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Production Systems

Growth and yield of orange (Washington Navel 141) grafted on different citrus rootstocks

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Abstract. *This investigation was conducted during 2014, 2015 and 2016 in the field of the citrus experimental station in Ciano, the general corps of scientific agricultural researches. The growth and yield of orange trees (Washington navel 141) budded on seven citrus rootstocks (Sour orange, Troyer citrange, Carrizo citrange, Citrumelo 4475, Citrumelo 1452, Macrophylla and Cleopatra mandarin) and farmed since 1989 have been studied. The results for the average of yield showed that the trees grafted on Cleopatra mandarin (58.33 kg. tree^{-1}) were significantly superior to those grafted on Macrophylla (34.17 kg. tree^{-1}). Orange trees grafted on Citrumelo 4475 and Citrumelo 1452 were significantly superior to other treatments in trunk section area of the rootstock (922.41 and 841.02 cm^2, respectively). The greatest fruit fresh weight was in trees grafted on Citrumelo 4475 (284.85 g. fruit^{-1}) which were significantly superior to those grafted on Carrizo and Troyer citrange (232.49 and 236.06 g. fruit^{-1}, respectively). The biggest total soluble solids (%) was in trees grafted on Carrizo and Troyer citrange (12.83% for both treatments) which were significantly superior to those grafted on Sour orange and Macrophylla (11.5% for both treatments), while the greatest total acids (%) was by Sour orange (2.08%) without significant differences.*

Keywords: Citrumelo, growth, navel, total soluble solids, total acids, yield

Introduction

Citrus cultivation in Syria is considered an important economic cultivation. According to the official statistics of the Ministry of agriculture and agrarian reform of Syria, in 2017 the number of orange trees in the country was about 8,717,700 trees occupying an area of 26,687 ha with yield of 722,236 t of orange fruits. The group of oranges includes several varieties, the most important of which is navel orange whose fruits are used for fresh consumption in many countries, as it is characterized by its large, seedless and easily peeling fruits (Manner et al., 2006). The most important variety of navel orange is Washington navel 141 whose cultivation has spread since 1873 in California, USA (Bitters, 1986).

Many citrus varieties including navel orange suffer from many diseases and problems. Perhaps the most important of these problems is the viral rapid deterioration disease (Tristeza), which affects the citrus tree and threatens its cultivation in the world (Ballester-Olmos et al., 1988). Fungal gum disease is also an important disease that affects citrus trees (Bitters and Batchelor, 1952). There are many other problems that citrus trees suffer from, such as relatively low temperature, lime, salinity, drought, etc., so it is important to resort to grafting on strong and disease-resistant rootstocks to increase the resistance of these citrus varieties against these problems, and thus, to increase the quantity and quality of yield when farming in different types of soils (Connelly, 2006). But the appropriate rootstock must be chosen when creating the citrus orchard. Beside rootstock adaptation to the environment and its resistance to insects and diseases and its positive impact on yield and quality, it must be compatible with the grafted variety and increase earliness and age of trees grafted on (Lacey and Foord, 2006). Anyway, using a particular rootstock seems very appropriate but may completely fail in the future including monoculture which may be the basic problem of all citrus growing estates. So, the selection of appropriate rootstock for scion cultivar may lead to the success or failure of the citrus plantation (Singh et al., 2019).

Sour orange *Citrus aurantium* L. is one of the citrus rootstocks spread throughout the world. But its popularity is decreasing due to its sensitivity to the viral rapid deterioration disease despite its many characteristics such as its good compatibility to the cultivated varieties, contributing to obtain good quality fruits, its tolerance against some diseases like Cashcsia disease, citrus exocortis viroid, fungal gum disease and Phytophthora root rot. Sour orange grows well in heavy

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soils, and it is tolerant to cold, salinity and lime. But it is sensitive to nematodes (Bitters and Batchelor, 1952; Hutchison and Grimm, 1973; Javed et al., 2008).

Citrumelo group was obtained by Walter Swingl in 1907 (Hutchison, 1974) from hybridization between grapefruit and three-leaf orange [*C. paradisi* Macf. × *Poncirus trifoliata* (L.) Raf.] and is also adopted as rootstocks around the world. This group is strong, gives homogeneous growth with a diffuse root system that is resistant to nematodes (Javed et al., 2008). It is tolerant to Triestesa, Phytophtora and citrus exocortis viroid (Castle et al., 1991), and has a moderate tolerance to salinity. It is a good rootstock for grapefruit and sweet orange since it increases their yield (Hutchison, 1974; Lacey and Foord, 2006). This group does not tolerate excess soil moisture, lime, light sandy soils and alkaline conditions, and is not compatible to lemon (Eureka) and mandarin varieties (Obreza, 1995; Bauer et al., 2004; Lacey and Foord, 2006).

