The Effects of Different Rootstocks on the Graft Success and Stion Development of Some Pear Cultivars
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ABSTRACT
In modern pear growing, quince and pear clonal rootstocks are used instead of pear seedlings. This study aimed to evaluate the effect of different quince and pear rootstocks on the graft success and the stion (scion+rootstock) growth performance of some pear cultivars/genotypes. In the study, quince (Quince BA 29, Quince A and Quince MC), pear (OHxF 333, Fox 11, Farold 40) clones and pear seedlings were grafted in two standard (Deveci and Williams) and 11 local (‘Bardak,’ ‘Dalkıran,’ ‘Eşek,’ ‘İstanbul,’ ‘Kara,’ ‘Karga,’ ‘Karpuz,’ ‘Kış,’ ‘Sarkum,’ ‘Tefenc’ and ‘Yaz Ziraati’) promising pear cultivars were used. Significant differences were observed in both rootstocks and varieties in terms of graft success and plant development in the study. The graft take, sprout and survival ratios were higher in pear rootstocks than in the quince rootstocks. While the highest graft survival ratio was observed in Fox 11, the lowest was in the BA 29 quince rootstock. The highest graft sprout and graft survival ratio were in ‘Deveci,’ the lowest in ‘Williams,’ ‘Bardak’ and ‘Kış’ varieties. While the highest shoot lengths and highest diameters were detected in the pear seedling, the lowest were in the MC rootstock. While the longest shoots were observed in ‘Kara,’ the thickest shoots were observed in ‘Eşek’ genotypes. As a result of this study, it was determined that the 13 pear cultivars/genotypes grafted on different rootstocks were sufficient in terms of graft success and stion growth performances and it was found that stion of sufficient quality could be grown in the field condition.

KEYWORDS
Graft sprout ratio; graft survival ratio; pear; shoot length and diameter; pear varieties; rootstock

Introduction
Pear (Pyrus communis L.) is one of the most cultivated temperate fruit species after grapes and apples and it is grown in all temperature regions in the world (Da Silva et al., 2018; Hancock and Lobos, 2008; Jackson, 2003). According to the FAO data for 2019, there was about 23.9 million tons of pear production in the world. Turkey, with 530.723 tons of pear production has a 2.2% share in this production; it is the 4th biggest producer after China, USA and Argentina (FAOSTAT database collections, 2021). Turkey has got many native fruit species and is one of the primary gene centers of pear. Turkey has a rich variety of pears with more than 600 genotypes and it is an indigenous spreading area to the natural flora of European pears (Ercisli, 2004; Özçağran et al., 2005).

In modern fruit growing, rootstocks with different known properties are generally used. Rootstocks play a crucial role in determining orchard efficiency in fruit crops. The role of rootstocks and their use in different fruit crops has a significant impact on fruit crop production by influencing canopy architecture, flowering, nutrition uptake, fruit yield and quality (Rom and Carlson, 1987). Also, rootstocks modify the size and shape of the trees by shortening the internodal length, altering the angle of the branches, increasing the development of fruit crops and are capable
of suppressing the growth of the grafted variety, as compared to the growth of that variety on its own roots (Webster, 1995). Plants grown on a seedling rootstock often develop a large and vigorous architecture, making its management difficult compared to clonal rootstocks (Dogra et al., 2018; Rom and Carlson, 1987). Rootstocks are essential component in modern fruit production because of their ability to adapt to a particular cultivar in diverse environmental conditions. It can also resist biotic and abiotic stresses such as soil pests, soil diseases, extreme temperatures, nutritional stresses by better anchorage (Barritt, 1992; Dolkar et al., 2018; Hartmann et al., 2011; Webster, 1995).

Modern pear growing in recent years with quince rootstocks such as Quince A, Quince C, BA 29, Adams, Sydo, have been recommended for quality fruit production because they have provided good fruit quality, harvesting and other cultural practices which are easy to manage on the other side size of the tree is small compared to the seedling or pear clonal rootstocks (Ozturk and Ozturk, 2014; Sharma et al., 2009). Commercial pear cultivars elsewhere in the world are usually grafted on rootstocks of Pyrus and Cydonia. Dwarfing Pyrus rootstocks, such as Pyrodwarf, BP, OHxF, Farold, Fox series and quinces rootstocks have been widely used due to some beneficial characteristics such as tree size reduction, yield precocity and improvements in fruit size and quality. Pyrus rootstock produces a large tree but it is slow to bear fruit (Barritt, 1992; Bell et al., 1996; Francescatto et al., 2010; Stern, 2008). In fruit growing, cultivars are grafted on rootstocks with different growth and development vigor. Grafting is an asexual method of reproducing fruit plants. The most suitable vegetative reproduction method in the pear is grafting (Rahman et al., 2017). The vegetative reproduction method, as in many fruit species, is mostly used in pear nursery production. Grafting can be made between different varieties of the same species as well as between species or genera. When the grafting is made on different genera or species, graft incompatibility may occur. Incompatibility that occurs when pear is grafted on the quince is located incompatibility. This phenomenon, which emerges as a delayed incompatibility many years after the grafting, causes significant economic losses for the producers as well as the death of trees (Bell et al., 1996; Ermel et al., 1999, 1997; Hartmann et al., 2011; Westwood, 1995).

The choice of a proper rootstock is an important stage of successful fruit production. The selection of rootstock in any situation depends upon the choice of the training system, spacing, site, vigor, scion variety, plant growth and development and soil e.g. the incidence of soil-borne diseases or replant diseases (Baron et al., 2019; Bhat et al., 2011; Rahman et al., 2017). Furthermore, the selection of a proper rootstock and a suitable variety is necessary in order for the relationship between the rootstock and scion to continue healthily and future economic losses of producers. In addition, it is important to reveal the relationship between the cultivar candidates which are chosen as promising with the rootstocks. Therefore, the present study was aimed to evaluate the graft success and plant growth response of pear cultivars/genotypes on different rootstocks during the nursery period.

