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Yield and fruit quality of 'Queen' orange [*Citrus sinensis* (L) Osb.] grafted on different rootstocks in Iran

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Abstract

The 'Queen' orange [*Citrus sinensis* (L.) Osb.] is highly adaptable to the climatic conditions of the Southwest of Iran. However, the success of its production is highly dependent on its compatibility with rootstocks. This paper describes fruit production and quality of 10-year-old 'Queen' orange grafted on six commercial rootstocks in a five year period. 'Queen' orange trees grafted on 'Volkamer' lemon (*Citrus volkameriana* Ten. and Pasq.) (VL) produced the highest cumulative fruit yields, whereas trees on ''Swingle'' citromelo [(*Citrus paradisi* (L.) × *Ponicrus trifoliate* (L.) Raf.] (SC) and 'Cleopatra' mandarin (*Citrus reshni* Hort. Ex Tan.) (Cleo) produced the least yield. The response of grafted trees in term of fruit production was intermediate on ''Carrizo'' citrange [(*Citrus sinensis* (L.) Osb.× *Ponicrus trifoliate* (L.) Raf.] (CC), 'Troyer' citrange [(*Citrus sinensis* (L.) Osb.× *Ponicrus trifoliate* (L.) Raf.] (TC), and Sour orange (*Citrus aurantium* L.) (SO). Trees grafted on VL produced larger canopy volume than trees on the other rootstocks (32.48 m^3), while Cleo had the lowest tree canopy volume (18.87 m^3). Trees grafted on VL and CC produced the largest fruits, whereas the smallest fruits were obtained from trees grafted on Cleo and TC. Fruit rind thickness and acid content were not significantly affected by rootstocks. Fruit from trees grafted on VL had the highest juice content (43.52%), whereas fruits from trees on Cleo produced the lowest juice content (40.70%). Fruit from trees on SO had the highest soluble solids (13.50%), while those from trees on VL were the lowest (12.08%).The study revealed that the rootstocks have significant effects on most of the measured parameters, indicating that tree size, yield, and fruit quality of 'Queen' orange can be controlled by proper selection of rootstock. This study showed that VL is a good rootstock for 'Queen' orange grafting.

Keywords: Citrus, 'Queen' orange, rootstocks, fruit yield, fruit quality.
Abbreviations: Cleo-Cleopatra mandarin; VL- 'Volkamer' lemon; SC-'Swingle' citrumelo; CC-'Carrizo' citrange; SO-Sour orange; TC- 'Troyer' citrange; TSS-total soluble solids; DMRT-Duncan's multiple range tests.

Introduction

Citrus is grown in more than 100 countries in tropical, subtropical and Mediterranean climates. Iran produces more than 4 million tons of citrus fruits annually, and holds sixth place in the world citrus production. Southwest of Iran is one of the sites for citrus production in the country. Oranges are the most popular citrus crops and account for 75% of all grown citrus in this area (Ministry of Agriculture, 2009). One of the orange varieties grown extensively in Iran is 'Queen' orange [*Citrus sinensis* (L.) Osb.]. This is a midseason variety, reddish in colour, high in soluble solids and hence rich in flavour, somewhat less seedy, and holds fruits on the tree reliably. The tree is vigorous, highly productive, and somewhat resistant to cold (Reuther et al., 1967). 'Queen' orange is regarded as highly adaptable to the climatic condition of the region. Because of its high adaptability, the cultivar is being considered as a suitable alternative for the area. The use of vigorous and healthy rootstock is a key element that affects the quality and yield of citrus fruits. In the process of plants growth and development, photosynthetic substances are transferred from sources to sinks; therefore, rootstocks are very important as a source. Fruit tree rootstocks have varying degrees of tree vigour and growth, salt and/or drought tolerance, resistance to pest and diseases and leaf mineral concentration. The most common citrus rootstock used in Iran is Sour orange (Sharifani et al., 2010). This rootstock is more favourable than other citrus rootstocks due to its resistance to gummosis, high adaptability to wide range of soil conditions, and the ability to produce high quality fruits (Wutscher, 1979). However, the Sour orange has shown to have some serious problems such as susceptibility to the citrus tristeza virus, poor compatibility with some citrus cultivars, and in some cases produce low fruit yields compared with other rootstocks (Castle, 2010). These drawbacks have reduced the use of Sour orange in many countries.

