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Rootstock and Training Effects on Growth and Fruit Quality of Young '0900 Ziraat' Sweet Cherry Trees

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Abstract

The study was conducted to determine the performance of '0900 Ziraat' cultivar grafted on Krymsk 5, Gisela 6 and Piku 1 rootstocks, and the effects of the combinations of these rootstocks with four training systems on yield and quality of sweet cherry. The rootstocks and training systems had a significant effect on vegetative growth and fruit quality. Krymsk 5 × Vogel central leader produced the largest trees. There were no differences between the rootstocks in terms of fruit size; however, the largest fruit was obtained from trees trained to Vogel central leader (VCL) and super slender axe (SSA) as compared to Kym Green bush (KGB) and upright fruiting offshoots (UFO). The coloration on the fruit of the trees grafted on Piku 1 and Krymsk 5 rootstocks and trained to the SSA training system was better and the fruit firmness values were higher with the Gisela 6 × SSA combination. The highest soluble solids content (SSC) values were recorded with Piku 1 × SSA and Gisela 6 × SSA combinations. The bioactive compound content of the fruit varied depending on the rootstock and training system. The fruit of Piku 1 × VCL combination had higher total phenolic content. Antioxidant activity was higher in Krymsk 5 × UFO combination. The study revealed that fruit quality was better with SSA and VCL training systems.

Keywords Antioxidant activity · Gisela 6 · Krymsk 5 · Phenolics · Piku 1

Introduction

Climate change induced by global warming is causing a decrease of global vegetative production areas. This situation necessitates the more efficient use of current production areas, to ensure adequate food supplies throughout the world. Therefore, the main aim in fruit production should be to obtain more and higher quality fruit from a unit area. This aim can be achieved with intensive planting systems, which limit the vegetative development, provide higher yield and quality fruit per unit area, and minimize the expenses of cultural practices such as harvest.

The establishment of these intensive planting systems is possible with the use of size limiting rootstocks and suitable modern training systems. When sweet cherry trees are grown with their natural habits, they grow upright and strong and produce large trees with yield and quality problems. Therefore, the use of size limiting rootstocks for sweet cherries is of great importance. Depending on the rootstock used, differences in vegetative development of the tree (Blažkova et al. 2010; Aglar et al. 2016), fruit quality characteristics such as fruit size (Facteau et al. 1996; Long et al. 2010), fruit firmness, color, titratable acidity, total soluble sugar (Gonçalves et al. 2005; Cantín et al. 2010; Lopez-Ortega et al. 2016; Milinoviç et al. 2016; Pal et al. 2017) and in the concentration of bioactive compounds such as phenolic compounds and flavonoids (Jakobek et al. 2009; Usenik et al. 2010; Milinoviç et al. 2016) may occur. In their natural form, sweet cherry trees produce narrow angled branches and a tall canopy. The growth of the tree is rapid and apical dominance is strong. The fruit yield and quality of such trees is low. These negative characteristics of sweet cherry trees can be changed by using size controlling rootstocks that ensure precocity.

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With size controlling rootstocks, limiting tree height is easier and branches occur at a naturally wider angle. However, it is difficult to obtain the desired yield and fruit quality from these trees without applying the proper training system (Long 2003). For this reason, the training system choice is of great importance and must be carefully considered, as the training system can have an effect on tree vigor, fruit quality, precocity and cultural applications (Long et al. 2010). In fact, the training system directly affects such characteristics as tree growth (Blažkova et al. 2010; Aglar et al. 2016; Demirsoy et al. 2017), precocity (Radunić et al. 2011), fruit yield (Whiting et al. 2005; Long et al. 2010), fruit size (Facteau et al. 1996; Aglar et al. 2016; Demirsoy et al. 2017), fruit firmness (Marini et al. 2009; Demirsoy et al. 2017), fruit color (Peterson et al. 2003; Cantín et al. 2010; Aglar et al. 2016), soluble solids content (Veberic 2005; Gonçalves et al. 2005; Usenik et al. 2010), and the concentration of bioactive compounds (Ates and Ozturk 2023; Serra et al. 2011). In previous studies (Long et al. 2010; Lopez-Ortega et al. 2016; Milinoviç et al. 2016; Pal et al. 2017), the various rootstock × training system combinations have been developed to ensure many specific needs such as smaller trees, greater yield per unit area, better quality fruit, and easier applications of cultural practices, such as harvest, etc.

There are almost no studies in this regard in Türkiye. The aim of the study is to determine the performance of '0900 Ziraat' cultivar grafted on Krymsk, Gisela 6 and Piku 1 semi-vigorous rootstocks, which allow denser plantings, and the effects of the combinations of these rootstocks with the training systems as it relates to yield and fruit quality.

