HortiS (2025) 42(1):33-40
http://doi.org/10.16882/HortiS.1617267

HORTICULTURAL STUDIES

RESEARCH PAPER

Effectiveness of Four Rootstocks against Fusarium wilt, Yield and Quality in Cucumber

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Article History
Received 04 September 2024
Accepted 10 January 2025
First Online 20 January 2025

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Keywords
Biotic stress
Cucurbits
Grafting
Resistance
Variety

Abstract

Fusarium crown root rot caused by *Fusarium solani* is one of the most important diseases that limiting cucumber cultivation all around the world. There is more than one way to deal with this disease, but sometimes these practices may be insufficient. For this reason, the use of resistant varieties and rootstocks gains importance in the control of soil-borne diseases. The objectives of this study are to determine the resistance of breeding materials to Fusarium and to evaluate their rootstock performance and to reveal their effects on fruit yield and quality. To determine the Fusarium resistance level, 48 breeding materials were tested and four moderate resistant materials were grafted onto the hybrid Gordion variety. The effects of grafted plants on fruit yield and vegetative growth were evaluated. Early yield was also significantly higher in grafted plants than in the ungrafted control. Strongtosa had the highest fruit per plant, followed by RS 841 and 13×18 hybrid rootstock. Although higher yields were generally obtained in grafted plants compared to the control group. Additinally fruit length, fruit diameter, fruit shape index, fruit firmness and panel test were evaluated in grafted plants. These materials used as rootstocks increased plant growth and yield.

1. Introduction

Cucumber is the most grown and economically important crop species of the Cucurbitaceae family. Several fungal soilborne diseases and several fungal pathogens threaten cucurbits all around the world. The *Fusarium wilt* is considered one of the major pathogens which constrains cucumber yield and its quality (Shi et al., 2016).

Fusarium wilt of cucumber is a serious vascular disease in the worldwide. One of them is Fusarium crown root rot caused by *F. solani* considered one of the most destroying diseases in cucurbits around the world (Champaco et al., 1993, Hamdi et al., 2019). *Fusarium solani* f.sp. *cucurbitae* exhibits host specificity within the cucurbitaceae family and is able to infect crops, such as melon, watermelon and cucumber under field conditions (Perez Hernandez et al., 2020). This pathogen was responsible for cortical roots at the stem base and at the upper portion of the tap roots causing yellowing and wilting of leaves, soft circular lesions developed for fruits in contact with soil (Hamdi et al., 2019). Fusarium wilt disease is a constant problem because it survives in the soil for years. Cultural measures, solarization, soil fumigation, biological control and fungicides are generally used to control this disease, but sometimes these practices may be insufficient.

Grafting is among the most ancient agricultural techniques having been practise since 2000 BC (Kyriacou et al., 2020). Many agricultural practices have been changed due to several environmental stresses, including the agronomic, breeding and

Published by Batı Akdeniz Agricultural Research Institute (BATEM) Antalya / Türkiye

genetic programs. Grafting is an important agronomic technique that could save the costs and time of breeding programs (Bayoumi et al., 2021). Nowadays vegetable grafting is widely used in Cucurbitaceous and Solanaceous crops (Kyriacou et al., 2016, 2017). Grafted vegetables onto tolerant or resistant rootstocks can cope with different purposes including increasing the vigor of plants and enhancing the water and nutrients uptake (Sallaku et al., 2019). One of the purpose of grafting is controlling soil-borne pathogens (Lee et al., 2010; Louws et al., 2010) resistant rootstocks is one of the most common alternative methods for the control of soil-borne pathogens. It has been executed over the past few decades and recently seems to be the most successful control means (Reyad et al., 2021).