Following these problems researchers and citrus growers have harnessed efforts to look for alternative rootstocks (Davies and Albrigo, 1998; Salibe, 1973; Tuzcu, 1978). For choosing a suitable rootstock, its adaptability to the soil conditions and the interactive effects with the scion cultivar has to be considered. The rootstocks significantly influence on the morphological and horticultural characteristics of the scion cultivar. Many horticultural characters such as tree growth, yield and fruit size, weight, rind thickness, juice content and total soluble solids of fruit are influenced by rootstocks (Davies and Albrigo, 1998). Fallahi et al. (1989), in a study involving 12 citrus rootstocks, reported that 'RedBlush' grapefruit with Sweet lime and 'Volkamer' lemon rootstocks produced the highest yield respectively, compared to the other rootstocks. Ghnaim (1993) reported that the yield and fruit quality of 'Shamouti' orange was markedly different when budded on different rootstocks. Similarly, significant effects of rootstocks on fruit yield and quality of 'Shamouti' orange were also detected when they grafted the orange on 15 rootstocks in Cyprus (Georgiou and Gregoriou, 1999).

They concluded that the highest yields are obtained when 'Shamouti' oranges grafted on 'Volkamer' lemon and 'Morton' citrange rootstocks. They also revealed that rootstocks significantly affected fruit size and weight, rind thickness, juice content, total soluble solids, and total acid contents. Bowman and McCollum (2006), in a study on 'Hamlin' orange grafted on 14 rootstocks, reported that fruits produced on 'Swingle' citrumelo, US-1203, and US-1205 produced fruit with low brix values, while those grafted on rootstocks US-1213 and US-1210 produced fruits with higher soluble solids concentrations. The effect of rootstocks was also reported for 'Valencia' orange, where 'Troyer' citrange was reported to produce higher yield than those on Sour orange (Abd El Motty et al., 2006). They also found that fruits from trees on 'Troyer' citrange were larger. Al-Maimoni Al-Mutairi (2008), investigated the growth yield, and fruit quality of 'Olinda valencia' orange trees grown on eight rootstocks in Riyadh, reported that the highest yield was achieved when the 'Olinda valencia' orange was grafted on Macrophylla and 'Volkamer' lemon rootstocks while those grafted on Cleopatra mandarin produced the lowest yield. The information pertaining to the effects of rootstock on the performance of 'Queen' orange is limited. The rootstocks used in this study were chosen due to the earlier or promising performance in other areas and with other citrus cultivars. Thus, this research was carried out to evaluate the vegetative growth, yield and fruit quality of 'Queen' orange, as newly introduced cultivar in agro-climatic conditions of Iran, grafted on six commercial rootstocks (Sour orange, Cleopatra mandarin, 'Volkamer' lemon, 'Carrizo' citrange, 'Troyer' citrange and 'Swingle' citrumelo).

Results

Fruit yield

Rootstocks had a significant effect on fruit yield (Table 2). The results of the effects of rootstocks on fruit yield are shown in Fig 1A. Overall, the highest cumulative yield of 'Queen' orange was obtained from the trees on VL, while the trees on Cleo and SC had the lowest yield ($p<0.01$). The trees on TC, CC, and SO produced similar yield and did not show any significant difference from each other. Superiority in fruit yield, resulted from utilization of VL as rootstock, was also recorded for 'Olinda valencia' and 'Parent Washington' navel orange (Ahmed et al., 2007; Castle et al., 2010; Zekri and Al-Jaleel, 2004) and for some other scion cultivars (Ahmed et al., 2007; Al-Jaleel et al., 2005; Castle et al., 2010; Georgiou and Gregoriou, 1999; Zekri, 2000).

