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## Studying the effects of rootstock compatibility on fruit yield and biochemical characteristics of grafted Khatooni Iranian melon

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### Abstract

**Objective:** This experiment aimed to study the effects of compatible and incompatible rootstocks on yield and some physiological and biochemical characteristics of the Khatooni melon (*Cucumis melo* Gr Inodorus, accession Khatooni).

**Methods:** The experiment was conducted using a randomized complete block design with three replications in the research station of the Department of Horticultural Science and Landscape Architecture, Faculty of Agriculture, University of Tehran, Karaj, Iran, in 2022. Seven different cucurbit rootstocks, along with the Khatooni melon as a control, were used in this research. Then, the diameter of the grafted zone, total yield, marketable yield, leaf area, leaf nitrogen concentration, fruit dry weight, root dry weight, total soluble solids, leaf and root total soluble sugars, sap flow, pH, and total acidity were measured.

**Results:** The yield and other measured characteristics were affected by the rootstock type. The highest total and marketable melon yield was obtained in the Shintozwa rootstock, followed by the RoutPower and Nangwoo 01 rootstocks. These three rootstocks were also superior in terms of leaf area, leaf nitrogen concentration, and leaf total soluble sugars. The Nangwoo 01 rootstock had the highest sap accumulation in 24 hours (986 CC) and root dry weight. In the grafted seedlings, the first morphological sign of incompatibility appeared with an increase in the grafting zone diameter. The Marvel rootstock had a very large diameter (39.29 mm) and was regarded as a highly incompatible rootstock. This rootstock also had the lowest values for the melon yield and other measured traits. Therefore, the rootstock incompatibility had a negative effect on the melon yield and all physiological, morphological, and biochemical aspects of the Khatooni melon.

**Conclusion:** The Marvel rootstock was identified as an incompatible rootstock, and the Shintozwa rootstock, followed by the RoutPower and Nangwoo rootstocks, were recognized and recommended as suitable compatible rootstocks for the Khatooni melon production.



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## Introduction

Vegetable grafting was established in 1920 with watermelon grafting on bottle gourd (squash) in Korea and Japan (Davis *et al.* 2008). In recent years, the use of grafted plants of the *Cucurbitaceae* family has become very common and has led to an increase in per capita vegetable production. More than 90% of pumpkin cultivated lands in Turkey, Greece, Japan, and Korea have been under grafted plants (Lee and Oda 2003). According to Fidebirlik (2016), grafted plants in Turkey have increased from 31 to 175 million seedlings. The Cucurbit hybrid (*Cucurbita maxima* x *Cucurbita moschata*) is one of the best-known and prevalent rootstocks (Kurum *et al.* 2017).

Grafting using a suitable rootstock is a well-known method for controlling biotic and abiotic stresses in the *Cucurbitaceae* family (Alizadeh *et al.* 2014; Balkaya *et al.* 2018). A suitable rootstock can improve the resistance of the scion plant to soil-borne diseases, which in turn improves the yield of the scion plant (Lee and Oda 2003; Devi *et al.* 2020). This effect can be very useful in the production of organic products due to a sharp decline in pesticide use (Cohen *et al.* 2002). The use of bottle gourd rootstock (*Lagenaria siceraria*) for watermelon scion has greatly controlled pathogenic mortality (Kubota *et al.* 2008).

It has been reported that the structure of pumpkin root improves the hydraulic flow of water and nutrients to the cucumber scion (Ceylan *et al.* 2018). The use of rootstocks from other species affects maturity and yield (Balkaya 2018). Improved yield and quality via grafted plants compared to the non-grafted plants has led to the frequent use of grafting plants nowadays (Galinato *et al.* 2016). Reports have revealed that using resistant Cucurbit rootstocks for melons could increase their yield up to 50% (Fereshtian *et al.* 2021).

The success of the grafting plant depends on the precise selection of rootstock and scion plants and proper performance of the graft. A proper performance helps the formation of a complementary bridge between two plants by forming callus from the rootstock and scion, and differentiation of parenchymal cell mass, and finally, formation of xylem vessels to establish the flow of water and nutrients from the rootstock to scion. If vascular connection does not occur, plant growth and function will be impaired due to limitation on the nutrient flow (Karaağaç and Balkaya 2013; Abbas *et al.*

2023). Compatibility between scion and rootstocks can increase root efficiency, and as a result, more water and nutrients will be transferred from the roots to the shoots (Johnson 2017).

There is limited information about the comparison of compatible and incompatible grafts with respect to anatomical and physiological aspects. What happens to the plant when the rootstock and scion are incompatible is not yet fully understood and needs to be investigated. Therefore, in the current study, several universally known rootstocks for grafted melons were used to identify the compatible and suitable rootstocks for the Khatooni melon (*Cucumis melo* Gr Inodorus cv. Khatooni) and to examine the anatomical and physiological aspects that may occur in the tissue of incompatible plants during grafting.