Materials and Methods

Plant Material

The study was carried out in the orchard of Sezai Karakoç Vocational and Technical Anatolian High School (40° 10′ 21.77″ North, 38° 06′ 02.34″ East and altitude 972 m) in Susehri district of Sivas province, Türkiye, between 2017 and 2020. Scion wood of '0900 Ziraat' sweet cherry cultivar, was grafted onto Krymsk 5, Gisela 6 or Piku 1 rootstocks and were trained to Kym Green bush (KGB), Vogel central leader (VCL), super slender axe (SSA) or upright fruiting offshoots (UFO) training systems. Trees were irrigated with a drip irrigation system. Since no diseases or pests were observed in the sweet cherry trees, a 2% burgundy slurry was applied only once in each winter period. After planting, each tree was given 10 g of ammonium nitrate, 5 g of potassium sulphate and 5 g of monoammonium sulphate per season.

Method

In the study, the trees were planted at a 4 m × 1 m and 4 m × 2 m planting density in 2017. The measurements of the vegetative growth were made in 2017, 2018 and 2019, while the fruit quality characteristics were determined by measurements made from fruit obtained during the harvest period of 2019 and 2020. However, due to lack of precocity in the KGB training system, fruit set did not occur on the trees trained to that system. Therefore, measurements and analyses regarding the fruit quality characteristics of these trees could not be made. The details of the measurements and analyses made in the trial are presented below.

Vegetative Characteristics

Trunk cross-sectional area (TCSA) (cm^2): The trunk diameter was measured 15 cm above the graft union with a digital caliper (QEM, KMP 150) with a sensitivity of 0.01 mm. TCSA was calculated by using the formula $TCSA = \pi.r^2$.

Leaf area (cm^2): In July of each growth period, 30 leaves from each tree were randomly collected from annual shoots and measured by a digital leaf area meter (LI-COR, Bioscience, USA) and expressed in cm^2.

Canopy volume (m^3): Two measurements were taken of the north–south and east–west directions in the middle of the tree canopy, and the canopy width (R, diameter) was determined by calculating the average of these two values. Then, the distance between the point where the lowest branch was formed and the top of the canopy was measured and the canopy height (h) was determined in meters. Canopy volume was calculated using the formula $V = \pi r^2.h / 2$ and expressed in m^3.

Fruit Quality Characteristics

Fruit weight (g): The weight of 20 fruit harvested randomly from each tree were measured by digital scales (Radwag, Poland) with a sensitivity of 0.01 g and average fruit weight calculated.

Fruit color: The fruit color was determined by the colorimeter (Minolta, CR-400, Japan) of 20 fruit collected from each tree. The measurements were taken from opposite points of the equatorial part of each fruit. Fruit color was determined as a *value.

Fruit firmness: The fruit firmness of 20 fruit from each tree was determined by a digital firmness meter (Agrosta 100 field, Agrotechnologie, Serqueux, France). The 10 mm end of the device was brought into contact with the opposite cheeks of the equatorial part of the fruit vertically, and then the percentage value appearing on the digital screen was recorded.

Soluble solids content (SSC) and titratable acidity (TA): A total of 20 fruit from each tree were juiced and then the juice samples were used for measuring SSC (digital refractometer PAL-1, Atago) and TA. TA was measured by titration with 0.1 N NaOH and expressed in g malic acid 100 ml of juice.

Bioactive Compounds and Antioxidant Capacity

For the determination of the vitamin C, the reflectoquant device (Merck r5qflex plus 10, Türkiye) was used. 0.5 ml of the fruit juice sample obtained for the SSC measurement, was taken, 0.5% oxalic acid was added to it and it was completed to 5 ml. Afterwards, the ascorbic acid test kit (Catalog no: 116981, Merck, Germany) was immersed in the solution for 2 s, it was waited to oxidize outside for 8 s, and then the reading was done by placing it in the test adapter of the Reflectoquant device until the end of the 15th second. The results were expressed as mg 100 g^{-1} (Ozturk et al. 2019).

For measurement of the total phenolics, antioxidant capacity and total anthocyanin, 30 fruit were harvested randomly from each repetition and the flesh were separated from the seeds. The fruit flesh was then homogenized with a blender, and approximately 100 g of the fruit flesh was stored in a deep freezer at –80 °C in falcon tubes until analysis was made.

Total phenolics were determined using the Folin–Ciocalteu reagent as described in the study of Singleton and Rossi (1965). Fruit extract, Folin–Ciocalteu and distilled water were mixed in a ratio of 1:1:20 and then 7% sodium carbonate was added. After 2 h of incubation, the solution, which turned into a bluish color, was measured in the spectrophotometer at 750 nm wavelength and the results were calculated as µg GAE g^{-1} fresh fruit in gallic acid.

The TEAC method was used to determine the antioxidant capacity. For TEAC analysis (Ozgen et al. 2006), 7 mM ABTS (2,2′-Azino-bis 3-ethylbenzothiazoline-6-sulfonic acid) was mixed with 2.45 mM potassium bisulphate and kept in the dark for 12–16 h. Then, this solution was simplified to an absorbance of 0.700 ± 0.01 at a wavelength of 734 nm in the spectrophotometer using sodium acetate (pH 4.5). Finally, by mixing 2.98 mL of prepared bafur into 20 µL of fruit extract, the absorbance was measured in the spectrophotometer at 734 nm wavelength after 10 min. The absorbance values obtained were calculated with Trolox (10–100 µmol/L) standard slope chart and expressed as µmol Trolox equivalent/g fresh fruit (µmol TE g^{-1}).