Materials and Methods

Experiment Location

The research was conducted at the research station of Ondokuz Mayis University in Samsun province of Turkey (North: 41°21’, East: 36°11’, Altitude: 173 m) between 2014 and 2016. Grafting was performed in the open field. The research area was flat and had a slope of about 1%. The nursery soil structure was clayed-loam, weakly acidic and it was lime-free, unsalted, rich in phosphorus and potassium as well as high in organic matter. The plants were protected from the weed by mulching and drip irrigation was implemented. The climate of the research area (Samsun) is temperate. The climatic data of the experimental area was measured with a mechanical data logger (KIMO KH-100 Temp/RH data logger) and presented in Figure 1.
In the study, 1-year-old clonal rootstocks of quince (Quince BA 29, Quince A, Quince MC) and pear (OHxF 333 and Fox 11 and Farold 40) and pear seedling were used. The rootstocks were planted 30 cm x 120 cm spacing in February 2014. Eleven promising pear genotypes were determined by Ozturk and Demirsoy (2013) in the province of Sinop, Turkey and were used as scions. The ‘Deveci’ and ‘Williams’ pear cultivars were used as standard cultivars. The ‘Deveci’ is known as being compatible with quince rootstocks (Özçağan et al., 2005) but the ‘Williams’ is known as being incompatible or moderately compatible with quince rootstocks (Dondini and Sansavini, 2012; Gulen et al., 2002; Hudina et al., 2014; Machado et al., 2016). Scions required for grafting were taken from the 5 year-old stock parcel in the experiment area.

**Grafting and Observations**

In the experiment, similar sized scions and rootstocks were selected in the grafting. The T-budding method, which is the most suitable graft method in the fall period (Hartmann et al., 2011; Lewis and Alexander, 2008) was used on the 1 of September 2014 and 2015. Rootstocks were grafted at a point 20 cm above the soil surface (Hartmann et al., 2011). A soft white silicone grafting tape was used to covering the grafted area. Cultivation practices such as irrigation, weed control and removal of suckers below the graft union were done regularly. The rootstocks used in the research were irrigated during the summer using drip irrigation systems. Fertilization was done with a drip irrigation system and fertilizer, which has NPK (20.10.20+ ME, 3–4 kg decare−1) 20 day intervals. There was no chemical spraying in the orchard.

In the study, graft (bud) take ratio (%), graft (bud) sprout ratio (%), graft survival ratio (%), graft shoot length (cm) and diameter (mm) and lateral shoot number (number plant−1) were determined according to previous relevant studies (Ozturk et al., 2011, 2009; Rahman et al., 2017; Zenginbal et al., 2017). After 20 days of budding, the brown and black and shriveled buds were taken as dead, but green buds indicated bud take. The graft take ratio (%) was determined by dividing the number of successful grafts with the total number of grafted plants. The bud sprout ratio (%) was determined by dividing the number of sprouted grafts with the total number of grafted plants after bud burst. The graft survival ratio (%) was determined by dividing the number of surviving grafts with the total number of grafted plants at the end of the vegetation period (December 1st). The graft shoot length (cm) was measured in meters from the graft point to the shoot tip at the end of vegetation (December 1st) for each application. The graft shoot diameter (mm) was measured in 0.01 mm with a sensitive digital caliper at a point 5 cm above the graft union at the end of vegetation (December 1st) for each application.

**Figure 1.** The observed data of mean temperature (°C) and relative humidity (%) in the experimental area during Sep. 2014-Dec. 2016.
lateral shoot number (number plant⁻¹) was determined by counting lateral branches from the main graft shoot at the end of vegetation (December 1st) in all sapling for each cultivar/rootstock combination.

**Data Analysis**

This study was arranged with a randomized complete block design with three replications and each replication contained 15 plants. The data was expressed as a percentage (bud take ratio, sprouting ratio and survival ratio) and was transformed using the arc-sin\(\sqrt{x}\) transformation. Non-transformed values were given in the tables. The data analyses were performed using the SPSS statistical analysis program (vers. 21.0; IBM corporation, New York, USA). The differences between the averages of rootstocks and cultivars and their interaction were determined by ‘Duncan’s Multiple Range Tests’ at a level of 0.05%. The results are given as a two-year average in the tables.

**Results**

**Graft Take Ratio (%)**

The effect of different rootstocks and cultivars on the graft take ratio in the pear is given in Table 1. Rootstocks and cultivars had a significant effect on the graft take ratio. Graft takes among cultivars varied between 90.5% and 99.7%, while it was varied between 90.9% and 96.1% among the rootstocks. The highest graft take ratio in terms of cultivars was found to be in ‘Deveci’ cultivar. The lowest graft take ratio was found to be in ‘Bardak,’ ‘İstanbul,’ ‘Williams,’ ‘Sarıkum,’ ‘Kiş’ and ‘Dalkıran’ pear cultivar/genotypes. In terms of rootstocks, the graft take ratio in the pear clone rootstocks was higher than in the quince. The highest graft take ratio was found to be in O'HxF33 rootstock and the lowest was in Quince A rootstock. According to the average of rootstocks and genotypes, the graft take ratios were observed to be over 90% in the study (Table 1).

**Graft Sprout Ratio (%)**

In the study, there was a significant difference between rootstocks and cultivars in terms of the graft sprout ratio (Table 2). It was determined that pear rootstocks had higher graft sprout ratios than quince rootstocks. The highest graft sprout ratio was observed in the Fox 11 rootstock (94.2%). The lowest graft sprout ratio was observed in the Quince MC (87.9%) and the BA 29 (88.1%) rootstocks.