Citrange group (Carrizo and Troyer) is also considered as citrus rootstocks that results from hybridization between [*C. sinensis*. (L). × *P. Trifoliata*. (L). Raf.]. It is not possible to distinguish between the rootstocks of this group by external appearance. This group is compatible with most cultivated varieties except for lemons (Eureka), and gives strong growth to section. It succeeds in most soils, and it is tolerant to cold, Triestesa, Phytophtora and nematodes, but sensitive to citrus exocortis viroid and does not grow well in calcareous and saline soils because the trees grafted on it become a subject to the lack of microelements, yield and the quality of fruits decrease (Garcia-Sanchez et al., 2003; Lacey and Foord, 2006; Javed et al., 2008).

Macrophylla (*C. macrophylla* Wester, Alemaow.) is tolerant to lime and resistant to Phytophthora (Hutchison and Grimm, 1973), but it is sensitive to Triestesa (Ballester-Olmos et al., 1988). Varieties grafted on it have strong growth and give big yield (Al-Obeed et al., 2005).

Cleopatra mandarin (*C. reticulata* Blanca.) is a common rootstock that is characterized by its slow growth in nurseries. It is tolerant to lime and salinity (Garcia-Sanchez et al., 2003). The trees grafted on it give an early yield and good quality of fruits but relatively small. This rootstock is suitable for all types of soils, and it is tolerant to Triestesa, citrus exocortis viroid and fungal gum disease, but it is sensitive to nematodes. It is compatible with most cultivated varieties, especially mandarin cultivars (Bitters and Batchelor, 1952; Lacey and Foord, 2006), and has a moderate resistance to Phytophthora (Hutchison and Grimm, 1973).

Tuzcu et al. (1998) results showed that Carrizo citrange and Citrumelo 1452 were the best rootstocks for grafting Washington navel orange trees to obtain good yield compared to Sour orange, Troyer citrange and Cleopatra mandarin. Ochoa et al. (1986) found Volkameriana and Swingle citrumelo were the best for grafting Washington navel orange in Venezuela compared to Sour orange and Troyer citrange, as the trees grafted on Volkameriana and Swingle citrumelo had the largest canopy, yield, fresh fruit weight and fruit diameter. While trees grafted on Sour orange and Swingle citrumelo gave the highest fruit juice percent, total soluble solids (TSS) and TSS:Total acids (TA) ratio compared to trees grafted on Troyer citrange. The highest fruit juice content of total acids was in the fruits of the trees grafted on Sour orange and Troyer citrange. The largest thickness of fruit peel was in trees grafted on Volkameriana and Sour orange, while the lowest was in trees grafted on Swingle citrumelo. Batchelor and Bitters (1952) noted from the results of field experiments since 1927 in Florida, USA that Cleopatra mandarin was suitable for grafting Washington navel orange trees as an alternative rootstock to Sour orange, although the grafted trees on Sour orange gave greater yield and less TA in fruit juice compared to trees grafted on Cleopatra mandarin whose percentage of total soluble solids in its fruit juice was slightly greater.

Results of a previous research by Al-Khatib (2001) showed that the largest size of canopy was in Washington navel orange trees grafted on Macrophylla, Sour orange and Citrumelo group, while the lowest size of canopy was in trees grafted on Carizzo and Troyer citrange without significant differences. The largest area of the rootstock stem section was in the trees grafted on Citrumelo 4475 and Citrumelo 1452, while the smallest area of the rootstock stem section was in the trees grafted on Sour orange and Macrophylla. Otherwise, the largest area of the graft stem section was in the trees grafted on Citrumelo 1452 and Cleopatra mandarin, while the smallest area was in the trees grafted on Troyer citrange. Studying the degree of compatibility between the rootstock and the graft depending on the matching between the area of rootstock and graft stem section showed that the compatibility was good between Washington navel orange trees and Cleopatra mandarin, Macrophylla, Citrumelo 1452 and Sour orange, while it was acceptable with Carrizo and Troyer citrange, but it was weak with Citrumelo 4475.

Ibrahim et al. (2014) found an insignificant increase in the yield of Washington navel 141 orange trees grafted on Sour orange, Citrumelo group and Citrange group, respectively. The degree of compatibility of the rootstock and the graft represented by the ratio of the rootstock stem section area to the graft stem section area varied with the progress in the age of the trees, and the degree of compatibility did not necessarily reflect the ability of the rootstock to increase the growth and yield of the trees grafted on it. Orange trees grafted on Citrumelo 4475 and Troyer citrange gave significantly the highest percentage of fruit juice by weight compared to those grafted on Cleopatra mandarin, while fresh fruit weight significantly increased in orange trees grafted on Citrumelo 4475.

Pitt et al. (2017) noticed that 29 years old Washington navel orange trees had the largest canopy and yield when they were grafted on Cleopatra mandarin compared to other rootstocks like Carrizo and Troyer citrange, and no obvious symptoms of incompatibility were observed, so they believed that the vigour differences appeared to be the result of competition rather than compatibility issues. They also observed that large fruit had lower juice content, while smaller fruit had higher juice content. On the other hand, there were no significant differences in total soluble solids between studied rootstocks. Anyway, they recommended to graft Washington navel on Cleopatra

mandarin, Swingle citrumelo (Citrumelo 4475), Carrizo and Troyer citrange to perform well.