The total anthocyanin amount in the fruit was determined by using the pH difference method (Giusti et al. 1999). The extracts were prepared at pH 1.0 and 4.5 and measured at 520 and 700 nm wavelengths. Total anthocyanin amount (molar extinction coefficient of 29,600 cyanidin-3-glucoside) was determined as absorbances ([A520 – A700] pH 1.0 – [A520 – A700] pH 4.5) and µg cyanidin 3 glycosides/g fresh fruit (µg cy-3-glu g^{-1}).

Statistical Analysis

The trial was established in spit plot design with four replications. After the data obtained were analyzed with analysis of variance, the level of the significance between the treatments was determined by the Tukey multiple comparison test. Statistical analysis was performed using the SAS package program (SAS 9.1 version, USA). The significance level was taken into account as $\alpha = 5\%$ in statistical analysis and interpretation of the results.

Table 1 Effects of rootstocks and pruning systems on trunk cross-sectional area (*TCSA*) of '0900 Ziraat' sweet cherry cultivar

Rootstocks	TCSA (cm^2)			
	KGB	VCL	SSA	UFO
2017				
Gisela 6	6.69 a-AB	8.97 a-A	5.43 a-B	7.69 a-A
Piku 1	6.15 b-A	5.31 b-B	4.01 c-C	5.14 c-B
Krymsk 5	6.47 a-A	5.64 b-AB	5.14 b-B	6.11 b-A
2018				
Gisela 6	11.52 c-B	19.78 a-A	13.32 a-B	19.31 a-A
Piku 1	27.14 a-A	15.83 b-B	11.46 b-B	15.61 b-B
Krymsk 5	21.06 b-A	20.34 a-A	14.65 a-B	17.05 ab-AB
2019				
Gisela 6	39.78 a-B	50.04 a-A	21.96 c-C	32.01 b-B
Piku 1	31.99 c-A	25.77 b-B	25.88 b-B	30.38 b-A
Krymsk 5	34.87 b-B	52.78 a-A	31.78 a-B	35.97 a-B

Means indicated with the same capital letter in same line, and with same lower-case letter in same columns do not differ according to Tukey's test at $P<0.05$

KGB Kym Green Bush, *VCL* Vogel Central Leader, *SSA* Super Slender Axe, *UFO* Upright Fruiting Offshoots

Results

Vegetative Growth

In the first year of the experiment, the lowest TCSA value on all three rootstocks was associated with the SSA training system. There was no significant difference between the TCSA values of KGB, VCL and UFO systems on Gisela 6 and Krymsk 5 rootstocks. On the Piku 1 rootstock, the TCSA of the trees with the KGB system was found to be higher than the TCSA of the trees trained with the other systems. When rootstocks were compared in the training systems, the trees grafted to Piku 1 rootstock in all four training systems had lower TCSA values than others. In the second year of the experiment (2018), the effect of the rootstock and training system interaction on TCSA became more evident. With Gisela 6, the TCSA value of trees trained to VCL and UFO systems was significantly higher than that of the trees trained with KGB and SSA. With Piku 1, the trees trained to KGB had higher TCSA values than those pruned with other training systems. With Krymsk 5, it was determined that the SSA training system produced a smaller TCSA value compared to other training systems. When the effect of rootstocks in training systems was examined, similarly, it was determined that the effect of rootstocks on TCSA changed depending on the training system. The most significant difference between rootstocks was seen in the KGB training system. In this training system, the TCSA values of the trees grafted to Gisela 6 rootstocks were found to be significantly lower than those grafted to the other two rootstocks (Table 1). In the third year, it was determined that TCSA values changed significantly depending on the effect of the rootstock × training system interaction. For example, on Gisela 6 and Krymsk 5 rootstocks, the highest TCSA value was obtained from the VCL training system, while on the Piku 1 rootstock, the TCSA value of the VCL training system was lower than the KGB and UFO training systems (Table 1).

In the first year of the experiment, the significant differences occurred in the canopy volume of the trees due to the rootstock and training systems. On all three rootstocks, the lowest canopy volume was measured on trees trained with the SSA training system. In the KGB training system, the highest canopy volume was obtained from the Piku 1 rootstock, while the lowest canopy volume was obtained from the Krymsk 5 rootstock. In the VCL and UFO training systems, the trees on Piku 1 formed a smaller canopy compared to those on Gisela 6 and Krymsk 5 rootstocks. When the rootstocks in SSA were compared, it was observed that the Krymsk 5 rootstock increased canopy growth compared to the other two rootstocks. In the second and third years of the experiment, the trees trained to VCL regardless of the rootstock had a larger canopy volume compared to those trained with other training systems. In the last year of the experiment, it was determined that the trees reached the highest canopy volume on Krymsk 5 rootstock, regardless of the training system (Table 2).

