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Rootstock-scion combinations affect chemical contents of Tomato and its productivity

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Abstract

This study was conducted in the greenhouse of the experimental station of the Department of Horticulture, Faculty of Agriculture, Benha University, to investigate the possibility of improving the production and quality of tomato crops using grafting technology. Two tomato cultivars (Reem and Karnak) were grafted onto four rootstocks (Heman, 1G-48-6031, 1G-48-6032 and Edkawy), and their effects on growth, yield and fruits quality were evaluated, compared to non-grafted or self-grafted plants. The results showed that all investigated factors "cultivar of scion, variety of rootstocks and rootstock-scion combinations" affected significantly tomato growth, chemical contents, fruit quality and fruit yield. The grafting treatments increased tomato growth, leaves nutrients contents and fruit yield compared to non-grafted plants of both cultivars. In comparison with non-grafted plants, grafting both cultivars on Heman, 1G-48-6031 and 1G-48-6032 rootstocks generally increased fruit yield as average by 67.3, 41.0, and 50.0%, respectively, and improved chemical contents of fruits.

Keywords: *Tomato, grafting, rootstocks, scion, productivity, chemical contents, quality*

1. Introduction

In Egypt and other parts of the Mediterranean Basin, Tomato (*Solanum lycopersicum* L.) is one of the most considerable greenhouses **[1, 2]** for which grafting is deemed a routine in commercial greenhouse cultivations **[3, 4]**. In most countries throughout the world with highly intense land use, fruity vegetable grafting has become a crucial strategy for sustainable production. Growers are finding it difficult to get the same yields on smaller, lower-quality plots of field **[5, 6, 7]**. This issue can be uniquely solved by grafting, which enables producers to choose their favourite vegetable kinds or scions to be grafted onto robust and/or disease-resistant rootstocks **[8]**. Grafted plants are frequently used in greenhouse vegetable production, although they are less common in Egypt's field production methods **[9]**.

In grafted plants, scion variety influences fruit size, production, and quality; however, rootstock effects can significantly change these quality attributes **[10]**. Grafting may modify the scion's physiological processes or cause metabolites linked to fruit quality to be translocated through the xylem, hence affecting the scion's quality attributes **[11, 12]**. The broad range of rootstock-scion combinations may result in varying outcomes with regard to the performance of grafted plants because there are a lot of rootstocks with varied qualities and a lot of scion cultivars with different fruit sizes and growth habits. For instance, it was demonstrated that interspecific hybrid rootstock (*S. lycopersicum* × *S. habrochaites*) might have either positive or neutral impacts on fruit yield when small-fruited tomato types were grown organically in greenhouse settings **[13]**. It was showed that *S. lycopersicum* × *S. habrochaites* rootstocks consistently increased the marketable yield when compared to the

non-grafted control under a high tunnel production system **[14]**. The increase seemed to be more correlated with the number of fruits than the weight of a single fruit. It was observed that production strategies may have an impact on the effect of interspecific rootstocks on marketable and total tomato yields **[15]**. There is a suggestion that grafted tomato plants with low vigour tendencies may grow less vigorously **[16]**, but very few studies have systematically investigated the effects of rootstock vigour characteristics on yield components of various tomato scion types. According to **[12, 13]**, all rootstocks increased the number of leaves on the plants and three out of four rootstocks raised the height of the grafted plants. Under high-tunnel **[14]** or greenhouse production **[13, 17]** conditions, rootstocks for large-fruited tomato can have varying effects on plant height, stem diameter, and plant biomass (DW) at crop termination.

Thus, the goal of the current study is to determine whether grafting tomato plants onto different rootstocks can enhance tomato growth, yield, and fruit quality.

2. Materials and Methods:

This experiment was conducted in the greenhouse of the experimental station of the Department of Horticulture, Faculty of Agriculture, Benha University, to investigate the possibility of improving the production and quality of tomato crops using grafting technology.

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Plant Materials and experimental procedures

Plant materials used in this experiment are shown in Table (1). The indeterminate commercial cultivars Reem (R) and Karnack (K) were used as scions, and Heman, 1G-48-6031, 1G-48-6032 and Edkawy were used as rootstocks. The process of cleft grafting was applied. 209 trays were used to sow scion seeds, and 84 trays were used to sow rootstock seeds. After 25-27 days from sowing, scion tomato seedlings (*Karnack and Reem cvs*.) were grafted onto the four rootstocks at the fourth true-leaf stage because it is suitable stage for grafting. In addition, self-grafting and non-grafted plants were used as control treatments.

The grafted plants were kept under tunnel with more than 95% relative humidity and 5-10% of normal light density "shading". After 48 hours, light density was gradually increased and 48 hours more air humidity was gradually decreased for adaptation and preparation of the grafted seedlings before transplanting them in greenhouse. The grafted plants were maintained in a tunnel that provided "shading" at a relative humidity of over 95% and 5-10% of the ambient light density. The grafted seedlings were prepared for transplantation in a greenhouse by gradually decreasing air humidity and increasing light density.

Grafted seedlings were moved into net greenhouse conditions after the grafting procedure took three weeks. A growing media consist of sand, clay and compost 8: 1: 1, respectively was used. The growing media was sand in texture. The mechanical and chemical analysis of growing media, are presented in Table (2).

Experimental design

Split plot designed was adopted, with three replicates. Where, cultivars were placed in main plots and rootstocks in subplot. Each replicate consisted of 2 cultivars within 4 rootstocks, 2 treatments of self-grafted and 2 treatments of non-grafted plants of both *cvs*.