El-Sayed et al. (2007) established that 11-year-old Washington navel orange trees budded on Volkamer lemon produced significantly higher yield, fruit length, diameter, volume, weight, rind thickness, juice volume and total juice acidity than those recorded on Sour orange rootstock, but the trees on Volkamer lemon produced fruits with lower total soluble solids and TSS:TA ratio at harvest time. El-Gioushy (2012) studied the effect of 3 rootstocks (Sour orange, Volkamer lemon and Balady lime) on young budded transplants of Washington navel orange and found that both sour orange and Volkamer lemon rootstocks resulted in relatively higher success percentage of successful grafts than Balady lime.

Ferguson et al. (1990) observed that the growth and yield of navel orange trees grafted on Cleopatra mandarin were good despite low yield in the early years but increasing with progress in the age of the trees (Castle, 1987; Forner-Giner et al., 2003). Shafieizargar et al. (2012) found that the Queen orange trees yield at the age of 10 years depends on their compatibility with the used rootstock as yield was low in the trees grafted on Citrumelo and Cleopatra mandarin, while it was moderate in the trees grafted on Sour orange, Carrizo and Troyer citrange. The smallest size of the canopy and fruits and the lowest content of juice were in the trees grafted on Cleopatra mandarin, while the largest size of fruit was in the trees grafted on Carrizo citrange compared to the trees grafted on Cleopatra mandarin and Troyer citrange. The thickness of fruit peel and TA in the fruit juice were not affected by the rootstock variation. Otherwise, the highest TSS in the fruit juice was in the trees grafted on Sour orange.

Al-Hosni et al. (2011) results showed that Hamlin orange trees grafted on Sour orange rootstock were the most productive, while trees grafted on Troyer citrange and Cleopatra mandarin were the least productive. On the other hand, Fruits from trees grafted on Cleopatra mandarin and Sour orange had the lowest fruit weight and the highest juice percentage, but fruits from trees grafted on Troyer citrange had the highest fruit weight. The lowest rind thickness was in fruits from trees grafted on Cleopatra mandarin, while the highest was in fruits from trees grafted on Sour orange and Troyer citrange. No effect of rootstocks was observed on total acids. Otherwise, fruits from trees grafted on Volkamer had the lowest total soluble solids, whereas fruits from trees grafted on Sour orange had the highest TSS and TSS:TA ratio.

Yildiz et al. (2013) noticed that Rhode Red Valencia and Valencia late orange trees budded on Troyer citrange had lower yield than those budded on Carrizo citrange and Sour orange. But trees on Troyer citrange had significantly higher yield efficiency than trees on Sour orange and Carrizo citrange, because the canopy volume of Troyer citrange was lower than the other rootstocks. The heaviest fruits of Valencia late orange trees were harvested from Carrizo citrange, while Rhode Red Valencia orange trees did not show differences regarding the rootstock. The rootstocks had no significant effects on juice content, TA and TSS:TA ratio. In another study, Benyahia et al. (2017) revealed that total cumulative yield of Valencia late sweet orange trees over five years was the highest when grafted on Citrumelo 4475 rootstock compared to most of the studied rootstocks. Otherwise, the use of Citrumelo 4475 and Citrumelo 1452 rootstocks significantly improved juice content of fruits. Concerning juice quality, Carrizo citrange, Citrumelo 1452, Citrumelo 4475 rootstocks enhanced both acid and sugar contents.

The importance of research lies in the possibility of adopting strong and disease-resistant citrus rootstocks adapted to the Syrian coast environment. This research aims to evaluate the effect of 7 rootstocks used globally in grafting citrus varieties on the growth and yield of Washington navel 141 orange trees under Syrian coast conditions.

Materials and methods

Area and period of the study

The research was carried out during 2014, 2015 and 2016 at the citrus research station of Ciano - Jableh - the agricultural scientific research center in Lattakia.

Plant material

Section: Washington navel 141 orange trees that are moderate in earliness and the color of the fruit peel is orange are used as a section. Trees were planted in 1989 with planting distances (6 x 6 m).

Rootstocks: 7 citrus rootstocks have been studied as follows:

1- Sour orange *Citrus aurantium* (L);

2- Citrumelo 4475 (*C. paradisi* Macf. × *Poncirus trifoliata* (L.) Raf.);

3- Citrumelo 1452 (*C. paradisi* Macf. × *P. trifoliata* (L.) Raf.);

4- Troyer citrange (*C. sinensis*. (L). × *P. Trifoliata*. (L). Raf.);

5- Carrizo citrange (*C. sinensis*. (L). × *P. Trifoliata*. (L). Raf.);

6- Macrophylla *C. macrophylla* Wester, Alemaow;

7- Cleopatra mandarin *C. reticulata* Blanca.

Measurements and observations

The following measurement and observations were done in the study:

1) Characteristics of growth and compatibility:

The canopy volume (m^3) was calculated by the following equation:

$$V = {}^{2}/_{3}\ \pi r^2 h,$$

Where: V- canopy volume, m^3; r- canopy radius, m; h- canopy height, m, according to Al-Khatib (2001).