In 2018, in all four training systems, the lowest leaf area was attained on trees grafted to the Piku 1 rootstock. The trees trained to KGB on Gisela 6 had smaller leaf area compared to other training systems. With the Piku 1 rootstock, the leaf area of the trees trained to the VCL and SSA systems were higher than the trees trained to KGB and UFO. On Krymsk 5, the trees trained to UFO have a smaller leaf area compared to those pruned with other systems. In 2019, the largest leaf area on all three rootstocks was measured in the KGB-trained trees. When the rootstocks were compared in the training system, it was determined that in the KGB system, the trees grafted to Gisela 6 formed a larger leaf area compared to those on the other two rootstocks. In

Table 2 Effects of rootstocks and pruning systems on canopy volume of '0900 Ziraat' sweet cherry cultivar

Rootstocks	Canopy volume (m^3)			
	KGB	VCL	SSA	UFO
2017				
Gisela 6	1.02 b-AB	1.38 a-A	0.26 b-C	0.65 a-B
Piku 1	1.21 a-A	0.74 b-AB	0.24 b-C	0.49 b-B
Krymsk 5	0.88 c-B	1.52 a-A	0.41 a-C	0.70 a-B
2018				
Gisela 6	2.42 b-B	5.19 a-A	2.15 b-B	1.55 b-B
Piku 1	2.62 a-B	4.23 b-A	2.30 b-B	1.45 b-B
Krymsk 5	2.23 c-C	5.88 a-A	3.56 a-B	1.95 a-C
2019				
Gisela 6	2.78 b-B	6.14 b-A	3.52 b-B	2.44 c-B
Piku 1	2.98 b-B	4.89 c-A	2.98 b-B	3.30 b-B
Krymsk 5	4.35 a-B	8.08 a-A	5.81 a-B	4.47 a-B

Means indicated with the same capital letter in same line, and with same lower-case letter in same columns do not differ according to Tukey's test at $P < 0.05$

KGB Kym Green Bush, *VCL* Vogel Central Leader, *SSA* Super Slender Axe, *UFO* Upright Fruiting Offshoots

Table 3 Effects of rootstocks and pruning systems on leaf area of '0900 Ziraat' sweet cherry cultivar

Rootstocks	Leaf area (cm^2)			
	KGB	VCL	SSA	UFO
2018				
Gisela 6	76.8 b-B	83.5 a-A	84.6 a-A	86.0 a-A
Piku 1	71.5 c-B	77.0 b-A	76.9 b-A	73.1 c-B
Krymsk 5	83.1 a-AB	85.6 a-A	85.1 a-A	80.9 b-B
2019				
Gisela 6	98.1 a-A	75.4 a-B	78.5 a-B	63.8 b-C
Piku 1	91.5 b-A	63.9 b-B	63.7 b-B	72.9 a-B
Krymsk 5	93.2 b-A	77.7 a-B	77.7 a-B	76.6 a-B

Means indicated with the same capital letter in same line, and with same lower-case letter in same columns do not differ according to Tukey's test at $P < 0.05$
KGB Kym Green Bush, *VCL* Vogel Central Leader, *SSA* Super Slender Axe, *UFO* Upright Fruiting Offshoots

the VCL and SSA systems, the leaf area of the trees on the Piku 1 rootstock was lower than those on the Gisela 6 and Krymsk 5 rootstocks. In the UFO training system, the trees grafted to Gisela 6 had a lower leaf area than those grafted to the other two rootstocks (Table 3).

Fruit Quality Characteristics

With some exceptions, similar fruit weight values were determined in general in all treatments. The only significant difference in 2019 was due to the Krymsk 5 rootstock. The trees on this rootstock produced the largest fruit when pruned to VCL and the smallest fruit when pruned to UFO. In 2020, a similar situation was observed with the Piku 1 rootstock. The trees trained to VCL on Piku 1 rootstock had larger fruit, while the trees trained to SSA produced smaller fruit (Table 4).

The rootstock and training system interaction caused significant differences in a * value. In 2019, the a * value of the fruit harvested from the trees grafted on Gisela 6 rootstocks and trained to UFO was higher than those on trees with other training systems. On the Piku 1 rootstock, the SSA system produced fruits with higher a * values than the other two training systems. Similarly, in 2020, the effect of the rootstocks differed depending on the training systems. For example, while the fruit with the highest a * value on Krymsk 5 rootstock were obtained from the SSA training system, the a * value of fruit obtained from UFO and VCL training systems on Gisela 6 and Piku 1 rootstocks was found to be higher than those obtained from the SSA training system (Table 5).