Table (1): List of rootstocks and scions used in this experiment

Cultivars		Scientific name	Specifications	Source of seeds
Root stocks	1- *Heman*	*Lycopersicon esculentum* × *Lycopersicon hirsutum.*	Resistance to S.SB.N.	Syngenta Seeds Co, Netherlands
	2- *(1G-48-6031)*	*Lycopersicon hirsutum*	Resistance to N.L.H.T.	Golden seeds Co., Greece
	3- *(1G-48-6032)*	*Lycopersicon hirsutum*	Resistance to N.L.H.T.	Golden seeds Co., Greece
	4- *Edkawy*	*Lycopersicon esculentum Mill., cv. 'Edkawy'*	Resistance to S.N.	Agric. Research Center, Egypt
Scions	1- *Reem*	*Lycopersicon esculentum Mill. cv. 'Ream'*	Indeterminate	Rijk Zwaan seeds Co., Netherlands
	2- *Karnak*	*Lycopersicon esculentum Mill. cv. 'Karnak'*	Indeterminate	Fito Co., Spain

S.SB.N.= salinity, soil born and nematode N.L.H.T.= nematode, low and high temperatures S.N.= salinity and nematode

Table (2): The mechanical and chemical analysis of growing media

A. Mechanical Properties

Moisture constants				Particle size distribution				Densities and porosity		
SP (%)	FC (%)	WP (%)	AW (%)	Sand (%)	Silt (%)	Clay (%)	Textural Class	B.D g/cm^3	P.D g/cm^3	TP (%)
32.00	14.52	6.12	8.40	93.51	4.12	2.37	Sand	1.62	2.60	37.70

B. Chemical properties

pH *	EC **	Soluble cations (mmolc/L)				Soluble anions (mmolc/L)				OM	$CaCO_3$	Gypsum
	dS/m	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Cl^{-}	$CO_3^{=}$	HCO_3^{-}	$SO_4^{=}$	(%)	(%)	(%)
7.14	1.7	13.2	7.0	25.0	0.82	10.9	0.00	2.80	32.52	0.084	1.32	1.11

Sp = Saturation percent FC = Field capacity WP = Wilting point AW = available water BD = Bulk density PD = Particle density TP = Total porosity OM = Organic matter * = 1:2.5 Soil: water suspension ** = Soil paste extract

Recorded data

Vegetative growth

Three plants in each replicate were chosen at the end of the growing season to record the plant height (cm), number of leaves per plant, stem diameter (mm), fresh and dry weight of leaves and stems/plant (g).

Plant chemical contents

Chlorophyll content of leaves was determined at flowering and fruit set stage, using of Minolta SPAD-502 Chlorophyll Meter, Minolta Co. Ltd, Japan. Samples of tomato leaves were prepared for chemical analysis according to **[18]**. Whereas samples were oven dried at 70ºC for a constant weight. Dried materials were then grounded to a fine powder and kept for chemical analyses as follow:

- Total nitrogen was determined in the digestion product, using the Micro - Kjeldahl method **[19].**
- Phosphorus was determined according to **[20].**
- Calcium and Potassium were determined photometrically in the acid digested samples by using flame photometer (Porkin Elemer mode-149) according to **[21]**.

Physical and chemical properties of tomato fruits

Total soluble solids percentage (T.S.S.) was measured using a hand refractometer **[22]**. Ascorbic acid content (Vitamin C) was determined using 2.6 dichlorophenol indo phenol method as described in **[22]**. Fruit firmness was measured on the two opposite sides of fruit using Effige Pentrometer, 2 mm probe and data in LbF recorded. In a representative sample of three fruits taken from each treatment at each harvesting time, the average fruit length and diameter were measured to calculate fruit shape index.

Yield and its components

Average fruit weight was calculated by dividing the total yield on the total number of fruits. Fruits number and weight/plant were recorded at each picking time. Then the following total yield and its components were calculated in the end of the growing season. The yield of the first three pickings was considered as early yield.

Statistical analysis

Data were subjected to the statistical analysis by the method of Duncan's multiple range test as reported by **[23]**. All statistical analysis was performed with SAS.

Results and Discussion

Vegetative Growth

Effect of cultivar of scion

Tomato plant height was not significantly affected by cultivars of scion (*Reem* and *Karnak*) when grafted on four rootstocks (*Heman, (1G-48-6031), (1G-48-6032)* and *Edkawy*). Stem diameter was significantly affected by cultivars during first season, where *cv. Reem*

recorded higher values of stem diameter than *cv. Karnak.* Meanwhile, no significant differences between both cultivars were detected during the second season. The number of leaves was not significantly affected by cultivars during the first season and was significantly affected in the second one. Whereas, *Karnak cv.* recorded the higher value of the number of leaves than *cv. Reem* as shown in Table (3) especially in the second season.

Vegetative fresh weight of tomato plant was significantly affected by cultivars of scion (*Reem* and *Karnak*) when grafted on four rootstocks and transplanted as shown in first season. But during the second one, it was not significantly affected (Table 3). Even so, *cv. Reem* recorded higher values of vegetative fresh weight than *cv. Karnak*. Vegetative dry weight of tomato plants was significantly affected in the first season and did not reach the 5% level of significance in the second one. Whereas, *cv. Reem* recorded higher values of dry weight as compared with *cv. Karnak* during both seasons.

Effect of variety of rootstocks

Data presented in Table (3) show that plant height, stem diameter, number of leaves, vegetative fresh weight and dry weight were significantly increased by four rootstocks compared to non-grafted and self-grafted of two cultivars in both seasons. Where, the highest values of plant height were represented when both cultivars were grafted on rootstock *Heman* followed by (*1G-48-6031*) and (*1G-48-6032*). The highest values of stem diameter were represented when both tomato cultivars were grafted on rootstock *(1G-48-6031)* followed by *Heman* in the first season. Meanwhile during the second one, the *Heman* and *(1G-48-6032)* rootstocks recorded the highest values. In this respect, the highest leaves numbers were represented with using rootstocks (*1G-48-6031) or Heman* then *(1G-48-6032*). The highest values of vegetative fresh and dry weight were represented when both tomato cultivars were grafted on rootstock *Heman* followed by (*1G-48-6031*) *and* (*1G-48-6032*) in both seasons. The opposite trend was obtained with self-grafted and non-grafted plants in both seasons which showed the lowest values in these parameters. Obtained results are matched with those reported by **[16, 24]** who demonstrated that grafted tomato plants improved plant growth as vegetative weight of tomato plants compared to the non-grafted plants. Furthermore, the obtained results in this investigation agree with those reported by **[12, 25]** who mentioned that grafted tomato plants onto *Heman* rootstock exhibited more vigorous growth than non-grafted ones.