The circumference and area of both the graft and rootstock stem section (above and below the grafting area by 10 cm), and the ratio between them, and the degree of compatibility between the graft and the rootstock were calculated based on the ratio between the area of the rootstock stem section and the area of the graft stem section. So, the degree of compatibility in terms of growth strength was divided into three degrees obtained and the lowest ratio is 1.11 for the trees grafted on

Cleopatra mandarin, and the highest ratio is 2.2 for trees grafted on Troyer citrange, and by subtracting the two ratios and dividing the result by the number of categories (3) we get the category range (Al-Khatib, 2001).

2) Yield and physical and chemical properties of fruits:

The average yield of 3 seasons was estimated in 2014, 2015 and 2016 (kg. tree^{-1}). The canopy load (kg. m^{-3}) was also calculated by dividing the yield of the tree (kg) by the canopy volume (m^3). 10 fruits were taken at random from each studied tree at harvest time of each season to measure the average fruit fresh weight (g), peel thickness (mm) and pulp thickness (cm) by a manual caliper and percentage of juice in relation to fruit weight. Percentage of total acids (TA) in fruit juice was determined by titration with NaOH (Palikiva, 1988). Proportion of total soluble solids (TSS) in juice was measured by using the hand refractometer. Maturity coefficient TSS:TA ratio was calculated based on the TA and TSS values obtained.

Statistical design and data analysis

A randomized complete block design was adopted with 7 treatments and 4 replications, each replicated plot was consisting of 1 orange tree (Washington navel 141) grafted on one of the studied rootstocks. So, the number of studied trees = 7 treatments x 4 replications x 1 tree = 28 trees.

Data were analyzed statistically by one-way ANOVA in a general linear model using 'SPSS for Windows' and the differences between the means were compared using the Duncan test (p=0.05). The results were presented as mean ± SD (n=4).

Results and discussion

The effect of the studied rootstocks on the characteristics of growth and compatibility with Washington navel 141 orange trees

Canopy volume: The results shown in Table 1 show that there were significant differences (p<0.05) between the treatments in the canopy volume of navel orange trees, so the trees grafted on Cleopatra mandarin and Sour orange (72.50 and 75.17 m^3, respectively) were significantly higher to the trees grafted on Macrophylla, Carrizo citrange and Citrumelo 4475 (56.39, 55.34 and 53.55 m^3, respectively).

Table 1. Effect of the studied citrus rootstocks on the canopy volume and area of the graft and rootstock stem section in Washington navel 141 orange trees (n=4)

Rootstock	Canopy volume (m^3)	Area of the rootstock stem section (cm^2)	Area of the graft stem section (cm^2)	The ratio between the area of the rootstock and graft stem section
Sour orange	75.17±7.05^a	556.73±69.09^c	541.62±229.53^{abc}	1.11
Citrumelo 4475	53.55±7.48^b	922.41±107.43^a	576.71±254.06^{ab}	2.02
Citrumelo 1452	68.33±9.70^{ab}	841.02±45.16^a	475.06a±125.29^{bcd}	1.84
Troyer citrange	65.61±6.42^{ab}	572.75±52.72^c	261.33±22.65^d	2.20
Carizzo citrange	55.34±10.72^b	536.15±47.68^c	364.95±151.15^{bcd}	1.61
Macrophylla	56.39±13.97^b	383.38±56.67^d	319.23±117.63^{cd}	1.28
Cleopatra mandarin	72.50±18.06^a	695.58±163.79^b	660.97±266.63^a	1.11

*Figures that share the same letter on the column have no significant differences, according to the Duncan test (p>0.05)

These results are consistent with the results of Al-Khatib (2001) and Pitt et al. (2017) regarding increasing the canopy volume of trees grafted on Sour orange and Cleopatra mandarin, and decreasing the canopy volume of trees when grafted on Carrizo citrange. Anyway, the results are not compatible with the results of Ochoa et al. (1986) and Al-Khatib (2001) regarding increasing the canopy volume of trees grafted on Macrophylla and Citrumelo group, and they also do not match the results of Shafieizargar et al. (2012) that showed the small volume of canopy in the trees grafted on Cleopatra mandarin. It can be concluded that there is a variation in the behavior of orange trees grafted on the studied rootstocks as they age.

The area of both the graft and rootstock stem section: As shown in Table 1, the largest area of the rootstock stem section was in the trees grafted on both Citrumelo 4475 and Citrumelo 1452 (922.41 and 841.02 cm^2, respectively) which significantly outperformed the rest of the rootstocks, followed by Cleopatra mandarin (695.58 cm^2) which significantly outperformed Macrophylla, Carrizo citrange, Sour orange and Troyer citrange. Also, the trees grafted on Troyer citrange, Carrizo citrange and Sour orange (572.75, 536.15 and 556.73 cm^2, respectively) were significantly superior to the trees grafted on Macrophylla (383.38 cm^2).

While the trees grafted on Cleopatra mandarin had the largest area of the graft stem section (660.97 cm^2), they significantly outperformed the trees grafted on Troyer citrange, Macrophylla and Carrizo citrange. The trees grafted on Citrumelo 4475 (576.71 cm^2) significantly outperformed the trees grafted on Troyer citrange and Macrophylla, while the trees grafted on Sour orange (541.62 cm^2) were significantly superior to the trees grafted on Troyer citrange (261.33 cm^2).