Table 4 Effects of rootstocks and pruning systems on fruit weight of '0900 Ziraat' sweet cherry cultivar

Rootstocks	Fruit weight (g)		
	VCL	SSA	UFO
2019			
Gisela 6	7.60 b-A	7.47 a-A	7.25 a-A
Piku 1	7.78 b-A	7.99 a-A	7.57 a-A
Krymsk 5	8.33 a-A	7.68 a-AB	6.52 b-B
2020			
Gisela 6	7.65 b-A	7.91 a-A	7.85 a-A
Piku 1	8.00 a-A	7.48 b-A	7.72 a-A
Krymsk 5	7.68 b-A	7.79 a-A	7.77 a-A

Means indicated with the same capital letter in same line, and with same lower-case letter in same columns do not differ according to Tukey's test at $P < 0.05$
VCL Vogel Central Leader, *SSA* Super Slender Axe, *UFO* Upright Fruiting Offshoots

Table 5 Effects of rootstocks and pruning systems on a* value of '0900 Ziraat' sweet cherry cultivar

Rootstocks	a*		
	VCL	SSA	UFO
2019			
Gisela 6	30.68 b-B	28.94 c-B	34.18 a-A
Piku 1	32.69 a-B	39.75 a-A	32.53 b-B
Krymsk 5	32.46 a-B	35.20 b-A	31.74 c-B
2020			
Gisela 6	23.24 a-A	18.67 b-B	22.25 b-A
Piku 1	23.05 a-B	18.98 b-C	27.35 a-A
Krymsk 5	19.61 b-B	24.09 a-A	18.45 c-B

Means indicated with the same capital letter in same line, and with same lower-case letter in same columns do not differ according to Tukey's test at $P < 0.05$
VCL Vogel Central Leader, *SSA* Super Slender Axe, *UFO* Upright Fruiting Offshoots

The effect of the rootstocks on the fruit firmness differed depending on the training system. In 2019, it was determined that the fruit harvested from the trees with SSA training system on Gisela 6 and Piku 1 rootstocks had higher fruit firmness. With the Krymsk 5 rootstock, the firmness values of the fruit harvested from the trees with SSA and UFO training systems was found to be higher than those harvested from the VCL training system. When the rootstocks were compared in the training system, there was no significant difference between rootstocks in terms of the fruit firmness in the SSA training system. With the VCL training system, the highest fruit firmness was obtained with

Table 6 Effects of rootstocks and pruning systems on fruit firmness of '0900 Ziraat' sweet cherry cultivar

Rootstocks	Fruit firmness *		
	VCL	SSA	UFO
2019			
Gisela 6	40.25 a-C	46.68-A	43.38 b-B
Piku 1	37.98 b-B	46.85-A	37.25 c-B
Krymsk 5	31.13 c-B	47.18-A	47.30 a-A
2020			
Gisela 6	71.48 a-A	61.38 b-B	57.95 b-B
Piku 1	57.27 b-C	72.85 a-A	66.78 a-B
Krymsk 5	69.80 a-A	58.50 b-B	65.30 a-A

Means indicated with the same capital letter in same line, and with same lower-case letter in same columns do not differ according to Tukey's test at $P < 0.05$. * The scale ranges from 0 to 100 for very soft to very firm surfaces

VCL Vogel Central Leader, *SSA* Super Slender Axe, *UFO* Upright Fruiting Offshoots

Table 8 Effects of rootstocks and pruning systems on acidity of '0900 Ziraat' sweet cherry cultivar

Rootstocks	Acidity (g malic acid 100 mL^{-1})		
	VCL	SSA	UFO
2019			
Gisela 6	0.51 b-B	0.58 b-A	0.60 a-A
Piku 1	0.49 b-B	0.68 a-A	0.50 b-B
Krymsk 5	0.56 a-B	0.66 a-A	0.52 b-B
2020			
Gisela 6	0.97 a-A	1.00 a-A	0.95 b-A
Piku 1	0.94 a-A	0.95 b-A	0.94 b-A
Krymsk 5	0.95 a-A	0.99 a-A	1.00 a-A

Means indicated with the same capital letter in same line, and with same lower-case letter in same columns do not differ according to Tukey's test at $P < 0.05$

VCL Vogel Central Leader, *SSA* Super Slender Axe, *UFO* Upright Fruiting Offshoots

Gisela 6 and the lowest fruit firmness values was recorded with Krymsk 5. In the UFO training system, the highest fruit firmness was measured with Krymsk 5 and the lowest with Piku 1. With fruit firmness, values measured in the second year, significant differences emerged due to the interaction between the rootstock and training system. For example, the trees grafted to Piku 1 produced fruit with the lowest fruit firmness when trained with VCL and the highest fruit firmness when trained to SSA and UFO (Table 6).

Although the SSC values of the applications were generally at a similar level, some significant differences also occurred due to the interaction effect of the rootstock and training system. For example, in 2019, Piku 1 rootstock yielded fruit with the lowest SSC value with the VCL training system, while the highest SSC value with the SSA training system. In 2020, while there was no significant difference between rootstocks in terms of SSC value in the UFO training system, Krymsk 5 with SSA training system; in the VCL training system, Piku 1 rootstocks had fruit with the lowest SSC value (Table 7).