Effect of rootstock-scion combinations

Concerning the effect of rootstock-scion combinations on tomato plant, grafted *cvs*. (*Reem* and *Karnak*) on four rootstocks increased the plant height, stem diameter, number of leaves, vegetative fresh weight and dry weight for grafted plants of *cvs. Reem* and *Karnak* on four rootstocks. Where, tomato plants of *cvs Reem* and *Karnak* grafted on rootstocks *Heman*, (*1G-48-6031*) and *(1G-48-6032*) recorded the highest plants and leaves number compared to those on *Edkawy*. Meanwhile the shortest plants were obtained with non-grafted and self-grafted plants of both cultivars as shown in Table (3). Obtained results are in agreement with those obtained by **[25]** who used tomato *cv. 'Big Red'* as scion and grafted on rootstocks *'Heman'* and *'Primavera'*.; **[26]** (*cv. Zhongza* on rootstocks *041-373, 031D158, Dorado, Genaros, Baofa009 and Trs-401* **[24]** *(Cecilia F_1* on three rootstocks, *Beaufort, Heman* and local Syrian tomato), and demonstrated that grafted plants were more vigorous than the non-grafted ones.

Concerning the stem diameter of tomato plant, the grafted tomato plants of *cv. Reem* on rootstock *Heman* recorded the highest values of stem diameter. Obtained results agreed with those stated by **[27]** who grafted aubergine onto wild *Solanum species* and **[26]** that used tomato *cv. Cecilia F_1* and grafted on three rootstocks *Beaufort, Heman* and local Syrian tomato. They found that the produced plants from grafting had the greatest stem diameter compared to no-grafted plants.

Regarding the vegetative fresh weight, data presented in Table (3) indicate that tomato plants of *cv. Reem* which grafted on rootstock *Heman* recorded the highest values in both seasons. Plants of *cv. Reem* which grafted on rootstock (*1G-48-6031*) recorded the highest values for dry weight in the first season. Meanwhile in the second one, *cv. Reem* grafted on rootstock *Heman* recorded the best values in this respect. Obtained results agree with those stated by **[28]** who grafted tomato (*'Rita' F_1*) and aubergine (*'Mission Bell' F_1*) on three rootstocks (*Energy, PG3 and Beaufort*)**)**; **[23]** (tomato *cv. 'Big Red'* grafted on *'Heman'* and *'Primavera'* rootstocks). and **[26] (***cv. Zhongza* grafted on *041-373, 031D158, Dorado, Genaros, Baofa009 and Trs-401* rootstocks), and demonstrated that grafted tomato plants improved plant growth as vegetative fresh and dry weight of tomato plants compared to the non-grafted plants. Meanwhile, the lowest values were obtained with non-grafted and self-grafted plants of two cultivars as shown in Table (3).

From the aforementioned results, it can be concluded that the grafting technique improved vegetative growth characters, i.e., plant height, stem diameter, and fresh as well as dry weights of shoots. Where, tomato cultivar *Reem* onto *Heman* and *(1G-48-6031)* rootstocks resulted in the highest values of vegetative growth characters. This can be attributed to compatibility between *Reem cv*. and *Heman* rootstock. This finding might be due to the strength of these rootstock compared with non- grafted plants. In general, the effects of rootstocks varied in terms of strength on plant biomass production. Strong rootstocks showed positive effects on plant biomass. Additionally, it was discovered that, in comparison to the non-grafted control, grafting a determinate tomato onto "DR0141TX" or "Estamino" rootstocks increased aboveground biomass at the conclusion of the cropping cycle **[14]**. Compared to the non-specialized rootstock and the non-grafted plants, the specialized rootstock resulted in higher plant, vegetative, and fruit biomass (on a dry weight basis) **[16, 29, 30]**. It may be due to the genetic background of the origin and its strength. Where, there has been speculation that certain resilient rootstocks are more suitable for large-fruited tomato varieties produced in lengthy cropping cycles, while other rootstocks are better suited for small-fruited tomato varieties cultivated in short cropping cycles or large-fruited varieties grown in no cropping cycles **[31]**.

Chemicals contents of tomato leaves

Effect of cultivar of scion

It appears from data in Table (4) that there is no significant effect of cultivars on chlorophyll content, N (%), P (%), K (%) and Ca (%) of tomato leaves in both seasons. Even so, *Reem cv.* recorded to some extent higher values compared with *cv. Karnak*.

Effect of variety of rootstocks

Data presented in Table (4) show that chlorophyll content and N (%) of tomato leaves was not significantly affected by trails of rootstocks in the first season but it was significantly affected in second one. Even so, grafted plants compared to non-grafted and self-grafted of two cultivars recorded the highest values of N (%) of tomato leaves (*1G-48-6032*) and *Heman* rootstocks recorded the highest values of the N (%) of tomato leaves compared to non-grafted and self-grafted of two cultivars. Obtained results are matched with those reported by **[30]** who found that leaf nutrients content of grafted tomato was nearly equal to un-grafted plants when grafted on *Solanum sisymbriyivlium*.

Such data presented in Table (4) show that P (%) of tomato leaves was significantly affected by four rootstocks compared with non-grafted and self-grafted of two cultivars. Whereas, rootstocks *Heman* followed by *(1G-48-6031*) recorded the highest values of the P (%) as compared with non-grafted and self-grafted plants of both cultivars. Obtained results are in accordance with those obtained by **[26]** who found that grafted tomato plants on, *Beaufort, Heman* and local Syrian tomato rootstocks, increased leaves content of P compared with non-grafted plants.