Canopy volume

Rootstocks had a significant effect on canopy volume (Table 2). Trees grafted on VL, SO and CC exhibited the highest canopy volume, which was significantly different from trees on the other rootstocks. Strong evidence of smaller canopy volume was observed in SC and Cleo grafted trees (Fig 1B). The findings of this study are consistent with the results of some previous researchers (Bassal, 2009; Castle, 1987; Castle et al., 2010; Yildirim et al., 2010).

Fruit diameter

Fruits from trees on VL and CC were significantly bigger than those produced on other rootstocks, whereas the smallest fruits were obtained from trees budded on Cleo and TC rootstocks, as depicted by the fruit diameter (Fig 1C). The diameter of fruits from trees on SO and SC were smaller than fruits from trees on VL and CC but there were no significant differences in fruit size among trees on SO and SC. It is apparent from the results that fruit size is greatly influenced by both rootstock and rootstock/scion combination. The importance of rootstock in enhancing fruit size of citrus has been reported by authors (Al-Jaleel and Zekri, 2002; Al-Jaleel et al., 2005; Yildirim et al., 2010; Zekri, 2000; Zekri and Al-Jaleel, 2004).

Rind thickness

Thickness of the rind has a significant importance to overall citrus quality both at pre-harvest and postharvest stages. Fruits with a thick rind would be more resistant to fruit splitting problem at farm stage and handling damage at postharvest stage. However, such fruits tend to have lower juice content. Therefore, fruits with a thicker rind would be less important in fruit destined for juice production compared with those for fresh consumption.

Table 1. The soil chemical analysis of the experimental site.

Depth (cm)	Electrical conductivity ($dS.m^{-1}$)	pH	Total nitrogen ($g.kg^{-1}$)	Organic carbon ($g.kg^{-1}$)	Available P ($mg.kg^{-1}$)	Available K ($mg.kg^{-1}$)
0-30	0.9	7.5	0.050	0.6	8	140
30-60	1.1	7.3	0.046	0.33	6	130

Table 2. Analysis of variance for fruit yield, canopy volume, fruit diameter, rind thickness, juice content, total soluble solids and acid content of 'Queen' orange trees on six rootstocks.

Source of Variance	df	Fruit Yield	Canopy volume	Fruit diameter	Rind thickness	Juice content	Total soluble solids	Acid content
Year	4	66930.69**	1984.43**	0.001 ^{ns}	10.34 ^{ns}	75.34 ^{ns}	75.09 ^{ns}	2.626 ^{ns}
Error	15	1085.96	10.58	2.136	2.30	28.40	35.82	1.184
Rootstock	5	15650.86**	381.73**	0.561**	1.79 ^{ns}	13.03*	15.12**	2.458 ^{ns}
Year × Rootstock	20	14598.56**	6.15 ^{ns}	0.032 ^{ns}	0.55 ^{ns}	5.11 ^{ns}	4.52 ^{ns}	0.109 ^{ns}
Error	75	3496.77	27.10	0.049	1.43	4.53	4.38	0.229
CV(%)		21.77	20.96	4.63	6.45	5.30	5.35	4.64

Note: *, **, and ns – denote significant difference at $P<0.05$, $P< 0.01$ and not significant, respectively.

In general, vigorous rootstocks like VL would induce thick rind fruit (Al-Jaleel and Zekri, 2003) and this is clearly shown in this study (Fig 1D). The findings of the current study are consistent with the results of previous studies (Bassal, 2009; Garcia–Sanchez et al., 2006; Tuzcu, 1978; Wutscher and Shull, 1976; Yildirim et al., 2010) but in contradiction with those reported by some other researchers (Al-Jaleel and Zekri, 2002; Muhtaseb and Ghnaim, 2006).