## Materials and Methods

### *Plant materials*

This experiment was conducted in the spring of 2020 in the research stations and greenhouses of the Department of Horticultural Science and Landscape Architecture, Faculty of Agriculture, University of Tehran, Karaj, Iran. In this study, seven Cucurbit cultivars were used as rootstocks, including Rout Power, ES 900, RZ 12, Nongwoo 01, RZ 6, Shintozwa, and Marvel. In addition, the Khatooni melon (*Cucumis melo* GR. Inodorus cv. Khatooni) was used as the control (Table 1).

**Table 1.** Cucurbit rootstocks that were used for the Khatooni melon grafting.

Cultivar	Scientific name	Company	Producing country
RoutPower (RP)	<i>Cucurbita pepo</i>	SAKATA	Japan
ES 900 (ES)	<i>Cucurbita. sp</i>	ERGON	Netherlands
RZ12 (RZ12)	<i>Cucurbita maxima</i> × <i>C.moschata</i>	RIJK ZWAAN	Netherlands
Nongwoo 01 (Nogw)	<i>Lagenaria siceraria</i>	NONGWOO BIO	South Korea
RZ6	<i>Cucurbita maxima</i> × <i>C.moschata</i>	RIJK ZWAAN	Netherlands
Shintozwa (Sh)	<i>Cucurbita maxima</i> × <i>C.moschata</i>	NONGWOO BIO	South Korea
Marvel (Mr)	<i>Cucurbita pepo</i>	TAKII SEED	Japan
Melon (Control) (Kh)	<i>Cucumis melo</i>	ROSSEN SEED	Netherlands

### *Planting rootstocks and scion seeds, and grafting*

The seeds of cucurbit rootstocks and the Khatooni melon were planted in a soil mixture of coco peat and perlite (4:1 ratio) in a controlled greenhouse with sufficient light (350-400 micromoles per square meter per second), with a day/night temperature range of 25-27/18-20 °C. Irrigation was done once a day.

Three weeks after planting, Cucurbit rootstocks and scion seedlings were ready for grafting (Salehi-Mohammadi *et al.* 2009). Drafting was performed by the simple splice grafting method. Grafted plants were transferred to the growth chamber under controlled conditions. The humidity of the growth chamber was adjusted to 95% in the first three days, 85% in the second three days, and 70% in the third three days. The amount of light was 80 to 100 micromoles per square meter per second, and the temperature was set at 25-22 °C (Wang *et al.* 2005).

### ***Field preparation and the experimental design for the grafted plants***

The experimental design was a randomized complete block design with eight grafting treatments (Table 1), three replications, and six observations per plot. An area of 1000 square meters was prepared in the research station of the Faculty of Agriculture, University of Tehran, Karaj, Iran (Latitude 35°N and Longitude 50° E) for planting the grafted plants. Physical and chemical properties of the field soil are presented in Table 2.

After plowing and adding required fertilizers into the soil, the adapted plants were transferred to the field one month after grafting and at the 4-leaf stage in mid-May 2022. Drip irrigation was repeated every two to three days. At the 7-leaf stage Paraquat herbicide (2 mL/L) and Captan fungicide (1.5 g/L) were sprayed to control the weeds and fungi, respectively.

### ***Measurement of traits***

Traits such as total melon yield, marketable yield, total soluble solids, total acidity, pH, nitrogen concentration, total leaf and root soluble sugars, sap flow rate, and the dry weight of fruits and roots were measured during the growing season. Also, the diameter of the grafted zone was measured at the end of the growing season.

**Table 2.** Results of the analysis of the soil in the experimental site.

<b>Soil texture</b>	<b>Mn (ppm)</b>	<b>Zn (ppm)</b>	<b>Cu (ppm)</b>	<b>Fe (ppm)</b>	<b>K (ppm)</b>	<b>P (ppm)</b>	<b>Organic matter (%)</b>	<b>Total N (%)</b>	<b>EC (dSm<sup>-1</sup>)</b>	<b>pH</b>
<b>Loam clay</b>	27.3	81.1	1.12	53.7	146	6.13	0.77	0.081	2.71	8.1

To measure the total soluble sugars in roots, a sample of 0.5 g fresh weight was taken from each grafted plant rootstock, extracted with 20 mL of 80% ethanol at 80 °C, and after evaporation of ethanol, it was dissolved in 2 mL of distilled water. Then, the amount of soluble sugars was determined by the reliable dinitrosalicylic acid colorimetric method (Miller 1959).

To measure the amount of total soluble sugars in the leaves, 0.2 g of iodine was added to 100 mg of potassium iodine solution, and the powdered sample was placed in this solution for one hour. Then, the amount of soluble sugars was read by a light spectrometer at 630 nm; glucose was used as the standard solution. The amount of soluble sugars was recorded as mg/g fresh weight (van Handel 1968). The product was put in a desiccator at 75 °C for 72 hours. Also, a 10-gram dry sample was used to measure the amount of total nitrogen according to Yang *et al.* (2000).