Data presented in Table (4) show that K (%) and Ca (%) of tomato leaves was significantly affected by four tested rootstocks compared with non-grafted and self-grafted of both cultivars. Grafted plants on rootstock *Heman* or *(1G-48-6031*) recorded the highest values of the K (%) and Ca (%), meanwhile the lowest values were recorded by non-grafted and self-grafted plants of two cultivars. Obtained results are coincided with those obtained by **[26]** who used *Beaufort, Heman* and local Syrian tomato as rootstocks and found that leaves content of K. (%) and Ca (%) increased compared to non-grafted plants.

Effect of rootstock-scion combinations

Data in Table (4) reveal that the differences regarding chlorophyll content of tomato leaves between cultivars X rootstocks were not significantly affected in first season. Although, *cv. Karnak* grafted on rootstock *(1G-48-6031)* recorded the highest values in both seasons**.**

The differences regarding N, P, K and Ca (%) of tomato leaves between rootstock-scion combinations were significantly affected in both seasons. Where, *cv. Reem* grafted on *Heman* rootstock showed the highest values in both seasons as shown in Table (4). Meanwhile the lowest values were recorded by non-grafted and self-grafted plants of both *cvs*. Obtained results are coincided with those obtained by **[26]** who found that grafted tomato *cv. Cecilia* F_1 on three rootstocks, *Beaufort, Heman* and local Syrian tomato led to increase NPK content compared to non-grafted plants.

Physical and chemical of tomato fruits

Effect of cultivar of scion

Data recorded in Table (5) clear that fruit firmness (g/cm^2), fruit shape index, acidity and vitamin C were not significantly affected by cultivars (*Reem* and *Karnak*) when grafted on four rootstocks (*Heman, (1G-48-6031), (1G-48-6032) and Edkawy*) and transplanted in both seasons. Meanwhile, a total soluble solid was significantly affected by cultivars (*Reem* and *Karnak*) where *cv. Reem* plants recorded higher values than those of *cv. Karnak.*

Effect of variety of rootstocks

No obvious trend regarding effect of various rootstocks on fruit firmness and shape index in both seasons.

Meanwhile, acidity of tomato fruits and their vitamin C were significantly affected by four rootstocks compared to non-grafted and self-grafted of both used cultivars. Where grafted plants recorded higher values of acidity compared to non-grafted and self-grafted plants of both cultivars. Obtained results are in confect with those reported by **[32].**

Effect of rootstock-scion combinations

Concerning the differences between rootstock-scion combinations, significant differences on fruit firmness, fruit shape index, total soluble solids, acidity and vitamin C were detected in both seasons. Grafted tomato plants of two *cvs*. on rootstock *Heman* were the best plants compared to self-grafted and non- grafted plants regarding fruit firmness (g/cm^2) in both seasons as shown in Table (5). Regarding the fruit shape index, grafted, tomato plants of *Reem cv.* grafted on rootstock *Edkawy* recorded the highest value in both seasons. Meanwhile, self-grafted and non- grafted plants of *cv. Reem* recorded the highest value of TSS in first season but both *cvs. Reem or Karnak* grafted on *(1G-48-6032*) rootstock recorded the highest values in second one as shown in Table (5). Obtained results are coincided with those obtained by **[25, 26, 32]**.

Concerning the vitamin C, grafted *cv. Reem* on *Edkawy* and *Heman* rootstocks recorded the highest values in first season but *cv. Karnak* on *(1G-48-6031*) rootstock followed by grafted *cv. Reem* on *Heman* and *Edkawy* rootstocks recorded the highest values in second one.

Yield components

Effect of cultivar of scion

Early yield was calculated as the yield of the first 3 pickings as shown in Table (6). Early yield was affected significantly by cultivars (*Reem* and *Karnak*) when grafted on four rootstocks (*Heman, (1G-48-6031), (1G-48-6032) and Edkawy*) and transplanted in both growing seasons. *cv. Reem* recorded higher significant early yield (g. /plant) as compared to *cv. Karnak* in both seasons. There is also significant effect of cultivars on number of fruits/plant in the first season whereas *cv. Reem* recorded the highest number of fruits/plant as compared with *Karnak cv.* Total fruit yield was affected significantly by cultivars (*Reem* and *Karnak*) in the first season but did not reach the 5% level of significance in the second one. Even so *cv. Reem* recorded higher total yield (1438.7 g/plant) than *cv. Karnak* (1362.0g /plant) as average of both seasons.

Effect of variety of rootstocks

Data presented in Table (6) show the early yield (g/plant), average fruit weight, number of fruits and total yield per plant as affected by four rootstocks compared with non-grafted and self-grafted of both tested cultivars. The highest values of these characters were represented when both tomato cultivars were grafted on all rootstocks *Heman*, *(1G-48-6031,) (1G-48-6032)* and *Edkawy* compared to non-grafted and self-grafted plants. The highest yield values (1788.7 g/plant) were represented when both tomato cultivars were grafted on rootstock *Heman* as an average of both seasons. In this respect the lowest values (1048.4 g/plant) were obtained with self-grafted plants of two cultivars as an average of both seasons. Obtained results are matched with those reported by **[25]** (*Heman* and *Primavera* rootstock); **[32]** (*Heman* and *Spirit* rootstock); **[33]** (*Beaufort* rootstock) and **[26]** (*Beaufort, Heman* and local Syrian tomato rootstock), and they demonstrated that grafted tomato plants on various rootstocks increased total yields more than non-grafted plants.