**Table 1.** The effect of different rootstocks on the graft take ratio (%) of some pear cultivars/genotypes.

| Cultivars/ Genotypes | BA 29 | Quince A | Quince MC | O'HxF33 | Fox 11 | Farold 40 | Seedling | Mean Genotypes |
|----------------------|-------|----------|-----------|---------|--------|----------|----------|----------------|
| Bardak               | 87.5 b | 85.0 b   | 84.3 b    | 95.8 a  | 91.0 ab | 95.0 a   | 95.2 a   | 90.5 d        |
| Dalkır ın            | 91.7 ab| 87.5 b   | 95.0 a    | 91.7 ab | 95.2 ab | 97.5 a   | 91.7 ab   | 92.9 d        |
| Deveci               | 100.0 a| 100.0 a  | 98.0 b    | 100.0 a | 100.0 a | 100.0 a  | 100.0 a  | 99.7 a        |
| Eşek                 | 100.0 a| 95.0 ab  | 88.3 b    | 100.0 a | 97.0 ab | 90.0 ab  | 90.0 ab  | 94.3 c        |
| İstanbul             | 85.8 b | 87.5 ab  | 95.0 a    | 95.8 a  | 95.0 a  | 85.8 b   | 89.0 ab   | 90.6 d        |
| Kara                 | 94.2 bc| 90.0 c   | 96.5 b    | 91.7 bc | 100.0 a | 95.0 bc  | 100.0 a  | 95.3 c        |
| Karga                | 91.7 ab| 87.5 b   | 90.2 b    | 95.8 ab | 96.7 a  | 97.5 a   | 97.1 a   | 93.8 cd       |
| Karpuz               | 81.7 e | 91.0 cd  | 83.8 de   | 100.0 a | 100.0 a | 96.7 b   | 91.7 c   | 92.1 cd       |
| Kiş                   | 91.7 a | 94.2 a   | 93.3 a    | 95.0 a  | 90.8 a  | 90.0 a   | 93.3 a   | 92.6 d        |
| Sarıkum              | 85.0 b | 82.5 b   | 96.7 a    | 95.8 a  | 93.2 ab | 93.3 ab  | 95.0 a   | 91.6 d        |
| Tefenc               | 90.0 a | 94.2 a   | 93.3 a    | 91.7 a  | 96.0 a  | 96.7 a   | 92.5 a   | 93.5 cd       |
| Williams             | 87.5 b | 87.5 b   | 88.3 b    | 95.8 a  | 96.7 a  | 93.3 a   | 91.7 ab  | 91.5 d        |
| Yaz Ziraati          | 100.0 a| 100.0 a  | 91.1 c    | 100.0 a | 96.7 b  | 97.5 ab  | 100.0 a  | 97.9 b        |
| Mean Rootstocks      | 91.3 b | 90.9 b   | 91.8 b    | 96.1 a  | 96.0 a  | 94.5 a   | 94.4 a   |                |

*Different letters in the same line indicate significant differences between rootstocks mean (P < 0.05)

Different letters in the same column indicate significant differences between genotypes mean (P < 0.05)
Table 2. The effect of different rootstocks on the graft sprout ratio (%) of some pear cultivars/genotypes.

| Cultivars/Genotypes | Rootstocks | Mean Genotypes |
|---------------------|------------|----------------|
|                     | BA 29      | Quince A       | Quince MC | OHxF333 | Fox 11 | Farold 40 | Seeding |             |
| Bardak              | 85.2 a     | 83.5 d         | 83.3 d    | 95.0 a   | 88.5 c  | 92.5 b    | 91.5 b   | 88.5 fg    |
| Dalkran             | 91.0 bc    | 85.0 c         | 88.3 c    | 90.0 c   | 94.8 b  | 97.5 a    | 88.5 c   | 90.7 de    |
| Deveci              | 94.2 c     | 100.0 a        | 95.0 c    | 100.0 a  | 100.0 a | 90.0 a    | 96.0 b   | 97.9 a     |
| Eşek                | 97.3 a     | 92.5 bc        | 83.5 d    | 91.5 bc  | 94.8 ab | 88.3 cd   | 87.5 cd  | 90.8 de    |
| İstanbul            | 85.0 b     | 85.0 b         | 84.2 b    | 92.5 a   | 92.5 a  | 84.0 b    | 87.5 b   | 87.2 g     |
| Kara                | 91.0 c     | 90.0 c         | 93.0 c    | 90.5 c   | 100.0 a | 91.7 c    | 97.5 b   | 93.4 c     |
| Karga               | 84.7 c     | 87.5 c         | 90.0 bc   | 95.0 ab  | 94.8 ab | 96.5 a    | 91.5 bc  | 91.4 d     |
| Karpuz              | 81.0 c     | 90.0 b         | 81.7 c    | 94.2 b   | 97.5 a  | 93.8 b    | 90.0 b   | 89.7 de    |
| Kış                 | 82.5 c     | 94.2 a         | 85.8 bc   | 85.2 bc  | 89.2 ab | 86.8 bc   | 89.2 ab  | 87.5 g     |
| Sarıkum             | 82.5 d     | 82.5 d         | 94.8 a    | 93.0 a   | 91.5 b  | 86.8 c    | 92.5 ab  | 89.4 ef    |
| Tefenc              | 89.0 de    | 94.2 ab        | 86.8 e    | 90.0 d   | 92.7 bc | 94.8 a    | 91.0 cd  | 91.2 de    |
| Williams            | 82.5 c     | 87.5 b         | 86.8 b    | 95.0 a   | 93.2 a  | 86.8 b    | 86.7 b   | 88.4 fg    |
| Yaz Ziraat          | 100.0 a    | 97.5 b         | 89.5 d    | 96.8 bc  | 94.8 c  | 94.2 c    | 100.0 a  | 96.1 b     |
| Mean Rootstocks     | 88.1 e     | 89.9 d         | 87.9 e    | 93.1 b   | 94.2 a  | 91.8 bc   | 91.5 c   |             |

a: Different letters in the same line indicate significant differences between rootstocks mean (P < 0.05) 

b: Different letters in the same column indicate significant differences between genotypes mean (P < 0.05)