The use of grafted seedlings provides resistance to soil-borne pathogens including Fusarium. Additionally grafted plants that are tolerant to abiotic stress factors, increase plant power, yield and quality (Jabnoun-Khiareddine et al., 2019, Bayoumi et al., 2021). There are many species compatible with cucumber in grafting. They are *Cucurbita maxima*, *Cucurbita moschata*, *Cucurbita ficifolia*, squash interspesific hybrid (*Cucurbita maxima* x *Cucurbita moschata*), *Lagenaria siceraria*, wax gourd, burr cucumber, luffa and melon (King et. al., 2010, Wang et al., 2004). The most widely used of these is the squash interspecific hybrid (*C. maxima* × *C. moschata*) (Davis et al., 2008; Velkov and Pevicharova, 2016; Balkaya et al., 2018; Guan et al., 2020; Kamel and Taher, 2021). *Cucurbita* spp. rootstocks also provide grafted plants tolerance to Fusarium wilt (Guan et al., 2020). Commercial rootstocks used for watermelon are also used for cucumber. However, there is a need for the widespread use of local rootstocks for cucumber and their adoption by producers.

From this point of view, the aim of this study was to evaluate the materials derived from the crosses between *C. maxima* and *C. moschata* and derived from *C. moschata* against *F. solani* f. sp. *cucurbitae*, evaluate the rootstock performance of the tolerant materials, evaluate plant growth, fruit quality and yield of commercial hybrid Gordion F1 grafted onto Fusarium tolerant materials.

2. Material and Methods

2.1. Material

The material of the study consisted of 48 genotypes with rootstock potential developed from *C. maxima* and *C. moschata* species within the scope of “Breeding of Rootstock in Cucumber” (Project number: TAGEM/BBAD/10/A01/P01/14). In the project the root structures and graft compatibility of materials belonging to *C. maxima* and *C. moschata* species obtained from Türkiye and abroad were evaluated. Commercial Gordion F1 cultivar was used as the scion.

2.2. Method

To determine Fusarium resistance level, 48 genotypes were tested, including *C. moschata* lines, *C. maxima* × *C. moschata* hybrids, which provide high grafting compatibility with hybrid cucumber scions. In this study, *Fusarium solani* f.sp. *cucurbitae* isolate was grown on liquid synthetic media prepared according to Pitrat et al. (1991) and seedling root dipping (10^6 conidia/ml) (Figure 1) was used as the inoculation method (Gordon et al., 1989; Zink and Gubler, 1985).

The severity of the disease was evaluated according to the scale (0–4) proposed by Erper et al. (2015). 0 = Healthy seedling, white roots, no symptoms, 1 = Slightly infected seedlings, normal seedling development, slight discoloration of stem veins, 2 = 50% infection in roots, disease severity was determined according to the disease scale values (3 = Severe infection of roots, stem deformity, moderate or severe yellowing and wilting of cotyledons, 4 = Dead plant). The % disease severity of the cultivars was determined by using the disease scale values obtained using the Tawsend-Heuberger formula (% Disease severity: $\Sigma(n.v)/V.N\times100$, n: Amount of samples corresponding to a certain disease degree on the scale, v: Scale value, V: Highest scale value, N: Total number of samples observed) (Townsend and Heuberger, 1943).

Then according to Martyn and McLaughlin (1983) disease resistance level was determined [I= ≤ 20%: Highly resistant (HR), II= 21-50%: moderate resistant (MR), III=51-80%: low resistant (LR), IV= > 80% susceptible]. According to this grouping four moderate resistant genotypes (Table 1) were grafted onto cucumber hybrid Gordion F1 and evaluated for graft compatibility, plant growth and cucumber yield during 2021 autumn trials as indicated below. Four moderate resistant genotypes, two of which are interspecies hybrids and two of which belong to the species *C. moschata* were grafted onto Gordion F1 hybrid cucumber cultivar. Ungrafted Gordion F1 was used as control (Figure 2).