A study of the ratio between the area of the rootstock stem section and the area of the graft stem section showed that the largest ratio was in the trees grafted on Troyer citrange (2.2), while the lowest ratio was in the trees grafted on Cleopatra mandarin and Sour orange which approached one (1.11).

These results agreed with the results of Al-Khatib (2001), as Citrumelo group showed a significant increase in the area of the rootstock stem section compared to the rest of the rootstocks. Also, the orange trees grafted on Cleopatra mandarin and Citrumelo group gave a greater development in the area of the graft stem section. This indicates that there is no variation in the growth of the area of both the graft and rootstock stem section as the trees get older.

The degree of compatibility: The results show that there is a good compatibility for the orange trees with Sour orange, Macrophylla and Cleopatra mandarin. Also, the compatibility for the orange trees with Carrizo citrange was acceptable. However, the compatibility for the orange trees with Citrumelo group and Troyer citrange was low (Table 2). By comparing these results with the results of Al-Khatib (2001), it was found that there was a decrease in the degree of compatibility of the orange trees with Citrumelo 1452 and Troyer citrange as the trees age, and this corresponds to the results of Ibrahim et al. (2014) that showed the difference in the degree of compatibility of the rootstock with the graft represented in the ratio of the area of the rootstock stem section to the area of the rootstock stem section as the trees get older.

Table 2. The degree of compatibility between Washington navel 141 orange trees and studied rootstocks

Degree of compatibility	Category range	Category	Rootstock
1	1.11-1.47	good	Sour orange, Macrophylla and Cleopatra mandarin
2	1.48-1.83	acceptable	Carrizo citrange
3	1.84-2.20	low	Citrumelo 1452, Citrumelo 4475 and Troyer citrange

The effect of the studied rootstocks on the yield and fruit physical and chemical properties of Washington navel 141 orange trees

Yield and canopy load: The results presented in Table 3 show the significant superiority of orange trees grafted on Cleopatra mandarin in the yield (48.75 kg. tree^{-1}) to the trees grafted on Macrophylla (18.75 kg. tree^{-1}) in the 2014 season. The differences were not significant when studying the yield in the 2015 season. However, the results of the 2016 season study show that the trees grafted on Sour orange, Citrumelo and Cleopatra mandarin (82.5, 82.5 and 77.5 kg. tree^{-1}, respectively) significantly outperformed the trees grafted on Citrumelo 4475 and Macrophylla (57.5 and 55 kg. tree^{-1}, respectively). Also, the trees grafted on Troyer citrange (73.75 kg. tree^{-1}) significantly outperformed the trees grafted on Macrophylla.

The results of the study of the average yield of 3 seasons (2014, 2015 and 2016) indicate the significant superiority of the trees grafted on Cleopatra mandarin (58.33 kg. tree^{-1}) to the trees grafted on Macrophylla (34.17 kg. tree^{-1}). Anyway, there were no significant differences between the treatments in the average canopy load for the three seasons, that the trees grafted on Cleopatra mandarin had the largest canopy load (0.84 kg. m^{-3}), while the trees grafted on Macrophylla had the lowest canopy load (0.61 kg. m^{-3}).

Table 3. Effect of the studied citrus rootstocks on the yield and canopy load of Washington navel 141 orange trees (n=4)

Rootstock	2014 Yield (kg. tree^{-1})	2015 Yield (kg. tree^{-1})	2016 Yield (kg. tree^{-1})	Average yield of 3 seasons (kg. tree^{-1})	Canopy load (kg. m^{3})
Sour orange	30.00±11.55^{ab}	46.25±28.69^{a}	82.50±5.00^{a}	52.92±12.65^{ab}	0.71±0.21^{a}
Citrumelo 4475	27.50±15.00^{ab}	37.50±32.28^{a}	57.50±9.57^{bc}	40.83±14.69^{ab}	0.79±0.34^{a}
Citrumelo 1452	35.00±25.17^{ab}	43.75±17.97^{a}	82.50±12.58^{a}	53.75±14.55^{ab}	0.79±0.20^{a}
Troyer citrange	31.25±19.31^{ab}	37.50±29.86^{a}	73.75±7.5^{ab}	47.50±10.32^{ab}	0.73±0.19^{a}
Carizzo citrange	26.25±9.47^{ab}	33.75±31.98^{a}	70.00±11.55^{abc}	43.33±12.25^{ab}	0.83±0.38^{a}
Macrophylla	18.75±14.36^{b}	28.75±35.21^{a}	55.00±5.77^{c}	34.17±17.72^{b}	0.61±0.27^{a}
Cleopatra mandarin	48.75±28.40^{a}	48.75±23.23^{a}	77.50±20.62^{a}	58.33±13.40^{a}	0.84±0.31^{a}

*Figures that share the same letter on the column have no significant differences, according to the Duncan test (p>0.05)

These results contradict the results of Tuzcu et al. (1998) who preferred grafting navel orange trees on Carrizo citrange and Citrumelo 1452 for good yield compared to Sour orange, Troyer citrange and Cleopatra mandarin. Also, the results contradict the results of Ochoa et al. (1986) that showed the superiority of Citrumelo to Sour orange in the yield of the navel orange tree. However, the results of this research do not correspond to the results of Batchelor and Bitters (1952), and Al-Hosni et al. (2011) as the trees grafted on Sour orange had more yield compared to the trees grafted on Cleopatra mandarin. Anyway, the increase in yield of the navel orange trees grafted on Cleopatra mandarin as the trees get older agreed with the results of Castle (1987) and Forner-Giner et al. (2003).