Effect of rootstock-scion combinations

Tomato plants of *cv. Reem* grafted on rootstock *Heman* and *1G-48-6031* recorded the highest values of early yield and average fruit weight than non-grafted plants. In the first season, plants of *cv. Reem* grafted on rootstock (*1G-48-6031*) recorded the highest number of fruits/plant. Whereases, grafted *cv. Karnak* on rootstock *Edkawy* recorded the highest number of fruits/plant in second season. In descending order, the total yield of tomato plants reached (1898.0, 1679.4, 1666.4. 1625.1, 1565.9 and 1404.2 g/plant) when grafted *cv. Reem* on *Heman, cv. Karnak on Heman, cv. Reem on (1G-48-6032*), *cv. Reem* on *(1G-48-6031*), *cv. Karnak* on *(1G-48-6032*) and *cv. Karnak* on *Edkawy*, respectively as an average of both seasons. Meanwhile, other trials as *cv. Karnak* on *(1G-48-6031*), *Reem* on *Edkawy*, non-grafted of *Reem*, non-grafted of *Karnak*, self-grafted of *Reem* and self-grafted of *Karnak* recorded the lowest values of total yield (1391.9, 1236.0, 1142.0, 1094.1, 1064.9 and 1031.0 g/plant), respectively as an average of both seasons.

Obtained results are coincided with those obtained by **[25]** (using tomato cv. Big Red onto Heman and Primavera); **[32]** (Cecilia F_1 cv. on two rootstocks Heman and Spirit); **[33, 34]** (tomato hybrids Compadre and Cacique on hybrid Maxifort); **[31]** Lemance F_1 on Beaufort F_1**), [23] (**Cecilia F_1 on three rootstocks, Beaufort, Heman and local Syrian tomato), and **[8, 35, 36]** they found that grafted tomato plants produced more than those of un-grafted plants.

In general, grafting both cultivars on Heman (1G-48-6031) and 1G-48-6032) rootstocks often resulted in higher overall yields than non-grafted plants by 67.3, 41%, and 50%, respectively, for the three rootstocks indicated. This is consistent with a larger body of research that indicates specific rootstocks can help producers in terms of production and fruit size even in the absence of known detrimental abiotic and biotic limitations **[8, 37]**. These data strongly suggest that increasing cultivars' fruit sizes is one way that grafting works. Increased fruit water content may contribute to the increase in fruit yield observed after grafting with vigorous rootstocks **[16, 24]**.

It was revealed that a significant factor influencing the ultimate fruit size is water accumulation. Greater water buildup results in higher fresh weight and lower dry matter content while the dry biomass of each fruit remains constant **[38]**. Additionally, earlier research has shown a significant positive correlation between the grafted tomato's yield characteristics and its total root length, root surface area, and root dry weight **[39]**. Additionally, grafted tomato plants that exhibit improved growth have been found to have a higher density of root length in the top 15 cm of the soil **[40]**. Vigorous rootstocks may be able to absorb and transfer more water due to their highly developed root systems, which could result in increased water accumulation in fruit. To better understand the function of the altered root system and investigate the contributions of fruit dry biomass and water accumulation to the total fruit yield of tomatoes grafted with vigorous rootstocks, more research is required.

Table (3): Effect of cultivar of scion, variety of rootstock and their combinations on vegetative growth of tomato plants during both seasons.

cv.	Rootstock	First season					Second season				
		plant height (cm)	Stem diameter (mm)	Leaves number	Fresh weight (g)	Dry weight (g/plant)	plant height (cm)	Stem diameter (mm)	Leaves number	Fresh weight (g)	Dry weight (g/plant)
cv. Reem		262.0^{a}	16.58^{a}	86.2^{a}	762.4^{a}	179.8^{a}	276.7^{a}	14.91^{a}	90.3^{b}	795.8^{a}	238.4^{a}
cv. Karnak		251.6^{a}	13.8^{b}	86.1^{a}	685.6^{b}	143.3^{b}	281.8^{a}	15.36^{a}	99.1^{a}	789.1^{a}	232.4^{a}
	Heman	284.1^{a}	15.6^{ab}	94.2^{a}	928.6^{a}	195.2^{ab}	313.7^{a}	17.8^{a}	113.2^{a}	1090.43^{a}	320.1^{a}
	1G-48-6031	285.2^{a}	16.9^{a}	99.0^{a}	846.6^{ab}	204.8^{a}	298.9^{b}	15.5^{bc}	108.8^{a}	892.95^{b}	269.3^{b}
	1G-48-6032	286.5^{a}	14.3^{c}	95.5^{a}	775.91^{ab}	171.8^{ab}	288.5^{b}	16.6^{ab}	105.4^{a}	823.85^{b}	257.2^{b}
	Edkawy	273.9^{a}	14.7^{b}	90.9^{a}	685.2^{b}	152.3^{b}	257.9^{c}	14.8^{c}	84.8^{b}	681.15^{c}	191.8^{c}
	Self-grafted	210.4^{b}	14.7^{bc}	71.6^{b}	566.7^{c}	134.3^{b}	262.9^{c}	13.2^{d}	75.4^{b}	636.05^{c}	188.6^{c}
	Non-grafted	201.2^{b}	14.8^{bc}	66.2^{b}	522.6^{d}	108.8^{c}	253.3^{c}	12.7^{d}	80.8^{b}	630.28^{c}	185.4^{c}
		Cultivars X rootstocks									
cv. Reem	*Heman*	290.8^{a}	17.7^{a}	93.8^{a}	1054.1^{a}	241.7^{a}	320.4^{a}	18.8^{a}	112.0^{a}	1203.1^{a}	342.7^{a}
	1G-48-6031	300.0^{a}	16.9^{ab}	101.8^{a}	934.8^{ab}	236.6^{ab}	302.5^{ab}	16.0^{bc}	105.5^{a}	907.8^{bc}	272.6^{ab}
	1G-48-6032	293.3^{a}	16.0^{bc}	95.5^{a}	800.3^{abc}	188.4^{abc}	281.0^{bc}	16.9^{ab}	99.5^{ab}	802.5^{bcdef}	265.4^{abc}
	Edkawy	273.8^{a}	15.1^{bcd}	95.5^{a}	709.3^{cde}	172.4^{abcd}	252.9^{d}	12.7^{ed}	73.9^{c}	655.2^{ef}	179.3^{d}
	cv. Reem	209.1^{b}	16.9^{ab}	68.0^{c}	539.8^{de}	125.3^{bcd}	259.2^{d}	12.7^{ed}	67.9^{c}	588.9^{f}	183.2^{d}
	Non-grafted	205.4^{b}	16.3^{ab}	63.0^{c}	500.8^{e}	109.8^{d}	244.2^{d}	12.4^{e}	82.9^{bcd}	617.4^{f}	187.4^{cd}
cv. Karnak	*Heman*	277.5^{a}	13.6^{de}	94.7^{a}	803.1^{abc}	148.7^{bcd}	312.0^{a}	16.9^{ab}	114.2^{a}	977.7^{b}	297.53^{ab}
	1G-48-6031	270.4^{a}	16.7^{ab}	96.2^{a}	758.3^{bcd}	172.9^{abcd}	295.4^{ab}	15.2^{bcd}	112.1^{a}	878.1^{bcd}	266.2^{abc}
	1G-48-6032	279.1^{a}	12.7^{ed}	95.5^{a}	751.5^{bcd}	155.2^{bcd}	295.8^{ab}	16.3^{ab}	111.2^{a}	845.2^{bcde}	248.9^{cd}
	Edkawy	274.5^{a}	12.7^{cde}	86.2^{ab}	661.1^{cde}	132.2^{cd}	262.9^{d}	16.9^{ab}	95.8^{abc}	707.0^{cdef}	204.3^{cd}
	cv. Karnak	211.6^{b}	12.4^{e}	74.7^{bc}	593.6^{cde}	143.3^{bcd}	266.7^{cd}	13.6^{cde}	82.9^{bcd}	683.2^{def}	194.0^{cd}
	Non-grafted	197.0^{b}	13.2^{de}	69.5^{c}	544.4^{de}	107.8^{a}	262.5^{d}	13.1^{de}	78.7^{cd}	643.1^{ef}	183.5^{d}