To evaluate the graft union diameter in the grafted melon plants, measurements were taken 12 weeks after transplanting the seedlings into the main field. The diameter was recorded at two points, one centimeter above and one centimeter below the graft junction using a digital caliper (Insize model 300-1108, 30 cm range, China). A difference exceeding one centimeter between the diameters measured above and below the graft zone was regarded as an indicator of graft incompatibility (Aloni *et al.* 2008).

Leaf area per leaf was determined using a leaf area meter (Delta T, England) in square centimeters. To measure the percentage of dry matter of roots and fruits, 100 grams of fresh fruit and root sample were dried in an oven at 75 °C for 72 hours, and then the percentage of dry matter was determined accordingly (Andrews *et al.* 2002):

$$\text{Dry matter (\%)} = (\text{Dry weight of the sample} / \text{Fresh weight of the sample}) \times 100$$

The pH of the fruit extract was measured using a digital pH meter (Model pH500, Taiwan). Total acidity of the fruit was estimated by using the titration method (Mostofi *et al.* 2003).

The percentage of total soluble solids (TSS) was measured in terms of Brix using a refractometer (Model ATAGO Brix 0-62%, USA) in the filtered fruit extract.

To estimate the amount of sap flow, the stem was cut above the grafted zone and placed in a graduated container. After 24 hours, the volume of extracted raw sap from the stem was measured (Aebi 1984).

### ***Statistical analysis***

After analysis of variance, the treatment means were compared using Duncan's multiple range test at  $p \leq 0.05$ . Data analysis was performed with SAS 19.4, and the figures were drawn using Excel software.

## Results and Discussion

### *Analysis of variance*

There were significant differences among rootstocks for all of the studied characteristics, showing the differential effect of cucurbit rootstocks on these traits (Table 3).

**Table 3.** Analysis of variance for the measured characteristics concerning the grafted Khatooni melon on different rootstocks.

Source of variation	df	Mean squares					
		Marketable yield	Total yield	Leaf area	RDW	FDW	PDW
Block	2	222.53	69.16	715418	5.27	1.55	2.57*
Treatment	7	965.22**	1500.67**	582930586**	122.3*	6.89**	5.64**
Error	14	67.47	115.17	166621	5.07	0.59	1.01
CV (%)	-	22.7	19.49	3	16.54	8.5	9.6

**Table 3 continued**

Source of variation	df	Mean squares						
		Sap	TSS	pH	TA	LTSS	RTSS	N
Block	2	113.79	0.22	0.04	1.24	0.04	0.04	0.42
Treatment	1	3288.04**	12.98**	0.69**	3.38**	12.65**	0.64**	4.07*
Error	2	116.34	0.44	0.02	2.06	0.0001	0.0006	0.137
CV (%)	-	6.66	6.98	2.27	4.07	4.44	0.03	12.42

\*, \*\*: Significant at 5% and 1% probability levels, respectively; df: Degrees of freedom, RDW: Root dry weight, FDW: Fruit dry weight, PDW: Plant dry weight, TSS: Total soluble solids, TA: Total acidity, LTSS: Leaf total soluble sugars, RTSS: Root total soluble sugars, N: nitrogen.

### *Mean comparisons*

Figure 1 indicates that the diameter of the grafting zone in the incompatible rootstock was higher than that of the compatible rootstock. Comparison of the difference of the grafted zone diameter with the diameter of the rootstock and scion showed that in the incompatible Marvel rootstock, this difference was much greater than in other rootstocks (18.99 mm compared to the rootstock and 20.17 mm compared to the scion), which had a negative effect on all growth and functional traits of the grafted plants (Table 4).



**Figure 1.** The zone of grafting in the incompatible rootstock (left) and the zone of grafting in the compatible rootstock (right).

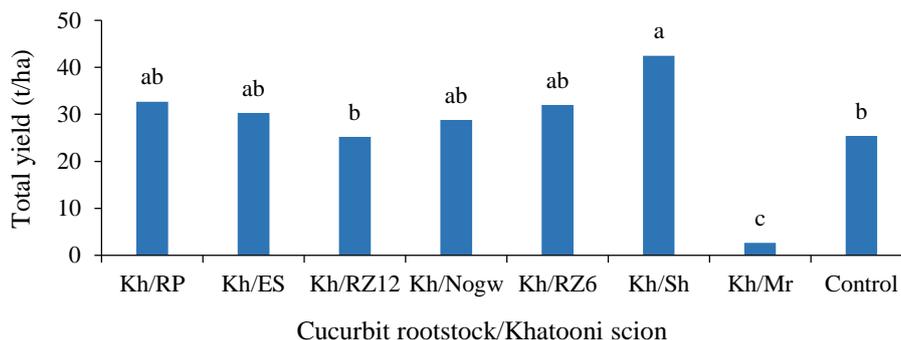
**Table 4.** Comparison of the average stem diameter (mm) of the grafted zone with scion and rootstock.