On the other hand, the results differ with what Ibrahim et al. (2014) reached when studying the average yield for two successive seasons, that the increase in yield was not significant with the trees grafted on Sour orange and Citrumelo group, but the results of the research are consistent with their results with regard to the fact that the degree of compatibility does not express the ability of the rootstock in increasing the growth and yield of trees grafted on it, and this applies to Macrophylla. Also, the results differ with the results of Benyahia et al. (2017) that showed the highest cumulative yield of Valencia late sweet orange trees over five years when grafted on Citrumelo 4475 rootstock compared to most of the studied rootstocks. Otherwise, the results contradict the results of Yildiz et al. (2013) that showed a significantly higher yield efficiency in Valencia trees grafted on Troyer citrange compared to the trees on Sour orange and Carrizo citrange, because the canopy volume of Troyer citrange was lower than the other rootstocks.

Physical properties of fruits: The results given in Table 4 show a significant superiority of the grafted trees on Citrumelo 1452 in the average fruit fresh weight (284.86 g) to the trees grafted on Carrizo and Troyer citrange (232.5 and 236.06 g, respectively), while the differences were insignificant among the rest of the treatments.

Table 4. Effect of the studied citrus rootstocks on the fruit physical properties of Washington navel 141 orange trees (n=4)

Rootstock	Fruit fresh weight (g)	Peel thickness (mm)	Pulp thickness (cm)	Percentage of juice in relation to fruit weight (%)
Sour orange	242.05±26.67^{ab}	3.53±0.30^{c}	6.90±0.47^{a}	31.95±4.91^{a}
Citrumelo 4475	244.27±35.82^{ab}	4.45±0.38^{ab}	6.73±0.67^{a}	34.27±2.69^{a}
Citrumelo 1452	284.86±32.29^{a}	4.63±0.48^{a}	7.24±0.63^{a}	31.92±2.28^{a}
Troyer citrange	236.06±24.36^{b}	4.04±0.27^{bc}	6.59±0.36^{a}	33.96±0.98^{a}
Carizzo citrange	232.50±40.86^{b}	3.88±0.25^{c}	6.88±0.76^{a}	34.08±2.38^{a}
Macrophylla	275.66±5.62^{ab}	3.90±0.46^{c}	7.28±0.28^{a}	36.24±4.00^{a}
Cleopatra mandarin	250.10±34.19^{ab}	3.89±0.22^{c}	6.69±0.34^{a}	34.69±4.48^{a}

*Figures that share the same letter on the column have no significant differences, according to the Duncan test (p>0.05)

The results of the average fruit peel thickness for the three seasons show a significant superiority of the trees grafted on Citrumelo 1452 (4.63 mm) to the trees grafted on the rest of the rootstocks except for the trees grafted on Citrumelo 4475 (4.45 mm) that significantly outperformed the trees grafted on Sour orange, Carrizo citrange, Cleopatra mandarin and Macrophylla (3.53, 3.88, 3.89 and 3.90 mm, respectively). Anyway, there were insignificant differences among the treatments in the fruit pulp thickness and the percentage of juice in relation to fruit weight.

These results agree with the results of Ochoa et al. (1986) that showed an increase in the average fruit fresh weight in the orange trees grafted on Swingl citrumelo, while the results do not agree with them about the increase in the average fruit diameter and the percentage of fruit juice with decrease in the fruit peel thickness when Citrumelo was used as a rootstock for navel orange trees compared to Troyer citrange. While the results of Al-Hosni et al. (2011) indicated the lowest fruit weight and the highest juice percentage were in the fruits taken from the Hamlin orange trees grafted on Cleopatra mandarin and Sour orange, fruits from trees grafted on Troyer citrange had the highest fruit weight. Anyway, the obtained results do not agree with Ibrahim et al. (2014) results that showed a significant superiority of the orange trees grafted on Citrumelo 4475 and Troyer citrange to the trees grafted on Cleopatra mandarin in the percentage of juice in relation to fruit weight. Also, the results do not match with Shafieizargar et al. (2012) results that the fruit peel thickness was not affected by the difference of the used rootstock in grafting. On the other hand, the results contradict the results of Benyahia et al. (2017) when they showed that grafting Valencia late sweet orange trees on Citrumelo rootstocks significantly improved juice content of fruits. However, it can be said that the increase in the fruit fresh weight and peel thickness of the trees grafted on Citrumelo 1452 was considered as a positive result in terms of product quality and marketing.