Among the investigated cultivars, the graft sprout ratio was highest in the ‘Deveci’ cultivar (97.9%), followed by ‘Yaz Ziraati’ (96.1%). The lowest graft sprout ratio was observed in the pear genotypes of ‘İstanbul’ (87.2%) and ‘Kış’ (87.5%) (Table 2). The highest graft sprout ratio (100%) was observed by grafting ‘Yaz Ziraati’ on the BA 29 rootstock; ‘Deveci’ on the QA and OHxF333 and Farold 40 rootstock; ‘Deveci’ and ‘Kara’ on the Fox 11 rootstock; and ‘Yaz Ziraati’ on the seedling rootstock. The lowest graft sprout ratios were observed by grafting ‘Karpuz’ on the BA 29 and the MC rootstocks and ‘Sarıkum’ on the BA 29 and the QA rootstocks. The graft sprout ratios were found to be over 87% in terms of the average of rootstocks and genotypes in the study (Table 2).

Survival Ratio (%)

Rootstocks and scion cultivars/genotypes had statistically significant effects on stion survival ratio (Table 3). The survival ratio was higher in pear rootstocks than quince rootstocks. The highest survival ratio was observed for the Fox 11 rootstock, followed by the OHxF333, the Farold 40 and seedlings, respectively. The lowest survival ratio was observed in the BA 29 rootstock, followed by the QA and MC. While the cultivar of the highest survival ratio was ‘Deveci,’ it was followed by ‘Yaz Ziraati.’ The

Table 3. The effect of different rootstocks on the survival ratio (%) of some pear cultivars/genotypes.

| Cultivars/Genotypes | Rootstocks | Mean Genotypes |
|---------------------|------------|----------------|
|                     | BA 29      | Quince A       | Quince MC | OHxF333 | Fox 11 | Farold 40 | Seeding |             |
| Bardak              | 75.7 f     | 80.0 e         | 82.5 d    | 95.0 a  | 88.5 c | 91.0 b    | 90.0 bc  | 86.1 fg    |
| Dalkran             | 74.2 e     | 83.5 d         | 85.8 cd   | 90.0 c  | 94.8 b | 97.5 a    | 88.3 cd  | 87.7 de    |
| Deveci              | 88.3 d     | 98.5 ab        | 94.0 cd   | 98.0 abc| 99.0 a | 98.0 abc  | 95.0 bc  | 95.8 a     |
| Eşek                | 95.8 a     | 92.5 ab        | 81.5 d    | 90.0 bc | 94.8 a | 85.8 cd   | 86.5 cd  | 89.6 d     |
| İstanbul            | 72.5 d     | 84.0 c         | 83.2 c    | 91.0 a  | 90.0 a | 84.0 c    | 87.5 b   | 84.6 g     |
| Kara                | 84.2 c     | 87.5 bc        | 91.0 b    | 90.5 bc | 99.0 a | 91.7 ab   | 97.5 c   | 91.6 c     |
| Karga               | 76.2 e     | 85.0 d         | 90.0 c    | 92.0 bc | 94.8 a | 94.5 ab   | 90.0 c   | 88.9 de    |
| Karpuz              | 81.0 c     | 87.5 b         | 81.7 c    | 94.2 a  | 94.0 a | 93.3 a    | 87.5 b   | 88.5 de    |
| Kış                 | 82.5 c     | 91.7 a         | 85.8 bc   | 84.2 c  | 89.2 ab| 85.8 bc   | 86.7 bc  | 86.5 fg    |
| Sarıkum             | 70.8 f     | 81.5 e         | 94.8 a    | 94.0 ab | 91.5 bc| 85.8 d    | 90.0 c   | 86.9 ef    |
| Tefenc              | 89.0 b     | 94.2 a         | 85.8 c    | 94.7 a  | 91.7 b | 94.0 a    | 91.0 b   | 91.5 c     |
| Williams            | 81.0 d     | 83.5 c         | 85.8 c    | 94.0 a  | 91.7 b | 85.8 c    | 84.2 c   | 86.6 fg    |
| Yaz Ziraat          | 85.8 d     | 95.0 b         | 89.5 cd   | 95.8 b  | 94.8 bc| 93.2 bc   | 100.0 a  | 93.5 b     |
| Mean Rootstocks     | 81.3 f     | 88.0 d         | 87.0 e    | 92.6 b  | 93.4 a | 90.8 c    | 90.3 c   |             |

a: Different letters in the same line indicate significant differences between rootstocks mean (P < 0.05) 

b: Different letters in the same column indicate significant differences between genotypes mean (P < 0.05)
cultivar/genotype with the lowest survival ratio was ‘İstanbul,’ followed by ‘Bardak,’ ‘Kış’ and ‘Williams’ (Table 3). The survival ratio was determined to be over 81.0% in terms of the rootstock average and over 84.0% in terms of the cultivar/genotype average in the study. Especially, survival ratio was higher in the pear clonal and seedling rootstocks than the quince rootstocks (Table 3).