Cultivar	Grafted zone (GZ)	Rootstock (RS)	Scion (S)	GZ - RS	GZ - S
RoutPower	30.95c	21.71bc	24.16ab	9.24bc	6.79 bc
ES900	33.27bc	23.03ab	24.47 ab	10.24b	9.08b
RZ 12	31.43 c	23.49 ab	25.47 a	7.94 bc	5.96 c
Nogwoo01	31.19 c	20.93bc	24.02ab	10.26 b	7.17 bc
RZ6	31.57 bc	21.73bc	25.26 a	9.84 bc	6.31 bc
Shintozwa	34.58b	26.18a	27.63 a	8.4 bc	6.95 bc
<b>Marvel</b>	<b>39.29a</b>	<b>19.12c</b>	<b>20.3c</b>	<b>20.17a</b>	<b>18.99a</b>
Control	24.77d	19.3c	21.49 bc	5.74d	3.28d

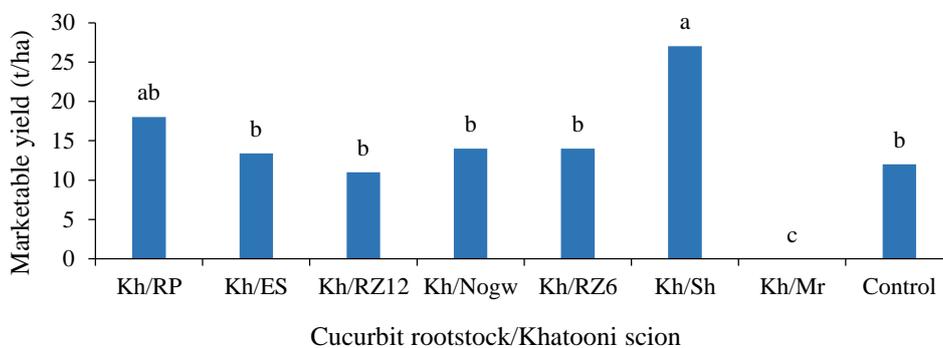
GZ – RS: Difference of the grafted zone diameter with the root stock diameter; **GZ – S**: Difference of the grafted zone diameter with the scion diameter; Means with difference letters in each column are significantly different at  $p \leq 0.05$  according to Duncan's multiple range test.

Shintozwa rootstock had the highest total yield per hectare compared to the control and the incompatible rootstock Marvel. The lowest performance was for the Marvel incompatible rootstock (Figure 2). According to Traka-Mavrona *et al.* (2000), the pumpkin rootstock increased watermelon yield by up to 30%, which is economically acceptable. Studies have shown that pumpkin rootstock transmits large volumes of water and nutrients to the scion due to its high growth and development power in the soil bed, which has led to the increased fruit yield (Fernandez-Garcia *et al.* 2004).

The marketable efficiency of the product is a very important characteristic for the melon production systems (Lee and Oda 2003; Thomas *et al.* 2023). The fruit weighing more than one kilogram with a normal shape is considered marketable. The Shintozwa rootstock showed the highest marketable yield (Figure 3), while the incompatible rootstock of Marvel did not show marketability, which can be attributed to the disturbance in the vascular system and low plant growth. According to Fereshtian *et al.* (2021), Cucurbits rootstocks caused changes in some traits of scion fruits, including fruit yield and weight.

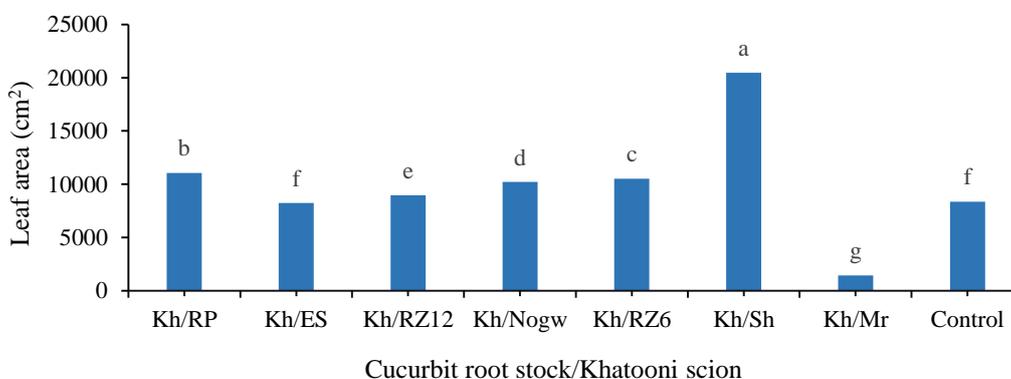


**Figure 2.** Effect of different Cucurbit rootstocks on total yield of the Khatooni melon; RP: RoutPower, Kh: Khatooni melon, ES: ES 900, Nogw: Nongwoo 01, Sh: Shintozwa, Mr: Marvel, Control: Khatooni melon; Means with difference letters are significantly different at  $p \leq 0.05$  according to Duncan's multiple range test.