Chemical characteristics of the fruit juice: As shown in Table 5, the grafted trees on Carrizo and Troyer citrange were significantly superior in the fruit juice content of total soluble solids (12.83% for both treatments) to the trees grafted on Sour orange and Macrophylla (11.5% for both treatments), while the differences were insignificant among the treatments regarding fruit juice content of total acids. Anyway, the largest maturity coefficient (TSS:TA) ratio value was in the trees grafted on Carrizo citrange (11.01), while the lowest value was in the trees grafted on Sour orange (6.73).

Table 5. Effect of the studied citrus rootstocks on the fruit chemical properties of Washington navel 141 orange trees (n=4)

Rootstock	Total soluble solids (%)	Total acids (%)	Maturity coefficient
Sour orange	11.50±0.43^{b}	2.08±1.30^{a}	6.73
Citrumelo 4475	12.42±0.42^{ab}	1.31±0.11^{a}	9.50
Citrumelo 1452	12.42±0.69^{ab}	1.30±0.24^{a}	9.75
Troyer citrange	12.83±0.80^{a}	1.45±0.13^{a}	8.85
Carizzo citrange	12.83±1.11^{a}	1.22±0.30^{a}	11.01
Macrophylla	11.50±0.79^{b}	1.21±0.23^{a}	9.67
Cleopatra mandarin	11.83±0.43^{ab}	1.36±0.12^{a}	8.72

*Figures that share the same letter on the column have no significant differences, according to the Duncan test (p>0.05)

The results of the research contradict the results of Ochoa et al. (1986) that showed an increase in TSS in the trees grafted on Sour orange and Swingle citrumelo compared to the trees grafted on Troyer citrange which had the lowest maturity coefficient value. However, the results of Yildiz et al. (2013) and Pitt et al. (2017) indicated no significant differences in TA, TSS and TSS:TA ratio between the studied rootstocks. The results also contradict the results of Batchelor and Bitters (1952) that showed a decrease in TA in the trees grafted on Sour orange compared to Cleopatra mandarin, but they match the results of Al-Hosni et al. (2011) that showed no effect of rootstocks on TA, but both TSS and TSS:TA ratio were the highest with Sour orange. Anyway, the results do not match the results of Shafieizargar et al. (2012) that showed an increase in TSS in trees grafted on Sour orange, while they match their results regarding the absence of a significant effect of the difference of the rootstock on TA. So, there is a variation in the behavior of grafted trees on the studied rootstocks about the fruit qualitative properties according to the research location and the age of the trees.

Conclusion

From the results of this research it can be concluded that grafting Washington navel 141 orange trees on Cleopatra mandarin significantly increases the yield compared to Macrophylla. Also, the average fresh weight of the fruit can be significantly increased in Washington navel 141 orange trees when grafted on Citrumelo 1452. However, the degree of compatibility of the rootstock and the graft represented by the ratio of the rootstock stem section area to the graft stem section area may differ with the age of the trees.

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References

Al-Hosni AS, Mustafa S, Al-Busaidi K, Al-Jabri M and Al-Azri H, 2011. Effects of different citrus rootstocks on growth, yield, quality and granulation of 'Hamlin' orange in Oman. Acta Horticulturae, 903, 563-568.

Al-Khatib Ali, 2001. The effect of soil calcium carbonate content on the growth of some citrus rootstocks and their tissue content of nutrients. Thesis for PhD, Department of Horticulture, Faculty of Agriculture, Tishreen University, Syria, 220 pages (Ar).

Al-Obeed RS, Harhash MM and Sourour MM, 2005. Performance of "Marsh" grapefruit and "Mexican" lime trees on seven rootstocks in Saudi Arabia. Journal of the Advances in Agricultural Researches, Fac. Agric. Saba Basha, 10, 165-179.

Ballester-Olmos JF, Pina JA and Navarro L, 1988. Detection of a Tristeza-seedling yellows strain in Spain. In: Proceeding of the 10th Conference IOCV, Riverside, pp. 28-31.

Batchelor LD and Bitters WP, 1952. High quality citrus rootstock Cleopatra mandarin, Troyer citrange rootstocks produce quick-decline tolerant trees bearing high-quality fruit. California Agriculture, September, 3-4.

Bauer MG, Castle WS, Boman BJ, Obreza TA and Stover EW, 2004. Root systems of healthy and declining citrus trees on Swingle citrumelo rootstock growing in the Southern Florida Flatwoods. In: Proceedings of the Florida State Horticultural Society, 117, pp. 103-109.

Benyahia H, Talha A, Fadli A, Chetto O, Omari FE and Beniken L, 2017. Performance of 'Valencia late' sweet orange (*Citrus sinensis*) on different rootstocks in the Gharb region (Northwestern Morocco). Annual Research and Review in Biology, Article no. ARRB.37924, 20, 1-11.

Bitters WP, 1986. Citrus rootstock: their characters and reactions. An Unpublished Manuscript, 6.

Bitters WP and Batchelor LD, 1952. Citrus rootstock problems, recommendations change as developments within citrus industry reflect influence of rootstock on tree and fruit. California Agriculture, 8-12.