2.2.1. Cucumber grafting and transfer to nursery conditions

Rootstock and scion seeds were sown in a private seedling company. Rootstock seeds were planted on 28 August, and scion seeds were planted 2 days later. Grafting was carried out approximately ten days after sowing the rootstock seeds, when both rootstock and scion seedling were at the first true leaf stage (Figure 3). The slant cut grafting technique was used. It is important to remove the first leaf and lateral buds when a cotyledon of rootstock is cut on a slant. After grafting, grafted seedlings are heated at 24-28 °C in the growth unit covered with plastic film. The newly inoculated plants were exposed to 100% relative

Figure 1. Inoculation.

Figure 2. Rootstock genotypes and scion.

Figure 3. Grafted seedlings.

Table 1. Genotypes disease severity (%) and resistance level.

Genotypes	Disease severity index[a] (%)	Disease resistance level[b]
13	38	MR
37	31	MR
13×18	45	MR
15×18	45	MR

[a] Calculated according to Townsend-Heuberger formula [b] I= ≤ 20%: Highly resistant (HR), II= 21-50%: moderate resistant (MR), III= 51-80%: low resistant (LR), IV= > 80%: susceptible (S).

humidity and temperatures ranging from 24 to 28°C. During the graft healing, the relative humidity was gradually reduced within 7-10 days by opening the sides of the plastic tunnel at regular intervals. At the end of this period, the seedlings were transferred to normal nursery conditions and grown nearly 20 days until the planting stage. Survival rate of grafted seedlings were determined as % before the grafted plants were planted in the greenhouse.

2.2.2. Growing conditions and experimental design

The experiment was conducted in autumn 2021 in an unheated greenhouse in the Batı Akdeniz Agricultural Research Institute in Antalya, Türkiye. Control and grafted plants were transferred to the greenhouse on the 30th of September. The experiment was conducted in a completely randomized block design with three replications (ten plants for each treatment). Rows were one meter apart and the distance between plants was 0.50 m. and a drip irrigation system was employed. During the growing season necessary cultural practices were carried out.

2.2.3. Vegetative growth, fruit and yield traits

The vegetative growth parameter including plant height (cm) was measured at 60 days after transplanting (DAT) on five random plants per experimental plot. Rootstock and scion hypocotyls diameter were measured at 30 days after transplanting by using a caliper above the grafting zone. Earliness of flowering was counted as the number of days from transplanting to first flowering. All plots were harvested, starting from the end of October, to measure the early and total yields. The yield obtained from the first four harvests was evaluated as early yield whereas the total yield included the entire harvest period. Five fruits from each plot were chosen to determine quality measurements. Average fruit length (cm), average fruit diameter (mm), fruit-shape index, flesh hardness (kg cm^2) were recorded. Data for all measurements were subjected to analyses of variance in MSTAT-C package program and the differences between the means were compared by using LSD test.

3. Results and Discussion

The effects of grafting on different rootstocks on survival rate, vegetative growth, fruit yield and quality were examined.

3.1. Survival rate

The survival rate of the plants grafted on different rootstocks is presented in Figure 4. Survival rate was calculated by counting the survived plants. The highest percentage of successful grafting was recorded Gordion/Strongtosa (%98) and Gordion/37. Survival rate changed depending on rootstock and scion compatibility (Lim et al.,1994; Oda et al., 1993; Davis et al., 2008). The suitable rootstock requires a strong affinity with the scion guarantee the survival rate of graft (Traka-Mavrona et al., 2000). Tamilselvi and Pugalendhi (2017) attributed the compatibility to vascular regeneration across the graft interface between the scion and the rootstock. Different researchers have reported that the grafted combinations have a special character other than rootstock compatibility (Salehi-Mohammadi et al., 2009).