**Figure 3.** The effect of Cucurbit rootstocks on the marketable yield of the Khatooni melon; RoutPower, Kh: Khatooni melon, ES: ES 900, Nogw: Nongwoo 01, Sh: Shintozwa, Mr: Marvel, Control: Khatooni melon; Means with difference letters are significantly different at  $p \leq 0.05$  according to Duncan's multiple range test.

Among treatments, the Shintozwa leaf with the average area per plant of 20466.7 cm<sup>2</sup> showed the widest area compared to other rootstocks and the control (Figure 4). The leaf area is directly related to photosynthesis and plant growth. It also affects the amount of nitrogen in the soil and the yield (El-Gazzar *et al.* 2016). Therefore, Shintozwa, with a higher leaf area, had better performance than other rootstocks.



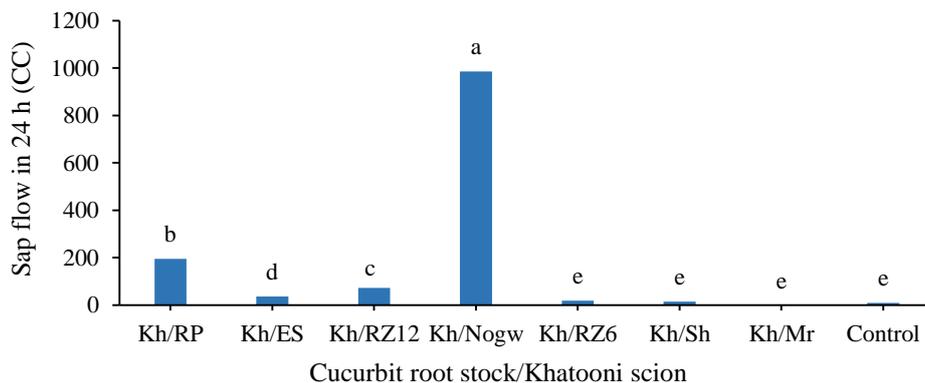
**Figure 4.** Effect of different Cucurbit rootstocks on the leaf area of the Khatooni melon; RoutPower, Kh: Khatooni melon, ES: ES 900, Nogw: Nongwoo 01, Sh: Shintozwa, Mr: Marvel, Control: Khatooni melon; Means with different letters are significantly different at  $p \leq 0.05$  according to Duncan's multiple range test.

Means with difference letters are significantly different at  $p \leq 0.05$  according to Duncan's multiple range test.

In total, among different rootstocks, the Shintozwa rootstock was the most compatible rootstock and the best grafted rootstock in terms of yield and growth, while the Marvel rootstock appeared as an incompatible rootstock.

The amount of sap accumulation above the grafting site over 24 hours was higher for some grafted plants as compared to the control. The highest amount (986 cc) was observed for the rootstock of Nongwoo 01, which was significantly different from other grafted plants, and reached nearly zero for the non-grafted (control) and incompatible rootstocks (Figure 5).

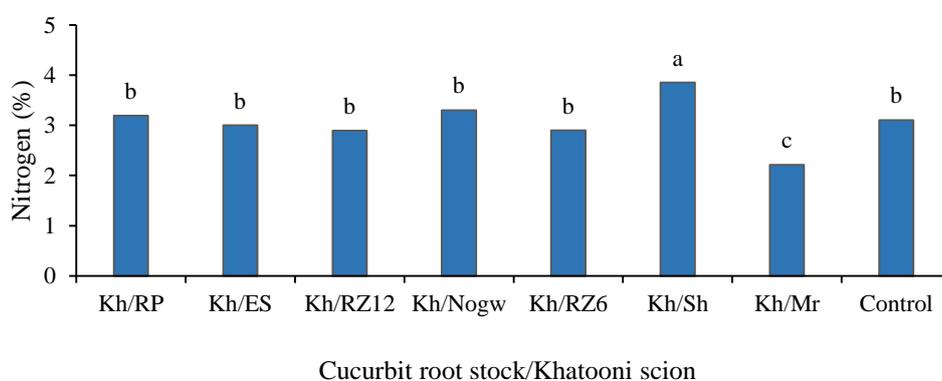
In general, the uptake performance and water-soluble ionic compounds increase with cucurbit rootstocks due to the high uptake power of the rootstocks compared to melons (VaziriMehr *et al.* 2024). The lack of development of a proper vascular network and obstruction of the path of water and minerals may have been the reason for the observed differences in the sap flow among rootstocks, which reduced the growth and the yield of scion in the incompatible and some incompatible rootstocks.