Shoot Diameter

In the study, rootstocks and cultivars/genotypes statistically had a significant effect on shoot diameter. The shoot diameter varied between 15.15 mm-24.82 mm in terms of the rootstock average and it varied between 17.74 mm-24.57 mm in terms of the cultivar/genotype average. The highest graft shoot diameter was observed for the pear seedling (24.82 mm), followed by the OHxF333 (22.63 mm) and the Quince A (22.21 mm) clonal rootstock. The graft shoot diameter was observed to be the lowest in the MC quince rootstock (15.15 mm). Among the cultivars/genotypes, the highest shoot diameter was determined to be in the ‘Eşek’ (24.57 mm) genotype, followed by the ‘Kara’ (23.21 mm) and ‘Sarikum’ (21.98 mm) and the lowest was in the ‘Yaz Ziraati’ and ‘Williams’ (17.74 mm and 18.64 mm, respectively). In the study, the MC rootstock was found to be the most dwarfed rootstock in those were examined. The shoot diameter was generally higher in the pear genotypes than the standard pear cultivars. Generally, an adequate shoot diameter was obtained from all rootstocks, except of MC (Table 4).

Shoot Length

Statistically significant differences were found between rootstocks and varieties in terms of graft shoot length. The shoot length was higher in the pear clone rootstocks than in the quince rootstocks. The average graft shoot length ranged from 82.6 cm to 183.2 cm for the rootstocks, and it varied from 113.9 cm to 176.0 cm for the cultivars/genotypes. The highest graft shoot length was observed in the pear seedling (183.2 cm), followed by the OHxF333 (171.5 cm) rootstock. The graft shoot length was observed to be lowest for the MC quince rootstock (82.6 cm). The longest graft shoot length among the cultivar/genotypes was seen to be in the ‘Kara’ (176.0 cm) genotype, followed by the ‘Sarikum’ (164.2 cm) and the ‘Bardak’ (161.9 cm). The shortest shoot length was observed to be in the ‘Kış’ and the ‘İstanbul’ pear genotypes (113.9 cm and 116.7 cm, respectively) (Table 5). The longest shoot lengths were obtained by grafting ‘Kara’ (259.0 cm) and ‘Sarikum’ (228.3 cm) on the seedling rootstock and ‘Kara’ on the BA29 rootstock (225.7 cm). The shortest shoot lengths were obtained by grafting

Table 4. The effect of different rootstocks on the shoot diameter (mm) of some pear cultivars/genotypes.

| Cultivars/ Genotypes | Rootstocks | BA 29 | Quince A | Quince MC | OHxF333 | Fox 11 | Farold 40 | Seedling | Mean Genotypes |
|----------------------|------------|-------|----------|-----------|---------|--------|----------|----------|---------------|
| Bardak               | 20.57 ab^a| 24.38 a| 14.93 c  | 22.63 a   | 15.65 c | 17.11 bc| 24.83 a  | 20.01 de  |
| Dalkaran             | 23.96 ab  | 20.91 bc| 13.58 d  | 23.29 ab  | 21.35 bc| 18.65 c | 26.76 a  | 21.21 cd  |
| Deveci               | 26.52 a   | 19.25 bcd| 12.87 e  | 21.04 bc  | 17.65 cd| 17.38 d | 22.19 b  | 19.56 de  |
| Eşek                 | 31.55 a   | 27.34 ab| 13.70 c  | 26.71 ab  | 24.42 ab| 20.27 bc| 28.03 a  | 24.57 a   |
| İstanbul             | 17.72 c   | 21.29 bc| 13.37 d  | 23.48 ab  | 22.15 abc| 20.79 bc| 25.83 a  | 20.66 cd  |
| Kara                 | 29.30 a   | 22.28 b | 15.93 c  | 22.63 b   | 23.20 b | 17.63 c | 31.53 a  | 23.21 ab  |
| Karga                | 14.15 b   | 23.67 a | 17.68 b  | 21.58 a   | 22.49 a | 23.01 a | 24.96 a  | 21.08 cd  |
| Karpuz               | 11.84 c   | 23.69 a | 13.13 c  | 26.00 a   | 20.23 b | 17.67 b | 24.85 a  | 19.63 de  |
| Kış                  | 22.13 a   | 20.59 a | 21.33 a  | 19.23 a   | 20.01 a | 20.68 a | 19.10 a  | 20.44 cd  |
| Sarikum              | 23.03 bc  | 18.23 c | 12.90 d  | 26.04 b   | 23.37 b | 18.48 c | 31.85 a  | 21.98 bc  |
| Tefenc               | 28.62 a   | 15.13 d | 18.05 cd | 22.16 bc  | 18.14 cd| 21.62 bc| 24.22 b  | 21.13 cd  |
| Williams             | 15.95 c   | 25.12 a | 15.86 c  | 20.64 ab  | 18.99 a | 15.38 c | 18.29 bc | 18.61 ef  |
| Yaz Ziraati          | 22.12 a   | 13.85 d | 13.68 d  | 18.78 bc  | 18.46 c | 17.08 c | 20.23 b  | 17.74 f   |
| Mean Rootstocks      | 22.11 bc  | 21.21 cd| 15.15 f  | 22.63 b   | 20.47 d | 18.90 e | 24.82 a  |           |

^a: Different letters in the same line indicate significant differences between rootstocks mean (P < 0.05)

Different letters in the same column indicate significant differences between genotypes mean (P < 0.05)
'İstanbul' (59.5 cm), 'Eşek' (60.2 cm) and 'Dalkuran' (72.2 cm) on the MC rootstock. The MC rootstock was found to be the most dwarfed rootstock in the ones examined. The average shoot length was generally higher in the pear genotypes than the standard pear cultivars. Generally, an adequate shoot length was obtained from all the rootstocks, except for the MC rootstock (Table 5).