3.2. Vegetative growth

The results of the vegetative growth of cucumber plants were observed 60 days after transplanting (Figure 5). No symptoms of Fusarium wilt were observed during the trial. The longest plant height was obtained from the commercial RS841 rootstock, followed by the 15×18 rootstock. Hybrid rootstocks had higher plant height than other

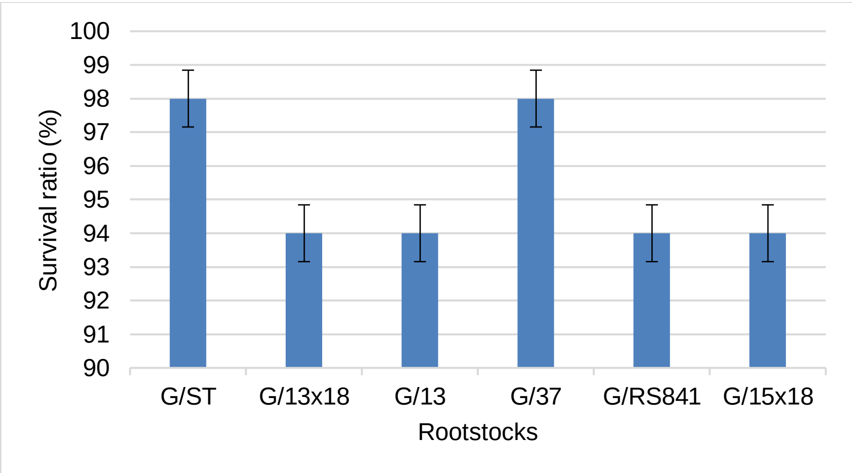

Figure 4. Survival ratio of cucumber plant cultivars grafted onto different rootstocks.

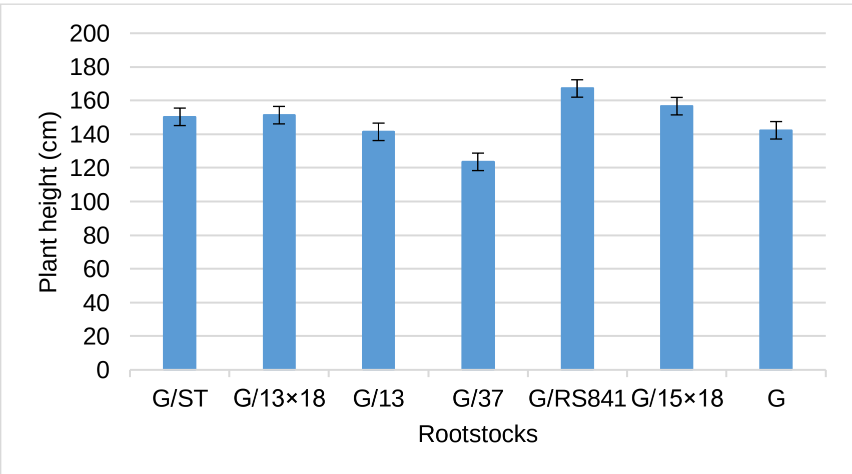

Figure 5. Plant height 60 days of transplanting in grafted and ungrafted cucumbers.

rootstocks used. The other studies using Cucurbita rootstocks have also reported positive results in cucumber grafting onto Cucurbita rootstocks, supporting our study (Colla et al., 2012; Colla et al., 2013; Savvas et al., 2013; El-Sayed et al., 2014).

Flower formation can be affected by rootstock in cucurbits (Traka-Mavrona et al., 2000). Hybrid rootstocks have lower abortion rates (Bayoumi et al., 2021). Earliness of flowering is presented in Table 2 which has significant differences between the grafted rootstock-scion genotypes. The rootstock 15×18 was the earliest flowering in the rootstocks. It was followed by rootstock 37, RS841, 13×18 and Strongtosa. Rootstock 13 delays the grafted cucumber flowering. Plant height and rootstock/stem diameter of cucumber (*Cucumis sativus*) plants grafted onto different cucurbitaceous rootstocks were presented in Table 3. Data of Table 3 indicated that the hybrid rootstocks showed significant increment in plant lenght. The highest plant length was obtained from RS 841 rootstock. Data presented in Table 3 shows that grafting cucumber scions onto RS 841 rootstock significantly increased in plant length (167.18 cm) compared to ungrafted plants. In stem diameter there was no statistically significant difference between the combinations. The largest stem diameter was obtained from Strongtosa rootstock (9.63 mm).