Table (4): Effect of cultivar of scion, variety of rootstock and their combinations on chemicals contents of tomato plants during both seasons.

cv.	Rootstock	First season					Second season				
		Chlorophyll reading (SPAD)	**N (%)**	**P (%)**	**K (%)**	**Ca (%)**	**Chlorophyll reading (SPAD)**	**N (%)**	**P (%)**	**K (%)**	**Ca (%)**
cv. Reem		43.68^{a}	5.20^{a}	2.10^{a}	2.60^{a}	4.30^{a}	45.54^{a}	3.70^{a}	1.90^{a}	2.40^{a}	4.66^{a}
cv. Karnak		42.34^{a}	4.50^{a}	2.00^{a}	2.90^{a}	4.46^{a}	45.32^{a}	3.60^{a}	1.70^{a}	2.20^{a}	4.53^{a}
	Heman	42.88^{ab}	5.2^{a}	2.60^{a}	3.10^{a}	4.80^{a}	46.72^{ab}	3.8^{ab}	2.00^{a}	2.50^{a}	5.10^{a}
	1G-48-6031	44.75^{a}	5.1^{a}	2.30^{ab}	3.00^{a}	4.36^{b}	47.42^{a}	3.6^{ab}	1.90^{ab}	2.60^{a}	4.93^{b}
	1G-48-6032	42.89^{ab}	5.1^{a}	1.80^{c}	3.20^{a}	4.41^{b}	47.09^{a}	3.9^{a}	1.70^{b}	2.20^{b}	4.84^{b}
	Edkawy	42.95^{ab}	5.1^{a}	2.0^{bc}	2.80^{ab}	4·37^{b}	43.80^{b}	4.0^{a}	1.80^{ab}	2.50^{a}	4·62^{c}
	Self-grafted	42.92^{ab}	4.7^{ab}	1.90^{c}	2.20^{b}	4.16^{c}	44.71^{b}	3.4^{bc}	1.80^{ab}	2.00^{b}	4.01^{d}
	Non-grafted	41.61^{b}	4.4^{b}	1.70^{c}	2.00^{c}	4.17^{c}	43.83^{b}	3.1^{c}	1.60^{b}	2.20^{b}	4.07^{d}
		Cultivars X rootstocks									
cv. Reem	*Heman*	43.05^{a}	6.59^{a}	3.10^{a}	3.30^{a}	4.67^{a}	45.25^{ab}	4.60^{a}	2.25^{a}	2.90^{a}	5.13^{a}
	1G-48-6031	43.99^{a}	4.98^{abc}	2.10^{bc}	2.70^{ab}	4.18^{b}	45.59^{ab}	3.38^{bcd}	2.12^{ab}	2.54^{ab}	5.06^{ab}
	1G-48-6032	43.49^{a}	5.05^{abc}	1.95^{bc}	3.10^{ab}	4.24^{b}	47.98^{ab}	3.64^{abcd}	1.70^{bc}	2.10^{bc}	4.74^{ab}
	Edkawy	44.99^{a}	4.55^{abcd}	1.95^{bc}	2.60^{ab}	4.25^{b}	43.23^{b}	3.66^{abcd}	1.92^{abc}	2.64^{ab}	4.70^{ab}
	cv. Reem	44.09^{a}	5.43^{ab}	1.85^{c}	2.00^{b}	4.27^{b}	44.92^{ab}	3.53^{bcd}	1.93^{abc}	1.99^{bc}	4.21^{cd}
	Non-grafted	42.44^{a}	5.40^{ab}	1.70^{c}	2.10^{b}	4.18^{b}	44.28^{a}	3.19^{cd}	1.85^{abc}	2.30^{abc}	4.15^{cd}
cv. Karnak	*Heman*	42.72^{a}	4.40^{bcd}	2.11^{bc}	3.00^{ab}	4.93^{a}	46.64^{ab}	2.95^{d}	1.83^{abc}	2.10^{bc}	5.07^{a}
	1G-48-6031	45.51^{a}	5.18^{abc}	2.48^{ab}	3.30^{a}	4.53^{ab}	49.25^{a}	3.90^{abcd}	1.82^{abc}	2.60^{ab}	4.80^{ab}
	1G-48-6032	42.29^{a}	5.15^{abc}	1.70^{c}	3.30^{a}	4.59^{ab}	46.21^{ab}	4.25^{abc}	1.80^{abc}	2.40^{ab}	4.93^{ab}
	Edkawy	40.91^{a}	4.93^{abc}	2.04^{bc}	3.10^{ab}	4.50^{ab}	44.36^{ab}	4.35^{ab}	1.75^{bc}	2.50^{abc}	4.54^{bc}
	cv. Karnak	41.75^{a}	3.86^{cd}	2.00^{bc}	2.20^{b}	4.04^{b}	43.42^{b}	3.34^{bcd}	1.65^{bc}	2.00^{bc}	3.81^{d}
	Non-grafted	40.84^{a}	3.32^{d}	1.83^{c}	1.90^{c}	4.15^{b}	43.37^{b}	2.98^{d}	1.45^{c}	2.30^{abc}	4.00^{d}