**Lateral Shoot Number**

The rootstocks and cultivars/genotypes statistically had a significant effect on the lateral shoot number. Average lateral shoots number in the graft shoot were between 3.5 and 12.1 number plant\(^{-1}\) for the rootstocks and it varied between 5.0 and 9.9 number plant\(^{-1}\) for the cultivars/genotypes. While the highest lateral shoots number in the graft shoot was found on the OHxF333 (12.1 shoots plant\(^{-1}\)), the lowest was found in MC quince rootstocks (3.5 shoots plant\(^{-1}\)). The highest lateral shoot number among the pear cultivars was found in the 'Karga' (9.9 shoots plant\(^{-1}\)), the lowest was in the genotypes of 'Kış', 'Kara' and 'Yaz Ziraati' (5.0, 5.1 and 5.7 shoots plant\(^{-1}\), respectively) (Table 6). The highest lateral shoots number was obtained by grafting 'Dalkuran' (17.0 shoots plant\(^{-1}\)), 'Deveci' (14.3 shoots plant\(^{-1}\)) and 'Eşek' (14.2 shoots plant\(^{-1}\)) on the OHxF333 rootstock. The lowest lateral shoots number

| Cultivars/Genotypes | BA 29 | Quince A | Quince MC | OHxF333 | Fox 11 | Farold 40 | Seeding | Mean Genotypes |
|---------------------|-------|----------|-----------|---------|--------|----------|---------|---------------|
| Bardak              | 5.2   | 8.0      | 5.3       | 11.8    | 4.8    | 7.2      | 9.0     | 7.3 abcde     |
| Dalkuran            | 11.3  | 5.5      | 3.0       | 17.0    | 5.8    | 6.5      | 12.5    | 8.8 abc       |
| Deveci              | 10.2  | 2.8      | 3.5       | 14.3    | 14.5   | 6.8      | 12.7    | 9.3 ab        |
| ‘Eşek’              | 12.2  | 7.8      | 2.0       | 14.2    | 6.8    | 6.5      | 14.2    | 9.1 ab        |
| İstanbul            | 3.0   | 4.7      | 3.3       | 11.5    | 7.8    | 6.3      | 11.3    | 6.9 ef        |
| Kara                | 3.5   | 2.7      | 2.0       | 8.0     | 3.5    | 3.0      | 12.8    | 5.1 g         |
| Karga               | 6.2   | 7.0      | 6.8       | 12.0    | 11.2   | 13.0     | 13.3    | 9.9 a         |
| Karpuz              | 3.3   | 7.8      | 4.3       | 11.7    | 1.7    | 7.3      | 7.5     | 6.2 fg        |
| ‘Kış’               | 4.8   | 6.8      | 3.5       | 6.8     | 5.2    | 5.5      | 2.5     | 5.0 g         |
| Sarıkum             | 2.2   | 1.7      | 3.0       | 12.7    | 10.2   | 9.0      | 11.3    | 7.1 def       |
| Tefenc              | 11.5  | 5.8      | 3.5       | 13.3    | 6.7    | 8.3      | 10.5    | 8.5 abcd      |
| Williams            | 5.7   | 2.5      | 3.0       | 15.5    | 11.0   | 9.3      | 8.5     | 7.9 bcde      |
| Yaz Ziraati         | 5.7   | 7.2      | 2.7       | 8.7     | 2.8    | 4.8      | 8.3     | 5.7 fg        |
| Mean Rootstocks     | 6.5   | 5.4      | 3.5       | 12.1    | 7.1    | 7.2      | 10.3    | 7.3 abcde     |

Table 5. The effect of different rootstocks on the shoot length (cm) of some pear cultivars/genotypes.

Table 6. The effect of different rootstocks on the lateral shoot number (number plant\(^{-1}\)) of some pear cultivars/genotypes.

\(a\): Different letters in the same line indicate significant differences between rootstocks mean \((P < 0.05)\)

\(b\): Different letters in the same column indicate significant differences between genotypes mean \((P < 0.05)\)
was obtained by grafting ‘Karpuz’ on the Fox11 and ‘Sarkum’ on the Quince A rootstock (1.7 shoots plant⁻¹). The lateral number of shoots were generally higher in the pear rootstocks than in the quince rootstocks (Table 6).

**Discussion**

Grafting is used to reproduce fruit species and varieties in current fruit growing practices. Grafting can be done in the same variety, cultivar, species or genus, as well as among the cultivars, species or genus (Darikova et al., 2011; Dogra et al., 2018; Hartmann et al., 2011). Pears can be grafted on their own seedlings or clone rootstocks, as well as on quince of different genera. However, the graft take ratio can vary considerably when grafting between genera (Jackson, 2003; Pio et al., 2008). Generally, the graft take ratio is lower in quince rootstocks than pear rootstocks. It is stated that the main reason for the low rate of grafting is due to genetic differences (Darikova et al., 2011; Dogra et al., 2018; Francescatto et al., 2010; Hartmann et al., 2011). In fact, it has been emphasized that the graft take ratio in the pear is lower when pear (*Pyrus*) and quince (*Cydonia*) are grafted with each others (Baron et al., 2019; Hartmann et al., 2011). In this study, it was determined that the pear and quince rootstocks affected the graft take ratio (Table 1). Our results are in accordance with Rahman et al. (2017) and Zenginbal and Bostan (2019), who observed that rootstocks and varieties have very important effect on the graft take ratio in the pear. The graft take ratio in previous studies were reported as the following: Elivar and Dumanoglu (1999) : 74.5–96.1%; Kadan and Yarlgac (2005) : 98%-99% and Zenginbal and Bostan (2019) : 60%-100%. Rahman et al. (2017) determined that pear varieties and rootstocks had a very important effect on the graft take ratio. In previous studies, higher graft take ratio were found for the pear rootstock than the quince rootstock, while the results of the graft take ratio obtained from the study were a bit similar to the study by Elivar and Dumanoglu (1999), it is very similar to the studies done by Kadan and Yarlgac (2005), Rahman et al. (2017) and Zenginbal and Bostan (2019).