**Figure 5.** Effect of different Cucurbit rootstocks on the sap flow from the grafted rootstocks; RoutPower, Kh: Khatooni melon, ES: ES 900, Nogw: Nongwoo 01, Sh: Shintozwa, Mr: Marvel, Control: Khatooni melon; Means with different letters are significantly different at  $p \leq 0.05$  according to Duncan's multiple range test.

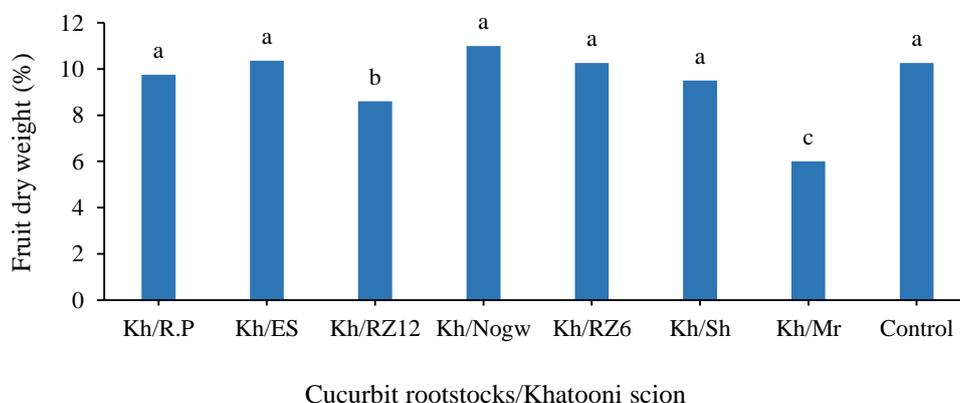
The leaf nitrogen content of the grafted rootstock Shintozwa was significantly higher (3.85%) than that of the Marvel rootstock (2.21%) and the non-grafted control (3.1%) (Figure 6). The high nitrogen uptake by the rootstock Shintozwa compared to the Marvel rootstock could be an important indicator for the compatibility of this rootstock and will ensure a proper yield to a large extent. Graft incompatibility affects the absorption of essential elements (Cohen *et al.* 2002; Edelstein *et al.* 2015). Incompatible rootstock has a great effect on the content of elements in the scion, and the main reason is the inefficiency of the vascular system at the junction of the rootstock and scion, which upsets the balance in uptake and consumption (Abas *et al.* 2023).

Minerals and nutrients in the plant tissue have a significant effect on the physiological activities such as growth, development, and transmission of signals in the plant (Wang *et al.* 2005). The water and nutrient uptake from the soil depends on the root system development, which is one of the important reasons for using grafting on rootstocks (Hänsch and Mendel 2009). It has been reported that the cucurbit root activity with watermelon scion and, consequently, the concentration of nitrate, ammonium, and phosphate ions in the sap, was higher than the non-grafted plants (Ntatsi *et al.* 2017).



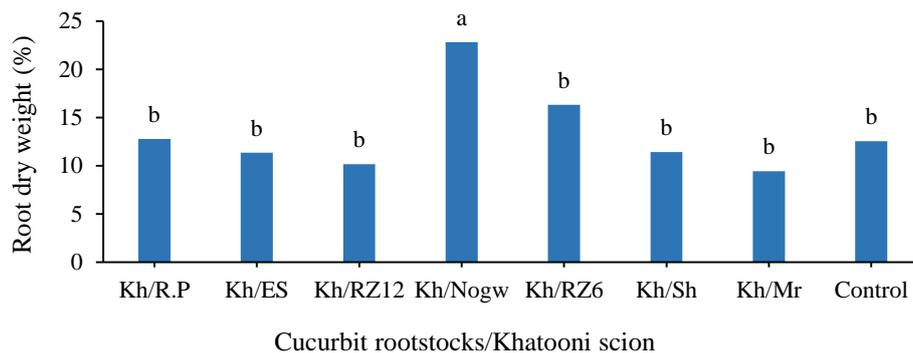
**Figure 6.** Effect of different Cucurbit rootstocks on the leaf nitrogen concentration of the Khatooni melon; RoutPower, Kh: Khatooni melon, ES: ES 900, Nogw: Nongwoo 01, Sh: Shintozwa, Mr: Marvel, Control: Khatooni melon; Means with different letters are significantly different at  $p \leq 0.05$  according to Duncan's multiple range test.

Results revealed that the fruit dry weight in the Marvel rootstock was significantly lower than of other rootstocks and the control; the average fruit dry weight in most grafted plants was higher than 10% (Figure 7).



**Figure 7.** Effect of different Cucurbit rootstocks on fruit dry weight of the Khatooni melon; RoutPower, Kh: Khatooni melon, ES: ES 900, Nogw: Nongwoo 01, Sh: Shintozwa, Mr: Marvel, Control: Khatooni melon; Means with difference letters are significantly different at  $p \leq 0.05$  according to Duncan's multiple range test.