Table (5): Effect of cultivar of scion, variety of rootstock and their combinations on physical and chemical of tomato fruits during both seasons.

cv.	Rootstock	First season					Second season				
		Fruit Firmness (gm/cm²)	**Fruit shape index**	**Total soluble solids**	**Acidity**	**Vitamin C**	**Fruit Firmness (gm/cm²)**	**Fruit shape index**	**Total soluble solids**	**Acidity**	**Vitamin C**
cv. Reem		5.18^{a}	1.31^{a}	5.85^{a}	1.46^{a}	29.32^{a}	6.63^{a}	1.57^{a}	7.96^{a}	1.48^{a}	25.62^{a}
cv. Karnak		4.95^{a}	1.28^{a}	5.39^{b}	1.35^{a}	29.00^{a}	6.53^{a}	1.728^{a}	7.15^{b}	1.48^{a}	24.84^{a}
	Heman	5.00^{a}	1.29^{a}	5.49^{cd}	1.59^{a}	32.56^{a}	7.10^{a}	1.53^{abc}	7.2^{a}	1.49^{ab}	26.75^{a}
	1G-48-6031	5.30^{a}	1.23^{a}	5.73^{ab}	1.49^{ab}	28.85^{ab}	6.10^{b}	1.64^{a}	6.2^{ab}	1.51^{ab}	27.24^{a}
	1G-48-6032	5.10^{a}	1.27^{a}	5.41^{d}	1.44^{ab}	28.10^{ab}	6.70^{ab}	1.52^{abc}	6.8^{a}	1.37^{bc}	22.10^{b}
	Edkawy	5.70^{a}	1.35^{a}	5.50^{cd}	1.59^{a}	30.18^{ab}	6.20^{ab}	1.47^{c}	6.2^{ab}	1.59^{a}	25.70^{a}
	Self-grafted	5.10^{a}	1.30^{a}	5.61^{bc}	1.34^{b}	28.17^{ab}	6.63^{ab}	1.50^{bc}	6.7^{a}	1.45^{abc}	23.67^{b}
	Non-grafted	5.00^{a}	1.32^{a}	5.80^{a}	1.35^{b}	27.09^{b}	6.30^{ab}	1.63^{ab}	6.4^{a}	1.32c	25.70^{a}
		Cultivars X rootstocks									
cv. Reem	*Heman*	5.33^{a}	1.26^{abc}	5.21^{bc}	1.50^{abc}	33.19^{a}	6.90^{a}	1.51^{b}	7.49^{abc}	1.86^{abc}	27.73^{ab}
	1G-48-6031	5.73^{a}	1.30^{abc}	5.73^{abc}	1.48^{abc}	29.80^{ab}	6.81^{ab}	1.56^{ab}	7.73^{ab}	1.68^{abc}	25.78^{abc}
	1G-48-6032	5.24^{ab}	1.30^{abc}	5.45^{abc}	1.40^{abc}	28.67^{abc}	6.79^{ab}	1.56^{ab}	8.29^{a}	2.31^{abc}	23.40^{bc}
	Edkawy	4.30^{b}	1.45^{a}	5.95^{ab}	1.62^{ab}	33.20^{a}	6.14^{ab}	1.74^{ab}	7.57^{abc}	2.18^{a}	27.62^{ab}
	cv. Reem	5.23^{ab}	1.24^{bc}	6.37^{a}	1.39^{abc}	27.05^{bc}	6.67^{ab}	1.488^{b}	6.70^{bc}	1.78^{abc}	23.83^{abc}
	Non-grafted	5.25^{ab}	1.27^{ab}	6.38^{a}	1.35^{bc}	24.00^{c}	6.49^{ab}	1.56^{ab}	7.02^{bc}	1.56^{c}	25.35^{abc}
cv. Karnak	*Heman*	4.72^{ab}	1.30^{abc}	5.68^{abc}	1.68^{a}	31.93^{ab}	7.45^{a}	1.57^{ab}	6.76^{bc}	1.776^{abc}	25.78^{abc}
	1G-48-6031	4.86^{ab}	1.45^{c}	5.83^{abc}	1.50^{abc}	27.91^{abc}	5.59^{b}	1.38^{b}	7.08^{abc}	1.94^{ab}	28.70^{a}
	1G-48-6032	5.13^{ab}	1.25^{bc}	5.35^{bc}	1.49^{abc}	27.52^{abc}	6.83^{ab}	1.54^{a}	8.28^{a}	1.62^{bc}	20.80^{c}
	Edkawy	5.13^{ab}	1.25^{bc}	5.16^{bc}	1.40^{abc}	27.16^{bc}	6.31^{ab}	1.50^{ab}	7.38^{abc}	1.80^{abc}	24.15^{abc}
	cv. Karnak	4.99^{ab}	1.37^{ab}	4.93^{c}	1.30^{c}	29.30^{abc}	6.67^{ab}	1.64^{ab}	6.95^{bc}	1.68^{abc}	23.50^{bc}
	Non-grafted	4.88^{ab}	1.35^{abc}	5.40^{bc}	1.35^{bc}	30.17^{ab}	6.34^{ab}	1.62^{ab}	6.40^{c}	1.62^{bc}	26.10^{ab}