Castle WS, 1987. Citrus rootstocks. In: Rootstocks for fruit crops (eds. R.C. Rom and R.F. Carlson), John Wiley & Sons Inc., pp. 361-399.

Castle WS, Pelosi RR and Lee RF, 1991. Growth and yield of young sweet orange trees on Swingle citrumelo rootstock inoculated with citrus viroids. In: Proceeding of the 11th Conference IOCV, Riverside, pp. 214-218.

Connelly M, 2006. Red-flesh grapefruit. Department of Primary Industry, Fisheries and Mines, Northern Territory Government, 1-2.

El-Gioushy SF, 2012. Physiological and anatomical studies on some factors affecting productivity and nutritional status of navel orange. Thesis for PhD, Department of Horticulture, Faculty of Agriculture, Benha University, Egypt.

El-Sayed SA, El-Saiada SAG and Ennab HA, 2007. Yield and fruit quality of Washington navel orange as affected by Sour orange and Volkamer lemon rootstocks. Journal of Agricultural Science, Mansoura University, 32, 9217-9226.

Ferguson LF, Sacovich N and Roose M, 1990. California citrus rootstocks. University of California, California, USA.

Forner-Giner MA, Alcaide A, Primo-Millo E and Forner JB, 2003. Performance of 'Navelina' orange on 14 rootstocks in Northern Valencia (Spain). Scientia Horticulturae, 98, 223-232.

Garcia-Sanchez F, Carvajal M, Cerda A and Martinez V, 2003. Response of 'Star Ruby' grapefruit on two rootstocks to NaCl salinity. Journal of horticultural science and biotechnology, 78, 859-865.

Hutchison DG and Grimm GR, 1973. Citrus clones resistant to *Phytophthora parastica*: 1973 screening results. Proceedings of the Florida State Horticultural Society, 88-91.

Hutchison DG, 1974. Swingle citrumelo - a promising rootstock hybrid. Proceedings of the Florida State Horticultural Society, 89-91.

Ibrahim AS, Ali IS, Sbeeh RN, Abboud RA and Alkaiem FS, 2014. Effect of seven citrus rootstocks on growth and production of Washington navel 141 orange. Syrian Journal of Agricultural Research, 1, 59-69 (Ar).

Javed J, Javed M, Ilyas MB, Khan MM and Inam-Ul-Haq M, 2008. Reaction of various citrus rootstocks (germplasm) against citrus root nematode (*Tylenchulus. semipenetrans* Cobb.). Pak. J. Bot., 40, 2693-2696.

Lacey K and Foord G, 2006. Citrus rootstocks for Western Australia. Department of Agriculture and Food, Farmnote, 155, 1-4.

Manner HI, Buker RS, Smith VE, Ward D and Elevitch CR, 2006. *Citrus* (citrus) and *Fortunella* (kumquat) *Rutaceae* (Rue family) species profiles for Pacific island agroforesty, P.A.R., Holoualoa, Hawai'I, 1-35 (www.traditionaltree.org).

Obreza TA, 1995. Soil $CaCO_3$ concentration affects growth of young grapefruit trees on Swingle citrumelo rootstock. In: Proceedings of the Florida State Horticultural Society, 108, pp. 147-150.

Ochoa F, Mendt R, Quintero D, Sanchez P, Gomez K and Romero G, 1986. Evaluation of citrus Tristeza virus tolerant rootstocks budded with Washington navel orange. Tenth ZOCV conference, Tristeza and related disease, pp. 113-115.

Palikiva F, 1988. Short ways of analysis fruit and vegetables. Kolos Publ. House, Moscow (Ru).

Pitt T, Skewes M, Tan J and Cox, 2017. Longevity and sustained performance of rootstocks in Lower Murray horticulture; viticulture and citrus. SARDI Project-SARMS IRSPR1-008, South Australian Research and Development Institute, 72-85.

Shafieizargar A, Awang Y, Juraimi A and Othman R, 2012. Yield and fruit quality of 'Queen' orange [*Citrus sinensis* (L) Osb.] grafted on different rootstocks in Iran. AJCS, 6, 777-783.

Singh S, Singh J and Mirza A, 2019. Evaluation of Mandarin cultivars on different rootstocks - A review. International Journal of Current Microbiology and Applied Sciences, 8, 1213-1222.

The statistical group of the Ministry of agriculture and agrarian reform, 2017. Statistics Office, Directorate of Statistics and Planning, Department of Statistics, Damascus, Syria, 17-20 (Ar).

Tuzcu O, Kaplankiran M and Seker M, 1998. The effects of some citrus rootstocks on fruit productivity of some important orange, grapefruit, lemon and mandarin cultivars in Çukurova Region. Turkish Journal of Agriculture and Forestry, 22, 117-126.

Yildiz E, Demirkeser TH and Kaplankiran M, 2013. Growth, yield, and fruit quality of 'Rhode Red Valencia' and 'Valencia late' sweet oranges grown on three rootstocks in eastern Mediterranean. Chilean journal of agricultural research, 73, 142-146.