In this study, it was determined that rootstocks and cultivars/genotypes had an important effect on the graft sprout ratio (Table 2). The temperature immediately after the grafting directly affects its success and in order for the callus tissue to form the graft formation, the environmental conditions and especially the temperature and humidity must be suitable (Baron et al., 2019; Dolkar et al., 2018; Hartmann et al., 2011). Having temperatures between 12.8°C and 32°C during or after grafting speeds up callus formation and allows the graft to continue rapidly. After grafting, the callus formation and the cambium junction between the rootstock and scion occur after 7–14 days (Hartmann et al., 2011; Lewis and Alexander, 2008); therefore, the air temperature in the first 15 days after grafting directly affects the success of the graft. In fact, the temperature was measured during the grafting period in the experiment area (Figure 1) and increased the graft take and sprout ratio. The graft sprout ratio in the pear was reported to be 67.9–92.9% by Elivar and Dumanoglu (1999) and 56.67% –100.0% by Zenginbal and Bostan (2019). A sufficient sprout ratio was obtained in some of these cultivar/rootstock combinations. In the study, it was observed that the graft sprout ratio was lower in combinations grafted on the quince rootstocks than the pear rootstocks. Although some genotypes have a high graft take ratio in the study, a low sprout ratio is possible and is associated with graft incompatibility. According to the results, it can be said that the graft sprout ratio on pear rootstocks was higher than the quince and it is caused by close inter-relative grafting. In fact, the high graft take ratio in the grafting of closely related plants also increases the graft sprout (Dogra et al., 2018; Dolkar et al., 2018; Hartmann et al., 2011). The observed differences between the rootstocks and varieties in terms of the graft sprout ratio may be due to the genetic differences between the rootstocks and varieties. Our results follow the fact that genetic differences affect the graft success (Hartmann et al., 2011; Zenginbal and Bostan, 2019; Zenginbal et al., 2017).

Botanically, as much as plants are closer, they show higher success rates of graft union (Hartmann et al., 2011; Rom and Carlson, 1987). Many factors can affect graft success including ecological, physiological, morphological and genetic. In addition, factors such as temperature, humidity, the growth stage of the rootstock, scion collection time the time of take of the grafted scion parts, the
technique of grafting, the and skill of the grafting expert and botanical relatedness between the scion and stock are also important. Failure of the grafting appropriate for the technique and time or a low rate of graft take can be caused by graft incompatibility (Hartmann et al., 2011; Lewis and Alexander, 2008). Graft incompatibility may occur, especially when different species/genera are grafted on each other. Due to the graft incompatibility in the pear/quince graft combination of different genera, the symptoms of incompatibility do not appear immediately but rather as a delayed reaction after a few years (Baron et al., 2019; Davarynejad et al., 2008; Ermel et al., 1999, 1997; Hartmann et al., 2011; Musacchi et al., 2002). In this study, the graft take and sprout ratios were found higher in pear rootstocks than quince rootstocks (Tables 1 and 2), and this was reflected in the survival ratio (Table 3). Difference in the survival ratio between pear and quince rootstocks and cultivars was observed. This could be resulted from pear/quince graft incompatibility. In particular, it was found that the variety of 'Williams,' which has a lower graft success ratio, showed graft incompatibility with some quince rootstocks (Dondini and Sansavini, 2012; Gulen et al., 2002) and pear clone rootstocks such as Fox11 (Hudina et al., 2014). It is thought that genotypes with a low sapling survival ratio such as the 'Williams' cultivar on different rootstocks may also have graft incompatibility with quince rootstocks (Darikova et al., 2011; Dogra et al., 2018; Errea, 1998; Francescatto et al., 2010; Gulen et al., 2002; Pina and Errea, 2005; Rahman et al., 2017). Genotypes with graft incompatibility, although all other factors be suitable, a common complete tissue cannot be formed between the grafted plant parts and these two parts cannot survive for a long time (Ermel et al., 1999). Hudina et al. (2014), investigated the graft compatibility/incompatibility status of some standard pear cultivars grafted on different rootstocks, reported that the variability of survival ratio between 25% and 100%. They reported that the lowest survival ratio was in the 'Williams,' 'Conference' and 'Abate Fetel' cultivars and emphasized that this was a result of biochemical causes. It has been emphasized that graft incompatibility is a complex event resulting from physiological, anatomical and biochemical causes, and that the survival ratio is lower in scion/stock combinations where graft incompatibility is high (Errea, 1998; Pina and Errea, 2005). Hudina et al. (2014) reported that the sapling survival rate was lower in cultivars grafted on BA29 and Fox11 compared to other rootstocks. The results of the research are partially similar to the results of this study. Rahman et al. (2017) reported that the sapling survival ratio varies significantly between rootstocks and cultivars, and in terms of cultivars, the highest sapling survival ratio is 'Williams,' the lowest is 'Santa Maria.' The results obtained in this study are in accordance with similar previous studies.

It was determined that pear rootstocks and cultivars had a significant effect on the diameter of the shoot (Table 4). Zenginbal and Bostan (2019) reported that the diameter of the graft shoot varies in terms of rootstock and varieties in different pear varieties grafted on seedling and OHxF333 rootstocks. In the pear saplings, the shoot diameter was determined to be 14.23–15.03 mm in ‘Santa Maria’ (Soylu and Basyigit, 1991); 14.71–18.24 mm in ‘Ankara,’ ‘Hacihamza,’ ‘Akça’ and ‘Williams’ pear cultivars (Bolat, 1993); 24.6 mm (Elivar and Dumanoglu, 1999); 9.83–14.81 mm (Rahman et al., 2017). In these previous studies, it was found that there were statistically significant differences between rootstocks and cultivars in the pear sapling shoot diameter. However, Cetinbas et al. (2018) reported that the effect of the rootstocks and cultivars on the graft shoot diameter was not statistically significant in the pear. The shoot diameter values obtained in the present study were higher than Bolat (1993), Cetinbas et al. (2018), Rahman et al. (2017) and Soylu and Basyigit (1991) and slightly lower than the results reported by Elivar and Dumanoglu (1999). In this research and other studies, the difference between the rootstock and cultivars in terms of graft shoot diameter was a result of the genetic differences between cultivars and rootstocks, as well as the growth vigor, cultivation practices, tree management and ecological conditions (Cetinbas et al., 2018; Hartmann et al., 2011; Rahman et al., 2017; Rom and Carlson, 1987; Zenginbal and Bostan, 2019).

