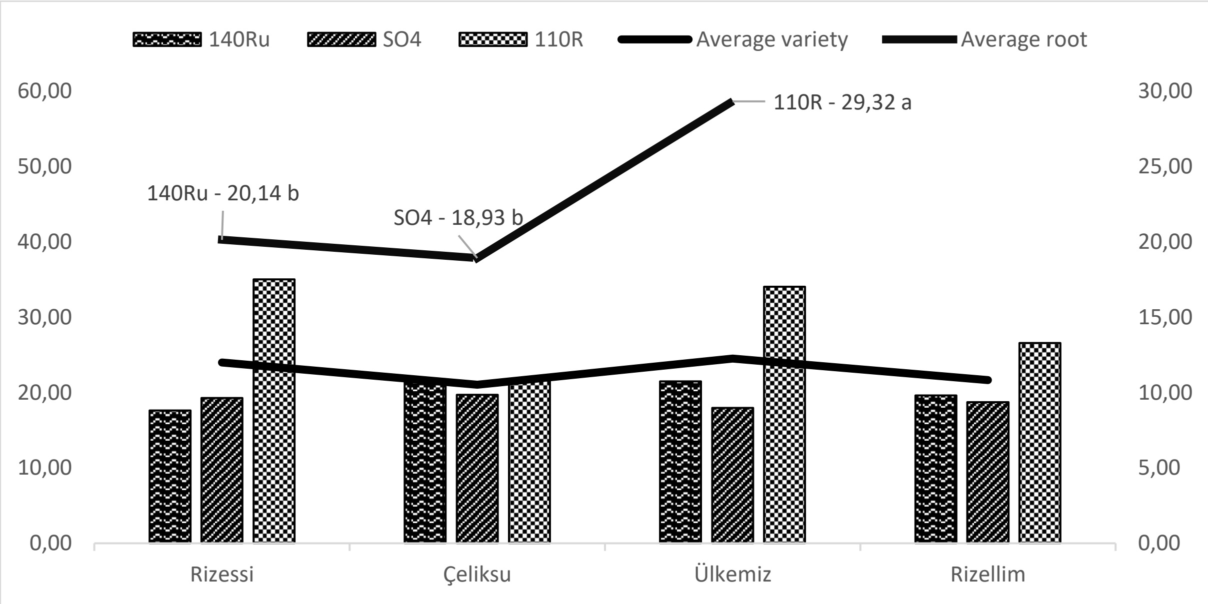

Figure 4. Root volume (cm^3) of American grape rootstocks grafted with different foxy grape varieties. Rootstock LSD: 4.39 p<0.01

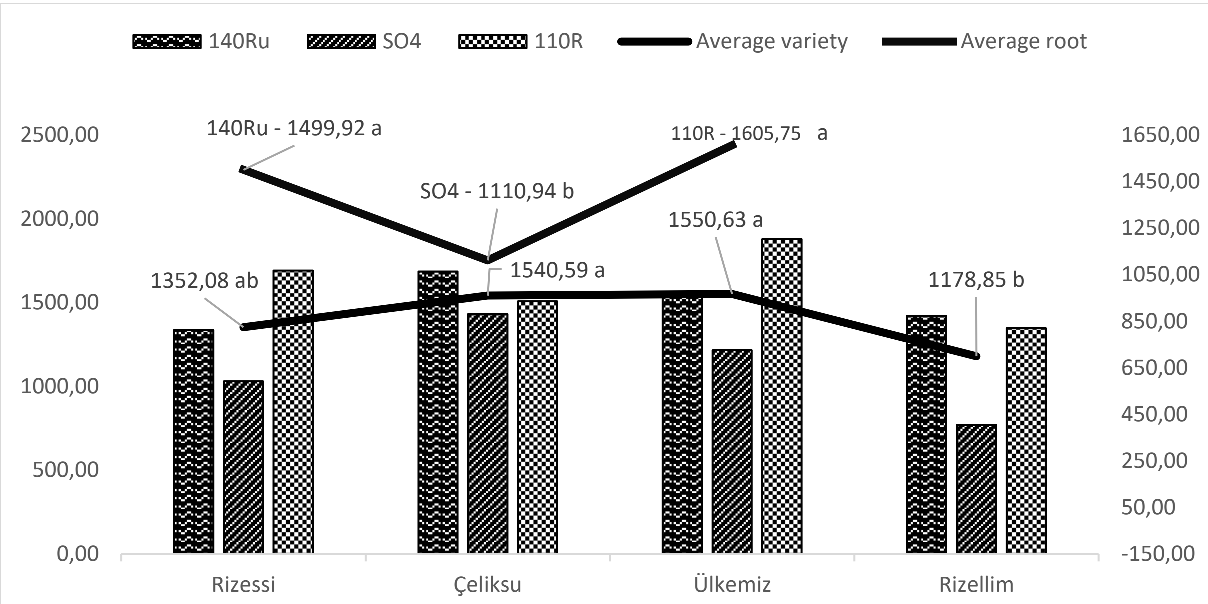

Figure 5. Number of root tips (pieces) in American grapevine rootstocks grafted with different foxy grape varieties. Rootstock LSD: 249.43 p<0.01, Variety LSD: 288.01 p<0.05