Juice content

Results in Table 2 show that juice content was significantly affected by the rootstock. Fruits from trees on VL had the highest juice content but it was not significantly different from those produced by trees on TC, CC and SC. Among the rootstocks tested, fruits produced by trees on Cleo contained less juice (Fig 2A).

Total soluble solids

Result in Table 2 revealed that rootstocks exhibited a significant impact on TSS of the juice of 'Queen' orange. The soluble solids concentrations in fruits from trees on SO was the highest (13.50), whereas TSS was the lowest for fruits from trees budded on VL (12.08%) (Fig 2B).

Acid content

Acid content in the juice extracted from 'Queen' orange was not affected by the rootstocks (Table 2). Despite of non-significant difference in acid content among rootstocks, fruits from trees on TC tended to have a higher acid content (Fig 2C). Fruits from trees grafted on VL had a tendency to lower acid content. The lack of clear effect of rootstock on acid content of citrus is a common phenomenon recorded in similar studies (Al-Jaleel and Zekri, 2003).

Discussion

Yield difference among rootstocks and their interactions with different citrus cultivars could be attributed to differences in morphology and physiology of rootstocks, which are reflected as tree growth vigour, size and depth of roots, water and nutrients uptake capability, carbohydrate synthesis, and also their adaptation to climatic and soil conditions, good compatibility between rootstock and cultivar and the possibility of fruiting potential of a cultivar on certain rootstocks (Continella et al., 1998; Zekri and Parsons, 1989). The compatibility between rootstock and scion is very important to achieve sufficient yield. These various characteristics of rootstocks can affect growth, fruiting, and fruit quality of the scion cultivar. Sour orange, the most common citrus rootstock, produced high quality fruits but smaller sized fruits out of marketable grade. In contrast, the 'Volkamer' lemon produced good quality marketable sized moderate number of fruits and proved as a reliable rootstock for 'Queen' orange. 'Volkamer' lemon usually produces a scion with an extreme vigour, great tree size, and large fruit. Induction of fruit production by 'Volkamer' lemon rootstock may be linked to its ability to generate a more extensive rooting system that would absorb more water and nutrients (Reuther et al., 1967). Trees with a bigger canopy volume would have a larger leaf area index and may produce larger amount of assimilates and this would support the production of more fruits.