Table 7 Effects of rootstocks and pruning systems on SSC of '0900 Ziraat' sweet cherry cultivar

Rootstocks	SSC (%)		
	VCL	SSA	UFO
2019			
Gisela 6	13.55 a-A	13.30 b-A	13.84 a-A
Piku 1	12.00 b-B	14.95 a-A	13.80 a-A
Krymsk 5	13.30 a-A	13.50 b-A	12.03 b-B
2020			
Gisela 6	15.97 b-B	18.00 a-A	16.80 a-B
Piku 1	17.10 a-A	17.67 a-A	16.67 a-A
Krymsk 5	17.30 a-A	16.83 b-A	17.03 a-A

Means indicated with the same capital letter in same line, and with same lower-case letter in same columns do not differ according to Tukey's test at $P < 0.05$

VCL Vogel Central Leader, *SSA* Super Slender Axe, *UFO* Upright Fruiting Offshoots

Although the TA values were generally at similar levels, some significant differences have emerged due to the interaction effect. For example, in 2019, while the fruit with the highest TA value in the VCL training system were obtained from the trees grafted on Krymsk 5 rootstock, the highest TA values were recorded with the trees grafted on Gisela 6 rootstock in the UFO training system. In 2020, while there was no significant difference between training systems in terms of the TA content of the fruit on all three rootstocks, some significant differences were detected between the rootstocks within the training systems (Table 8).

Bioactive Compounds and Antioxidant Capacity

Regardless of the rootstock, in 2019, the highest vitamin C was obtained from the SSA training system among the training systems. The effect of the rootstocks differed depending on the training system. In the VCL training system, Krymsk 5 had the highest vitamin C content, while the same rootstock had the lowest vitamin C in the UFO training system. In 2020, while there is no significant difference in terms of vitamin C between the training systems, some significant differences have emerged between the rootstocks in the training systems. For example, in the VCL training system, the fruit with the lowest vitamin C were obtained from Gisela 6, while the vitamin C content of the fruit on Gisela 6 in the SSA and UFO training systems was higher than those on Krymsk 5 (Table 9).

While there was no significant difference between the training systems on Piku 1 rootstock in terms of total phenol content in the first measurement year, the total phenol content of the fruit obtained from the VCL training system on Krymsk 5 was found to be higher than those obtained

Table 9 Effects of rootstocks and pruning systems on vitamin C of '0900 Ziraat' sweet cherry cultivar

Rootstocks	Vitamin C (mg 100 g^{-1})		
	VCL	SSA	UFO
2019			
Gisela 6	5.80 b-B	6.85 a-A	6.05 a-B
Piku 1	5.30 c-C	6.80 a-A	6.15 a-B
Krymsk 5	6.25 a-B	6.75 a-A	5.85 b-C
2020			
Gisela 6	4.63 c-B	6.40 a-A	6.17 a-A
Piku 1	6.50 a-A	6.30 a-A	6.53 a-A
Krymsk 5	5.97 b-A	5.37 b-A	5.23 b-A

Means indicated with the same capital letter in same line, and with same lower-case letter in same columns do not differ according to Tukey's test at $P < 0.05$
VCL Vogel Central Leader, *SSA* Super Slender Axe, *UFO* Upright Fruiting Offshoots

Table 10 Effects of rootstocks and pruning systems on total phenolics of '0900 Ziraat' sweet cherry cultivar

Rootstocks	Total phenolics (μg GAE g^{-1})		
	VCL	SSA	UFO
2019			
Gisela 6	1263 b-A	1192 b-A	1088 b-B
Piku 1	1228 b-A	1240 a-A	1250 a-A
Krymsk 5	1424 a-A	1154 c-B	1013 b-B
2020			
Gisela 6	646 b-A	593 a-AB	553 b-B
Piku 1	683 a-A	562 b-B	559 b-B
Krymsk 5	577 c-A	554 b-A	588 a-A

Means indicated with the same capital letter in same line, and with same lower-case letter in same columns do not differ according to Tukey's test at $P < 0.05$
VCL Vogel Central Leader, *SSA* Super Slender Axe, *UFO* Upright Fruiting Offshoots

from other training systems. With Gisela 6, the total phenol content of the fruit with the UFO training system was lower than those trained with the SSA and VCL training systems. In the second year, the significant differences emerged in the total phenol content due to the effect of the rootstock × training system interaction. While Krymsk 5 yielded fruit with the lowest total phenol content with the VCL training system, it yielded fruit with the highest phenol content with the UFO training system (Table 10).

In 2019, the highest total monomeric anthocyanin amounts on all three rootstocks were obtained from the UFO training system among the training systems. Regardless of the training system difference, the highest anthocyanin values were reached with Krymsk 5 rootstocks. In 2020, the effect of the rootstocks differed depending on the training systems, while the effect of pruning systems differed depending on the rootstocks. For example, while Gisela 6 produced fruit with the lowest anthocyanin content with the VCL training system, it produced fruit with the highest anthocyanin content with UFO training system (Table 11).