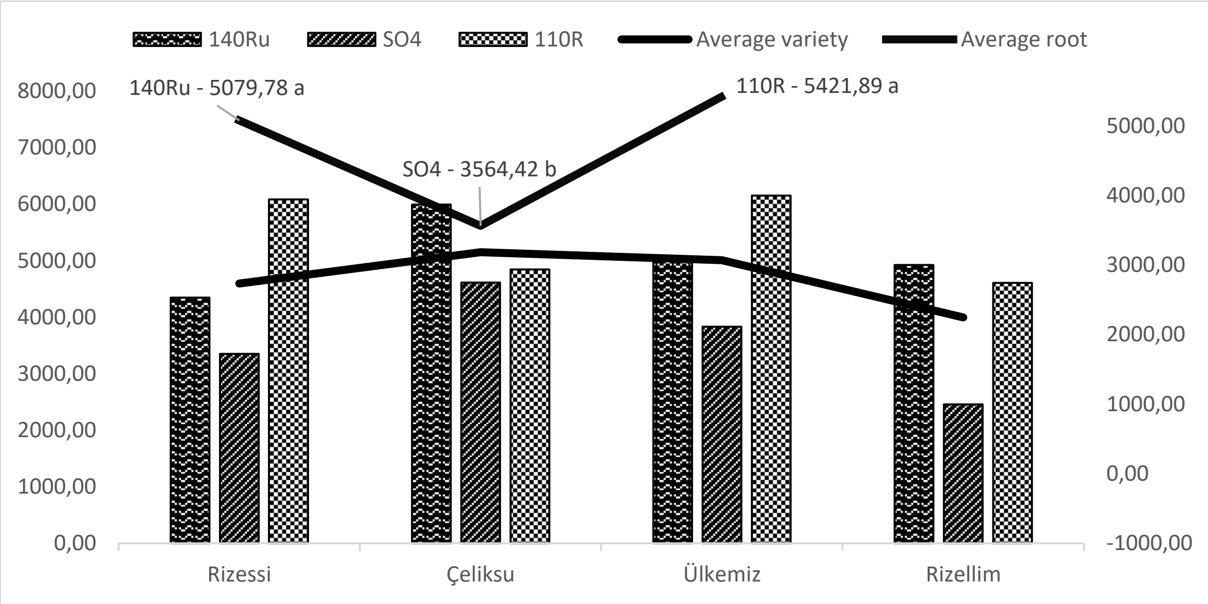

Figure 6. Root fork number (pieces) in American grapevine rootstocks grafted with different foxy grape varieties. Rootstock LSD: 961.31 p<0.01

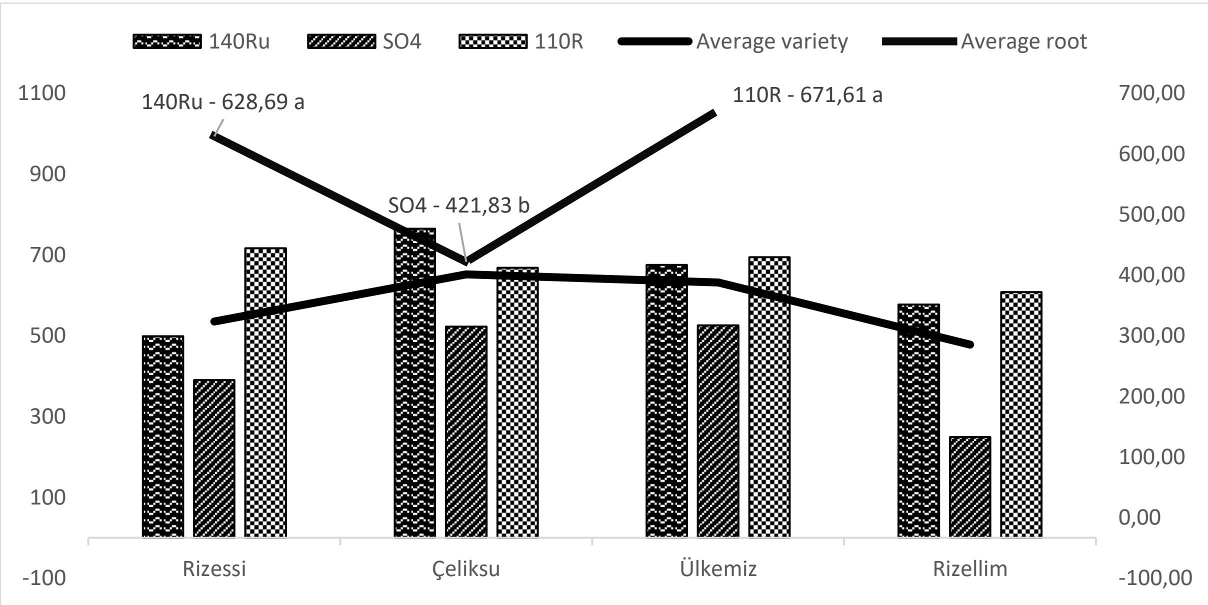

Figure 7. Number of root crossing (pieces) in American grapevine rootstocks grafted with different foxy grape varieties. Rootstock LSD: 154.77 p<0.01

Table 1. Correlations between the results obtained

	Root surface area	Average root diameter	Root volume	Number of tips	Number of fork	Number of crossing
Total root length	0,793*	-0,428*	0,363*	0,627*	0,691*	0,397*
Root surface area		0,085	0,827*	0,786*	0,870*	0,614*
Average root diameter			0,609*	0,103	0,124	0,240
Root volume				0,646*	0,722*	0,572*
Number of tips					0,973*	0,903*
Number of fork						0,900*

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