Table (6): Effect of cultivar of scion, variety of rootstock and their combinations on yield components of tomato plants during both seasons.

cv.	Rootstock	First season				Second season			
		Early yield	**Average fruit weight(g)**	**Fruit number /plant**	**Total yield (g)**	**Early yield**	**Average fruit weight (g)**	**Fruit number /plant**	**Total yield (g)**
cv. Reem		92.7^{a}	58.2^{a}	16.1^{a}	935.4^{a}	257^{a}	67.6^{a}	28.5^{a}	1927.9^{a}
cv. Karnak		62.1^{b}	59.3^{a}	14.5^{b}	843.3^{b}	218.3^{b}	66.2^{a}	28.6^{a}	1893.7^{a}
	Heman	113.5^{a}	63.5^{a}	17.4^{a}	1105.4^{a}	281.1^{ab}	83.0^{a}	29.8^{ab}	2472.0^{a}
	1G-48-6031	102.1^{a}	58.4^{a}	16.9^{a}	987.9^{a}	321.2^{a}	74.9^{ab}	27.1^{ab}	2029.1^{bc}
	1G-48-6032	100.2^{a}	62.9^{a}	16.5^{a}	1037.9^{a}	314^{ab}	69.2^{bc}	31.7^{a}	2194.4^{ab}
	Edkawy	96.8^{a}	56.5^{a}	16.4^{a}	925.8^{a}	247.5^{b}	55.8^{d}	30.8^{ab}	1718.9^{cd}
	Self- grafted	16.4^{b}	49.4^{a}	13.0^{b}	628.3^{b}	95.0^{d}	56.8^{cd}	26.5^{ab}	1506.1^{d}
	Non-grafted	35.8^{b}	56.7^{a}	11.7^{b}	650.0^{b}	167.3^{c}	60.8^{cd}	25.4^{b}	1544.6^{d}
		Cultivars X rootstocks							
cv. Reem	*Heman*	163.7^{a}	66.3^{a}	18.5^{ab}	1225.8^{a}	316.8^{bc}	76.9^{ab}	33.4^{ab}	2570.2^{a}
	1G-48-6031	174.5^{a}	54.9^{a}	19.2^{a}	1055.0^{abc}	437.9^{a}	90.3^{a}	24.3^{cd}	2195.2^{ab}
	1G-48-6032	80.8^{bcd}	64.6^{a}	17.3^{abc}	1121.7^{ab}	286.3^{bcd}	68.0^{bcd}	32.5^{abc}	2211.1^{ab}
	Edkawy	66.6^{bcd}	55.9^{a}	17.6^{abc}	990.0^{abcd}	220.0^{ced}	61.7^{bcd}	24.0^{cd}	1481.1^{c}
	cv. Reem	32.5^{d}	49.9^{a}	11.9^{de}	593.3^{f}	130.8^{ef}	50.9^{cd}	30.2^{abcd}	1536.7^{c}
	Non-grafted	38.3^{cd}	53.6^{a}	12.3^{cde}	626.7^{ef}	150.4^{ef}	60.0^{bcd}	26.2^{bcd}	1573.4^{c}
cv. Karnak	*Heman*	63.3^{bcd}	60.8^{a}	16.2^{abcd}	985.0^{abcd}	245.4^{bcde}	91.0^{a}	26.1^{bcd}	2373.8^{ab}
	1G-48-6031	29.5^{d}	63.9^{a}	14.4^{bcdd}	920.8^{abc}	204.6^{cde}	62.5^{acd}	29.8^{abcd}	1862.9^{bc}
	1G-48-6032	119.5^{abc}	60.8^{a}	15.7^{abcdd}	954.2^{abcde}	341.7^{ab}	70.2^{abc}	31.0^{abcd}	2177.7^{ab}
	Edkawy	127.0^{ab}	56.8^{a}	15.7^{abcdd}	861.7^{bcde}	275.0^{bcd}	52.0^{d}	37.6^{a}	1956.7^{bc}
	cv. Karnak	0.0^{d}	48.2^{a}	14.1^{bcdd}	663.3^{ef}	59.2^{f}	64.7^{bcd}	22.8^{d}	1475.4^{c}
	Non-grafted	33.3^{d}	60.1^{a}	11.2^{d}	673.3^{ef}	184.2^{de}	62.3^{bcd}	24.3^{cd}	1515.6^{c}

Conclusion

According to current study, grafted tomato has a significant impact on plant development, earlier reproductive development, earlier harvesting and higher fruit yield compared to non-grafted plants. Tomato grafting therefore benefits plant development and growth, fruit yield, and earliness. The variety of rootstock influences the amount of chlorophyll, which improves photosynthesis efficiency. Among the rootstocks, Heman (1G-48-6031) and (1G-48-6032) rootstocks performed the best among the group in terms of graft success percentage, field survival rate, plant growth, early harvest and higher fruit output. Concerning, rootstock-scion combinations, the *cv. Reem* grafted on *Heman* rootstock resulted in the best tomato growth, chemical composition of tomato growth and the yield. In this instance, the total yield was raised by 76.5% when it was used grafted seedling, i.e., Reem/Heman compared to non-grafted seedling, i.e., Reem.

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