The highest percentage of the root dry weight was observed in the Nongwoo 01 rootstock (22.8%) (Figure 8). Nongwoo 01 also had the highest sap flow among rootstocks (Figure 5), and its total yield ranked second (together with RoutPower, ES 900, and RZ6) after the Shintozwa rootstock (Figure 2). Cucurbit rootstocks, generally, due to their larger root volume compared to melons, can expand the growth of the scion section (Rouphael *et al.* 2008).



**Figure 8.** Effect of different Cucurbit rootstocks on root dry weight of the grafted plants; RoutPower, Kh: Khatooni melon, ES: ES 900, Nogw: Nongwoo 01, Sh: Shintozwa, Mr: Marvel, Control: Khatooni melon; Means with difference letters are significantly different at  $p \leq 0.05$  according to Duncan's multiple range test.

Figure 9 shows the effect of Cucurbit rootstocks on the total soluble sugars in roots and leaves of the grafted plants. The highest total soluble sugar content of the leaves ( $11.3 \text{ mg g}^{-1}$  fresh weight) and roots ( $1.901 \text{ mg g}^{-1}$  fresh weight) was observed in the Shintozwa rootstock. One of the main reasons for the high content of leaf sugar in grafted scion with Shintozwa rootstock is the better flow of nutrients from roots to leaves, which consequently enhances the photosynthetic capacity and sugar products, resulting in better growth (Yang *et al.* 2015). Also, the transfer of sugars from the leaves to organs that are not capable of photosynthesis (roots) is carried out by the phloem, which, after the development of the vascular system and the regular and integrated communication between the two parts, will guarantee the transfer of the assimilates to the roots (Shane and Lambers 2005), resulting in a better root growth and consequent yield enhancement. On the other hand, the Marvel rootstock, due to the incompatibility between the rootstock and scion, and the very weak sap flow, showed significantly lower total soluble sugars, as the main product of the photosynthesis (Liu *et al.* 2010), in the leaves and roots as compared to other rootstocks. Also, due to vascular flow blockage, the assimilates in the leaves are not transferred to the roots, consequently, the roots are unable to expand sufficiently and are weak in absorbing water and nutrients (Svistoonoff *et al.* 2007).

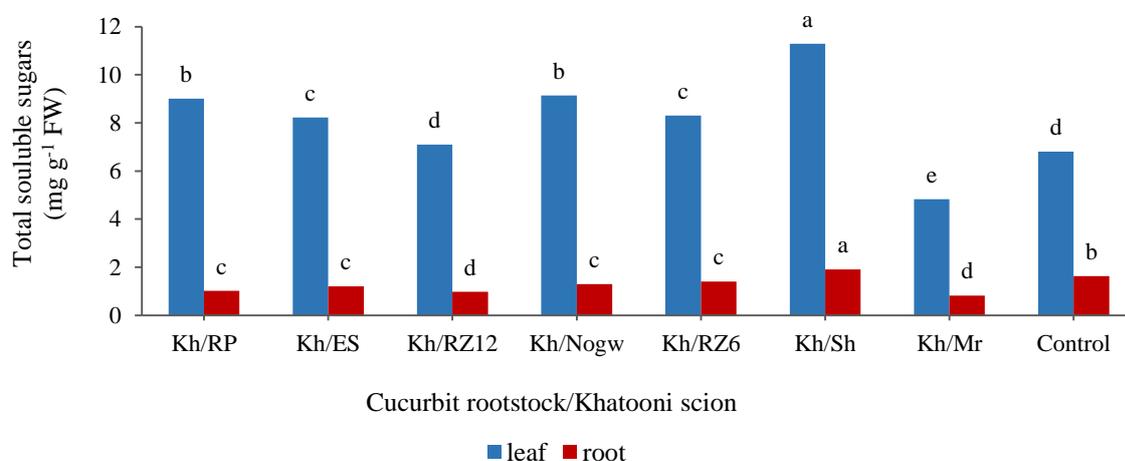
Carbohydrates are the most important biochemical compounds that play an essential role in determining the quality of melon fruit. A higher total soluble sugar content in the compatible rootstock of Shintozwa is one of the reasons for the better quality of the fruit when the Shintozwa

rootstock is combined with the Khatooni melon. In reverse, the graft incompatibility impairs the transfer of sugars to the fruit and reduces the quality of the product. According to Aloni *et al.* (2008), grafting melons onto the Cucurbit rootstock increases the sugar content of the fruit and improves the quality of the fruit.

Although Cucurbit rootstocks have a positive effect on the amount of total soluble sugars in the melon leaves, sometimes grafting reduces the fruit sugar to a limited extent (Rouphael *et al.* 2021). However, it has been reported that using the Cucurbit rootstock-melon grafting technique improves the melon yield from 25% to 55% (Lee and Oda 2003; Salehi *et al.* 2014).