3.3. Physical characteristics of cucumber fruits

The effect of six rootstocks on cucumber fruit characteristics (fruit lenght, fruit diameter, fruit-shape index, fruit firmness, panel test) was presented in Table 4. Among the rootstocks, the highest fruit length (14.32 cm) was obtained from Strongtosa rootstock. In the contrary, the smallest

Table 2. Effect of rootstocks on the earliness of flowering.

Rootstocks	Earliness of flowering (days)
Strongtosa	11.0 b
13×18	11.0 b
13	14.0 a
37	9.0 c
RS 841	11.0 b
15×18	8.0 d
Gordion (Control)	14.0 a
LSD	2.92
CV (%)	14.0
Standard deviation	2.26

*Means followed by different letter within same column (factors) are significantly different at $P< 0.05$

Table 3. Effect of rootstocks on vegetative growth of grafted cucumber plants.

Rootstocks	Plant length (cm)	Stem diameter (mm)
Strongtosa	150.33 ±7.6 bc	9.63±1.1
13×18	151.33±6.8 bc	8.93±1.3
13	141.41±7.7. c	9±0.1
37	123.58 ±9.8 d	8.23±0.4
RS 841	167.18±9.9 a	8.93±0.5
15×18	156.66±12.1 ab	9.53±0.8
Gordion (Control)	142.33 ±0.6 bc	
LSD	15.03	n.s.
CV (%)	5	9
Standard deviation	13.72	0.50

*Means followed by different letter within same column (factors) are significantly different at $P< 0.05$

Table 4. Effect of rootstocks on fruit length, fruit diameter, fruit shape index, fruit firmness and panel test

Rootstocks	Fruit lenght (cm)	Fruit diameter (mm)	Fruit-shape index	Fruit Firmness (kg cm^{-2})	Panel test
Strongtosa	14.32±14.3	26.25±1.1	5.45±0.2	2.44±0.16	4.33±0.99 ab
13×18	13.70±13.7	23.58±3.5	5.86± 0.7	2.37±0.15	3 ±1.06b c
13	14.03±14	24.65±3.7	5.75± 0.7	2.39±0.11	2.33±0.71 c
37	13.53±13.5	24.51±0.5	5.52± 0.1	2.45±0.11	2.66±0.74 c
RS 841	13.60±13.6	25.05±0.8	5.42± 0.1	2.41±0.06	3.33±0.83 abc
15×18	13.83±13.8	22.41±2.5	6.20± 0.4	2.52±0.06	4.66±1.20 a
Gordion (Control)	14.08±14.1 ns	26.43±1.2 ns	5.33± 0.2 ns	2.54 ±0.08 ns	3.33±1.25 abc
LSD					1.41
CV (%)	4	9	7	4	23
Standard deviation	0.29	1.42	0.31	0.06	0.85

*Means followed by different letter within same column (factors) are significantly different at $P< 0.05$

fruits (13.53 cm) were obtained from 37 rootstock. Non-grafted Gordion and Strongtosa had the highest fruit diameters (26.43 and 26.25 cm) respectively. Regarding to the effect of different rootstocks on fruit firmness in grafted cucumber data exhibited the highest firmness was obtained from Gordion (2.54 kg cm^2) followed by 15×18 rootstock. Fruit shape index values varied between 5.33 and 6.20. Many studies have reported that grafting has no effect on fruit shape index (Karaağaç and Balkaya, 2013, Rouphael et al. 2008). The effect of rootstock on the taste of cucumber fruits was found to be statistically significant and among the rootstocks, 15×18 rootstock significantly improved the taste (4.66, 4.33) after Strongtosa rootstock. There are many studies on the effect of rootstocks on the physical characteristics of cucumber fruit. Németh et al. (2020) and Zaki et al. (2018) reported that grafting doesn't significantly affect physical parameters such as fruit length, fruit diameter, fruit firmness. In accordance with this study the rootstocks weren't significantly affected fruit length, fruit diameter, fruit firmness. In agreement with this researchers Khapte et al. (2021) reported that grafting did not affect fruit firmness. The taste and aroma are due to the effect of different pumpkin rootstocks (Huang et al., 2016).