It was determined that the training systems did not cause a significant change in the antioxidant levels of the fruit. The effect of the rootstocks differed depending on the training systems. In first year measurements, with the VCL training system, the antioxidant capacity of the fruit on the Piku 1 and Krymsk 5 rootstocks was higher than those on the Gisela 6 rootstock. While Krymsk 5 yielded fruit with the lowest antioxidant content with the SSA training, it yielded fruit with the highest antioxidant content with the UFO training system. In 2020, the effect of the rootstock on VCL and SSA training systems was the same as in the first year. In the UFO training system, the antioxidant content of the fruit on Gisela 6 was found to be higher than those on the other two rootstocks (Table 12).

Discussion

The vigorous tree growth in sweet cherry is a significant problem as it affects fruit yield and quality as well as cultural practices, such as harvest. For this reason, the primary

Table 11 Effects of rootstocks and pruning systems on total monomeric anthocyanin of '0900 Ziraat' sweet cherry cultivar

Rootstocks	Total monomeric anthocyanin (μg cy-3-glu g^{-1})		
	VCL	SSA	UFO
2019			
Gisela 6	20.50 b-B	18.40 b-B	26.70 b-A
Piku 1	21.70 b-B	19.20 b-B	28.30 b-A
Krymsk 5	32.50 a-B	28.40 a-B	41.10 a-A
2020			
Gisela 6	1.16 c-B	6.68 a-A	7.74 a-A
Piku 1	4.35 b-A	5.72 b-A	1.87 b-B
Krymsk 5	7.84 a-A	6.58 a-A	1.57 b-B

Means indicated with the same capital letter in same line, and with same lower-case letter in same columns do not differ according to Tukey's test at $P < 0.05$
VCL Vogel Central Leader, *SSA* Super Slender Axe, *UFO* Upright Fruiting Offshoots

Table 12 Effects of rootstocks and pruning systems on antioxidant capacity of '0900 Ziraat' sweet cherry cultivar

Rootstocks	Antioxidant capacity (μmol TE g^{-1})		
	VCL	SSA	UFO
2019			
Gisela 6	3.10 b-A	3.47 a-A	3.40 b-A
Piku 1	3.50 a-A	3.45 a-A	3.28 b-A
Krymsk 5	3.52 a-A	3.24 b-A	3.78 a-A
2020			
Gisela 6	1.24 b-A	1.84 a-A	1.63 a-A
Piku 1	1.62 a-A	1.84 a-A	1.49 b-A
Krymsk 5	1.64 a-A	1.43 b-A	1.48 b-A

Means indicated with the same capital letter in same line, and with same lower-case letter in same columns do not differ according to Tukey's test at $P < 0.05$

VCL Vogel Central Leader, *SSA* Super Slender Axe, *UFO* Upright Fruiting Offshoots

goal in sweet cherry production is tree vigor control. This can be achieved with proper rootstock and training system choices. It has been shown by studies that changes occur in the vegetative development of the tree depending on the rootstock used (Blažkova et al. 2010; Aglar et al. 2016) and the chosen training system (Whiting et al. 2005; Long et al. 2010; Radunić et al. 2011; Aglar et al. 2016; Demirsoy et al. 2017). The results obtained in the study we conducted for this purpose support the researchers.

The effects of the rootstock and training system on tree growth vigor, determined by measuring TCSA, canopy volume and leaf area were found to be significant. The growth of the trees on the Krymsk 5 and Gisela 6 rootstocks, which are in the semi-vigorous rootstocks category, was higher than the trees on the semi-dwarf Piku 1 rootstock. Jimenez et al. (2006), Long et al. (2010), Cantín et al. (2010), as well as Sitarek and Bartosiewicz (2012), who reported that the tree strength varied according to the rootstock, determined that vigorous rootstocks had more vegetative growth than dwarf rootstocks. Again Fajt et al. (2009) stated that the rootstock directly affected vegetative performance of the cultivar, and that trees on the vigorous rootstock (F12/1) had a larger canopy volume than trees on dwarf, semi-dwarf and semi-vigorous rootstocks (Tabel Edabriz, Weiroot 72, Weiroot 158, Gisela 4, Gisela 5, Gisela 12). It was determined that the training system had affected the vegetative growth of the tree and that the vegetative development was greatest in trees trained to the VCL training system. It was clear that the different training techniques had a direct effective on these results. Long et al. (2010), reported that the training system treatment affected the tree growth and stated that tree height was kept to 2.5 m with the Spanish Bush training system and 3.5–4 m with the VCL system.