In addition to the yield enhancement of the Khatooni melon through the grafting technique using the compatible Cucurbit rootstocks, the resistance of cucurbits to soil pathogens and environmental stresses is another reason for their effectiveness in producing higher yields. Their roots are generally less sensitive to diseases and biotic and abiotic stresses than melons (Abbas *et al.* 2023). Also, due to the resistance of the Cucurbits rootstocks to soil-borne pathogens, it will reduce the consumption of chemical fertilizers and produce a healthier product, which is a very important goal in the production of organic agricultural products.

The comparison of fruit quality characteristics demonstrated that the choice of Cucurbit rootstock had a significant effect on fruit flavor quality. Among the rootstocks evaluated, Shintozwa exhibited the highest TSS and TA, indicating a better fruit quality. The control plants and ES 900 rootstocks ranked next, also showing relatively good fruit quality after Shintozwa. The TSS/TA ratio, as a quantitative indicator for evaluating flavor quality and physiological maturity of fruits, remained comparable among the rootstocks, except for a higher ratio for RZ12, but was markedly lower in the Marvel rootstock (Table 6).



**Figure 9.** Effect of different Cucurbit rootstocks on total soluble sugars of the Khatooni melon; RoutPower, Kh: Khatooni melon, ES: ES 900, Nogw: Nongwoo 01, Sh: Shintozwa, Mr: Marvel, Control: Khatooni melon; Means with difference letters are significantly different at  $p \leq 0.05$  according to Duncan's multiple range test.

**Table 6.** Effect of different Cucurbit rootstocks on quality characteristics of the Khatooni melon fruit.

Treatments	Trait			
	pH	TSS (Brix)	TA	TSS/TA
RootPower	6.65bc	10bc	0.16b	62.5b
ES900	7.6a	12b	0.18b	66.7b
RZ 12	7.42c	9bcd	0.13b	69.2a
Nogwoo01	6.5c	11bd	0.18b	61.1b
RZ6	6.44c	12b	0.19b	63.2b
Shintowza	<b>6.88b</b>	<b>13.3a</b>	<b>0.22a</b>	<b>60.5b</b>
Marvel	3.8d	5.0d	0.088c	56.8c
Control	7.65a	12b	0.18b	66.7ab

TSS: Total soluble solids, TA: Total acidity.

Graft incompatibility may be due to the type of graft composition, adverse environmental factors, physiological and structural factors, or the grafting method. Due to different conditions, incompatibility can occur from the beginning of grafting to the end of plant growth. In this study, it was shown that incompatibility affects the whole plant growth, and the physiological and biochemical systems of both rootstock and scion. As the growing conditions were similar for both compatible and incompatible rootstocks, however, in the early stages of grafting (three weeks after transferring the grafted seedlings to the field), there was evidence of incompatibility due to defects in the development of the vascular system between the root and scion (Moosavi-Nezhad *et al*, 2021).

The rootstocks Shintozwa and Rout Power had a higher leaf area and fruit dry weight percentage, and yield than the Marvel rootstock, in which the melon yield and other characteristics, including leaf area, fruit dry weight, nitrogen content, total soluble sugars, and TSS were lower than normal, due to the graft incompatibility which is considered as a type of stress for the grafting plants.

The first sign of incompatibility was detected by measuring the diameter of the grafting zone and comparing it with the diameter of the rootstock and scion. Swelling at the graft zone occurs due to the incompatibility of the vascular system of the rootstocks and scion, which prevents the transfer of water and nutrients to other organs (VaziriMehr *et al*. 2024). In the Marvel rootstock, the grafted zone diameter was higher than that of other rootstocks, which showed incompatibility from the initial stages of grafting. By early identifying the incompatibility after grafting by producers, the transfer of the incompatible seedlings to the field could be prevented, and subsequent economic losses could be

restricted. Therefore, choosing a strong compatible rootstock will play an important role in the success of the melon cultivation (Ghasembaghlou *et al.* 2022).

## Conclusion

The Shintozwa rootstock performed better than other compatible rootstocks, the control, and the incompatible Marvel rootstock in terms of important characteristics, including total melon yield, marketable yield, leaf area, TSS, and total leaf and root soluble sugars. Therefore, the Shintozwa rootstock can be recommended as a suitable compatible rootstock for the Khatooni melon scion, followed by the Rout Power and Nangwoo rootstocks. Also, the Marvel rootstock was identified as the incompatible rootstock. The application of compatible rootstocks in the production of Khatooni melon cannot only increase the yield but also reduce the consumption of chemical fertilizers due to the resistance of the Cucurbits rootstocks to soil-borne pathogens. The production of a healthier product is an important goal in the organic agriculture systems.

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## Ethical considerations

The authors avoided data fabrication and falsification.

## Conflict of Interest

The authors declare that they have no conflict of interest with any organization concerning the subject of the manuscript.

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