3.4. Fruit yield characteristics

The effects of rootstocks on early yield, total yield and number of fruits per plant are shown in Table 5. Early yield, total yield and number of fruits per plant were significantly affected by the rootstocks. In grafted plants yield is a feature that varies depending on the rootstock used, the variety and the environmental conditions (King et al., 2010). Many studies have been carried out on yield in grafted cucumber (Noor et al., 2019; Papadaki et al., 2017; Guan et al., 2020; Aslam et al., 2020). When interspecific winter squash rootstocks were used as rootstocks, significant increases in growth characteristics and yield parameters were obtained. Depending on different rootstock/scion combinations it was determined that early yield was 2450 g to 4146.6 g. All the grafted plants produced significantly higher yield than ungrafted plants. The highest early yield and total yield was obtained from Strongtosa rootstock (4146.6 g, 11281.6 g). Thirteen rootstock exhibit significant decreased with lowest value in early yield (1143.3 g) and total yield (3548.3 g).

There are significant differences in the number of fruits per plant between different rootstock/scion combinations. The number of fruits per plant in cucumbers grafted onto different rootstocks varied between 31.3-118.3. Strongtosa had the highest fruit per plant (118.3), followed by RS 841 (113.6) and 13×18 (100.6) hybrid rootstock. Although higher yields were generally obtained in grafted plants compared to the control group, it is thought that the difference in combinations that did not yield high yields was due to rootstock/scion compatibility. At this point, there are many studies showing whether grafting increases productivity (Velkov and Pevicharova, 2016) or not (Üre and Aktaş, 2019).

4. Conclusion

Grafted seedlings are widely used by watermelon growers in Türkiye. However, its use is not common in cucumber due to rootstock-scion compatibility problems. The selection of rootstock-scion combination is one of the criteria to be considered to increase the yield of grafted cucumber fruits. Moreover, grafting onto Fusarium wilt-tolerant pumpkin rootstocks provides control for this soil-borne pathogen in continuous cultivation in greenhouses.

The use of local landraces as rootstocks will significantly reduce the cost of grafted seedlings. In the present study, the effects of Fusarium tolerant local interspecific cucurbita hybrids on rootstock potential and yield and fruit quality of cucumber were investigated. The present study demonstrate that the fruit yield of cucumber Gordion F1 was increased when grafted onto two *C. maxima* × *C. moschata* hybrid and two *C. moschata* genotypes compared to non-grafted plants. Further studies should look into the effects of grafting on Cucurbita species for cucumber crop improvement in the future.

Table 5. Effect of grafting on early yield, total yield and number of fruits per plant.

Rootstocks	Early yield (g)	Total yield (g)	Number of fruits per plant
Strongtosa	4146.6±1053 a	11281.6 ±819.5 a	118.3± 41a
13×18	3163.3±1565.58 c	10083.3 ±2016.4 b	100.6± 7.5 c
13	1143.3±249.65 e	3548.3± 695 f	31.3±18.90 g
37	3040± 433.27c	5680 ±315.1 e	54± 13.11f
RS 841	3843.3±865.88 b	11186.6± 1940.7 a	113.6 ±37.89 b
15×18	3083.3± 695.27c	6383.3±6392.1 d	60.00 ±1 e
Gordion (Control)	2450±691.77 d	8088.3±3632.3 c	76±7.93 d
LSD	2.92	3.26	0.05
Standard deviation	417.19	2974.22	32.86

*Means followed by different letter within same column (factors) are significantly different at $P<$ 0.05

Acknowledgement

This research was financially supported by grants from the General Directorate of Agricultural Research and Policy. Republic of Türkiye Ministry of Agriculture and Forestry under TAGEM/BBAD/Ü/19/A1/P1/1761 project number.

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