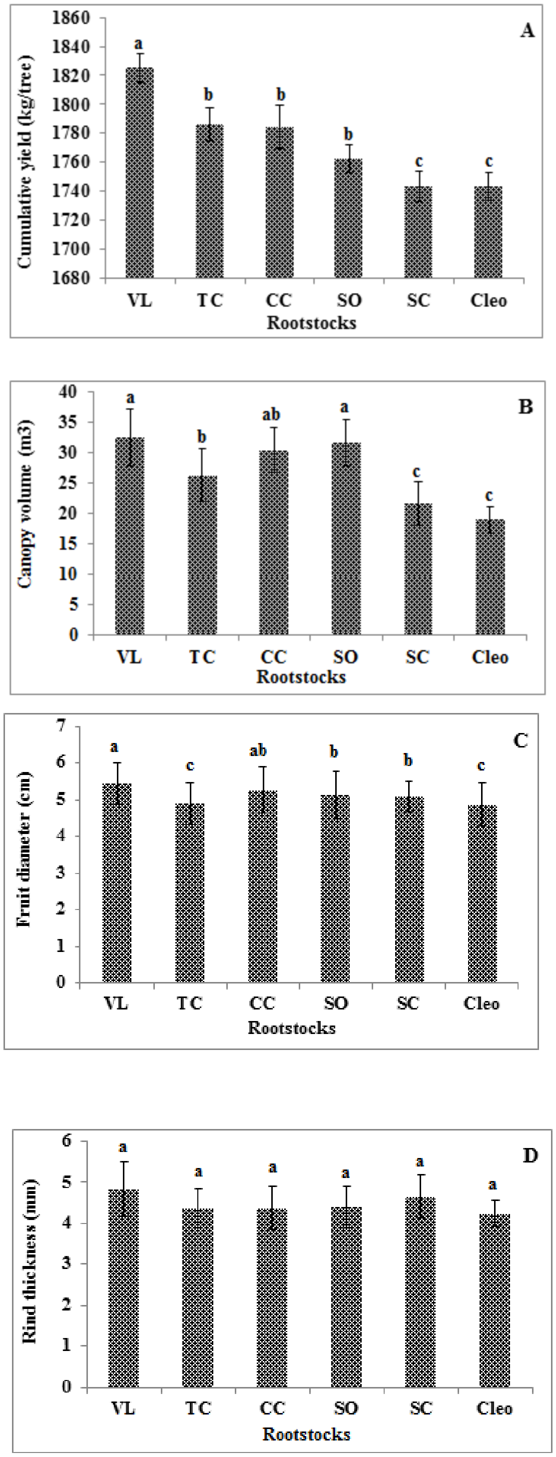

Fig 1. Effect of rootstocks on cumulative yield (A), canopy volume (B), fruit diameter (C) and rind thickness (D) of 'Queen' orange. Bars indicate ±SE. Bars with different letters indicate significant differences among means according to DMRT at P<0.05.

Such trees could also possess a higher number of fruiting sites. However, excessive foliar production on a fruit tree could exert a competition on fruit growth and retention. Therefore, a proper balance between vegetative and reproductive growth may need to be looked into when selecting a suitable rootstock for a scion cultivar. Therefore, no clear relationship exists between fruit yield and canopy size in this study. For example, trees on VL which had the largest canopy (32.48 m^3) produced the highest yield (1825 kg/tree/5years). However, in the case of trees on TC, albeit of having relatively small canopy (26.23 m^3) but the trees produced yield as high as those produced by trees on SO which have much larger canopy volume (31.59 m^3).

In citrus, larger fruits would receive a higher consumer preference and fetch higher price. Apparently, the result of fruit diameter and hence fruit size is closely associated with the accumulated fruit yield. This is clearly shown in the case of fruit produced by trees on VL and CC with their respective diameter of 5.43 and 5.25 cm which produced higher fruit yield compared with trees on other rootstocks. The results suggest that fruit size which may be measured by fruit diameter or fruit weight could be regarded as an important selection parameter in citrus rootstock evaluation. Furthermore, as fruit size is highly affected by many growth factors such as nutrients and water availability and extensive rooting system, it could have contributed to the bigger fruits of trees on VL and other vigorous rootstocks. The juice percentage in the fresh citrus fruit is considered to be very important factor due to the increasing demand in fruit juice consumption. Results regarding the fruit juice production showed 'Volkamer' lemon was superior and produced the highest juice percentage (43.52) which makes it an ideal rootstock for this purpose. These findings are in harmony with those of Ahmad et al. (2006) for 'Kinnow' mandarin who found that the highest juice content was with VL rootstock. The concentration of sugar which is represented by total soluble solids (TSS) in this study is important as it determines the taste of fruits.

In the juice industry, fruits are sold based on the amount of soluble solids content and therefore the growers are interested to maximize the productivity of soluble solids. As shown in the results, maximum TSS was recorded in Sour orange rootstock (Fig 2B). The excellent performance of Sour orange is due to the inherent characteristics of this rootstock. The result is in agreement with those of Georgiou and Gregoriou (1999) for 'Shamouti' orange, who found that fruits from trees on 'Morton'

citrange, Sour orange and *C. amblycarpa* had the highest Brix. Similar results were recorded for 'Clementine' mandarin (Georgiou, 2002) and 'Allen' Eureka lemon (Zekri, 2000). Working with 'Parent Washington' navel, Al-Jaleel and Zekri (2003) reported that fruits from trees on Sour orange and 'Cleopatra' mandarin had the highest TSS as compared with fruits of trees on other rootstocks. Generally, some vigorous rootstocks such as VL and rough lemon, which normally have an extensive rooting system, are able to absorb more water and produce heavy crop loads with higher juice content but this is sometimes coupled with low TSS. Some other rootstocks such as Sour orange and 'Cleopatra' mandarin produce fruits with lower juice content but with high TSS (Reuther et al., 1967).