Based on the linear proportion between fruit quality and light intake in the tree, it is possible to achieve high fruit quality in sweet cherry production with the proper rootstock, pruning and training system applications. In this study, low fruit set, due to tree age was helpful in fully revealing the effect of rootstock and training system on fruit size. Indeed, Whiting et al. (2005) and Fajt et al. (2009) emphasized that there was a negative correlation between fruit size and yield per tree and that the difference between rootstocks was significant in terms of fruit size. It was seen that the rootstock and the training system treatment had no effect on the fruit size. However, previous studies have revealed that the rootstock (Facteau et al. 1996; Long et al. 2010) and the training system (Aglar et al. 2016; Demirsoy et al. 2017) affect the size of the fruit. However, some researchers (Blažkova et al. 2010; Long and Kaiser 2010; Radunić et al. 2011) have suggested that the training system had no effect on fruit size.

The significant fruit quality criteria such as fruit color, firmness, SSC and TA changed depending on the training system treatment. Similar to our results, in previous studies it was revealed that the training system had effected quality characteristics such as fruit firmness (Marini et al. 2009; Demirsoy et al. 2017), fruit color (Peterson et al. 2003; Cantín et al. 2010; Aglar et al. 2016) and SSC (Veberic 2005; Gonçalves et al. 2005; Usenik et al. 2010). In the study, it was seen that rootstock had an effect on fruit color and fruit firmness, but not on SSC and TA. Lopez-Ortega et al. (2016), who supports our results by expressing that the rootstock affected fruit firmness, but there were no significant differences between the rootstocks on SSC or TA ratios, have reported that contrary to our results, the rootstock had no significant effect on fruit color. Usenik et al. (2010) determined that rootstock affected the SSC ratio in sweet cherry where the SSC ratio was higher on the dwarf rootstocks, while Dziedzic and Błaszczyk (2019) reported that the rootstock did not affect fruit firmness, but SSC and TA varied depending on the rootstock.

Sweet cherry is rich in bioactive compounds such as sugars, organic acids, vitamins, antioxidants, phenolic compounds and flavonoids, which are effective in the formation of quality characteristics such as taste, flavor and color in the fruit and determine the value of the fruit in terms of human health (Jakobek et al. 2007; Usenik et al. 2008; Fazzari et al. 2008). The concentration of these bioactive compounds varies depending on ecological factors (climate and soil), the rootstock (Usenik and Stampar 2002; Spinardi et al. 2005), the cultivar (Mozetic et al. 2002; Kim et al. 2005; Usenik et al. 2008) and cultural applications such as irrigation, fertilization and pruning (Serra et al. 2011). In the study, the changes in the concentration of bioactive compounds such as vitamin C, total phenolics and total monomeric anthocyanin and antioxidant capacity occurred depending on the rootstock used. The rootstock can affect the concentration of bioactive compounds such as vi-

tamin C, polyphenol and anthocyanin in the fruit of the cultivar grafted on it (Usenik et al. 2010; Milinoviç et al. 2016). Dziedzic and Błaszczyk (2019) reported that trees with different vigor had different phenolic acid and favonol content, while Jakobek et al. (2009) stated that the phenolic and flavonal content of the fruit on the Piku rootstock, which had the highest tree vigor, were higher. In the study, the differences in the concentration of bioactive compounds of the fruit can be explained by the effects of the rootstock on tree physiology. The training system may cause changes in the concentration of bioactive compounds due to its effect on tree growth Serra et al. (2011). In accordance with this explanation, in the study, the differences in the concentration of bioactive compounds in fruit depending on the training system treatment occurred.

Conclusions

It was concluded that rootstock had a significant effect on the vegetative growth and fruit quality of the tree, and trees on Krymsk 5 had more vigorous growth when vegetative growth characteristics such as trunk cross sectional area, canopy volume and leaf area are taken into account. There was no significant effect of rootstock on fruit size. It was found that the rootstock affects fruit color, and that the coloration of the fruit grown onto trees grafted on Piku 1 and Krymsk 5 rootstocks was better. Rootstock also affected fruit firmness. The firmness of the fruit on the trees grafted on Gisela 6 rootstock was highest. The effect of the rootstock on SSC was significant, but it had no significant effect on TA. It was determined that the rootstock did not have a significant effect on the vitamin C content, and the phenol content of the fruit harvested on the trees grafted on the Piku 1 rootstock was highest.

Significant differences occurred between rootstocks in terms of antioxidant activity. With Krymsk 5 rootstock, the fruit with the highest antioxidant activity were obtained. It was also demonstrated that there were differences in terms of vegetative growth and fruit quality between training systems. The trees trained to the VCL system were the largest by canopy volume, but trees trained to KGB had the greatest TCSA. The largest fruits were obtained from trees trained with VCL and SSA training systems. The fruit color and fruit firmness values also varied depending on the training system. The SSA training system had the highest fruit color and firmness values. It was determined that fruit obtained from trees trained to the SSA training system had higher SSC and TA content. The bioactive compound content also changed depending on the training system.

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Conflict of interest E. Aglar, B. Ozturk, O. Saracoglu, L. Edwards Long, K. Yildiz, S. Gun and S. Has declare that they have no competing interests.

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