There were statistically significant differences between both rootstocks and cultivars on the graft shoot length (Table 5). Cultivars, grafted on strong rootstocks, generally showed vigor shoot growth (Cetinbas et al., 2018; Hartmann et al., 2011; Jackson, 2003; Rahman et al., 2017; Rom and Carlson, 1987; Zenginbal and Bostan, 2019). Cetinbas et al. (2018) cited that pear rootstocks and cultivars had
an important effect on shoot length and they reported that the sapling shoot length was higher in the ‘Santa Maria’ than the ‘Deveci’ cultivar and the OHxF333 rootstock was higher than other rootstocks. In other previous studies, the graft shoot length in the pear was 185.7–194.0 cm (Soylu and Basyigit, 1991); 43.7 cm (Elivar and Dumanoglu, 1999); 31.82–91.62 cm in some pear varieties grafted on quince and Pyrus pashia rootstocks (Rahman et al., 2017). The graft shoot length were obtained, difference probably due to genetic, ecological conditions and cultivar/tion practices or may be depending on the genetic differences of the cultivar and rootstock, ecology and growing conditions (Hartmann et al., 2011; Pektas et al., 2009).

In modern fruit growing, well-branched and wide-angled saplings are more advantageous than unbranched as they start to yield earlier and show more dwarf development (Buban, 2000; Magyar et al., 2008; Saracoglu and Cebe, 2018). The juvenility period of the trees in the established orchard with well-branched and wide-angled saplings is short; they have more flower buds in the first few years and have higher yields with quality fruit (Johann, 1983; Quinlan, 1978). In this study, branched saplings were obtained without any application to the seedlings (Table 6). Cetinbas et al. (2018) cited that the number of lateral branches in the shoot was higher in the ‘Deveci’ than ‘Santa Maria’ cultivar. They reported that the highest lateral branch number in the ‘Deveci’ cultivar was obtained from the grafted on the OHxF97 rootstock, and the ‘Santa Maria’ cultivar on the OHxF333 rootstock. Similarly, Rahman et al. (2017) reported that rootstocks and varieties had a significant effect on the lateral branch number per sapling in nursery conditions. Since the rootstocks and cultivars/genotypes had an important effect in the present study, the number of lateral branches in the sapling were also different (Table 6). This situation is due to the different genetic characteristics of rootstocks and cultivars. As a matter of fact, it was found that rootstocks and cultivars with different growth and development characteristics may have a different number of shoots (Rahman et al., 2017; Rom and Carlson, 1987; Warner, 1991; Webster, 1995). In addition, lateral branch development in the plants is associated with hormonal balance, especially between auxin and cytokine can be effective on the lateral branch number (Hrotko and Magyar, 2004). Auxin increases main shoot (trunk) development and it reduces lateral shoot development (Taiz and Zeiger, 2003). Nevertheless, a cessation that may occur in the growth or enter the dormancy of the bud at the top of the main shoot causes the side buds to continue. This reduction in the dominance of auxin causes with increasing of cytokine and this effect increases the emergence of lateral buds and lateral branch number (Shimizu-Sato et al., 2009). However, since the auxins produced at the top of the shoots cannot be carried to the lateral buds, auxins have no direct effect on the growth of the lateral buds (Leyser, 2003; Ongaro and Leyser, 2008). On the other hand, cytokine has direct effects on lateral bud growth, as cytokine produced in the nodes on the main shoot are transported directly to the lateral buds and growing lateral buds increase significantly (Ongaro and Leyser, 2008; Shimizu-Sato et al., 2009; Taiz and Zeiger, 2003). Graft components may reduce the transport of certain substances, such as hormones (eg, auxins), from scion to down rootstock or, vice versa, from rootstock to scion (Dun et al., 2006). As a result, the amount of cytokine transported from the roots of the sapling to the shoot may be higher, and the number and growth of the lateral shoots may increase as the lateral shoots suck more cytokine. Also, Warner (1991), Rom and Carlson (1987), Rahman et al. (2017) and Baron et al. (2019), reported that those with a dwarfed development especially in terms of growth vigor may have a higher lateral branch number and different varieties and rootstocks may show different growth characteristics that may affect shoot growth.

**Conclusion**

The rootstocks and cultivars were observed to have a significant effect on all of the examined traits of pear stion. Graft success and stion development performance were affected differently by rootstocks and cultivars/genotypes. While sufficient graft take and sprout ratio was obtained for different rootstocks and cultivars/genotypes, the survival ratio for different stion was higher in pear rootstocks than quince rootstocks. Similarly, tall and branched stion with rootstocks and varieties of sufficient thickness were obtained in this study. Although no different treatment was done in this research,
branched stions, which are the requirements of modern fruit growing, were obtained. This is due to the different genetic traits of rootstocks and varieties. In order to better evaluate the growth performance of the stions obtained from the rootstock and cultivar combinations examined as a result of this study, the future conditions of the orchard should be evaluated. In addition, an orchard establishment with combinations of a low stions survival ratio should be avoided or suitable inter-stocks should be determined to eliminate graft incompatibility.

**Disclosure statement**

No potential conflict of interest was reported by the author(s).

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