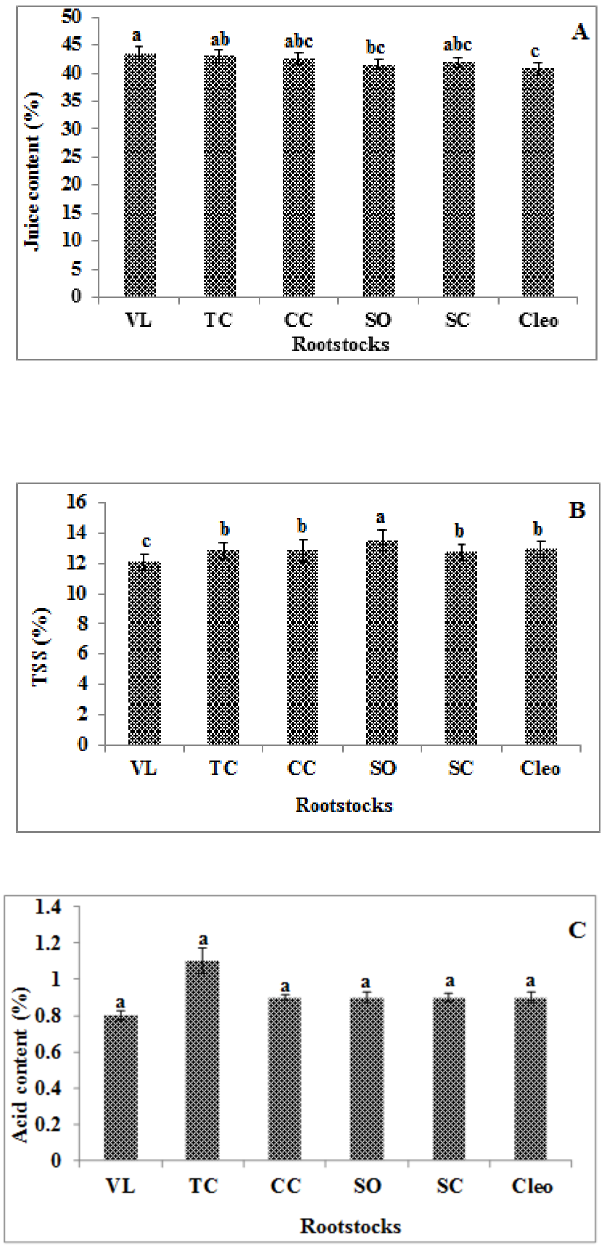

Fig 2. Effect of rootstocks on juice content (A), total soluble solids (TSS) (B) and acid content (C) of 'Queen' orange. Bars indicate ±SE. Bars with different letters indicate significant differences among means according to DMRT at P<0.05.

Materials and methods

Experimental site

This study was conducted in Safiabad Agricultural Research Centre in Southwest of Iran at latitude 32° 16´ N and longitude 48° 25´ E, 82 m above the sea level. This area has a sub-tropical climate with 348 mm mean annual precipitations, mean annual temperature of 24.8°C (temperature range: -5 to 52.4°C) and 48% mean annual humidity. Soils are calcic with 48% calcium carbonate and a pH between 7.8 and 8.0. Salinity of the soil extract is less than 1 dS/m. Table 1. shows the results of soil chemical analysis of the experimental site.

Plant materials and orchard management

The 'Queen' orange orchard used in this study was established in December 1998 with a 6.0 m × 6.0 m planting distance. The trees were budded on six rootstocks, namely 'Cleopatra' mandarin (*Citrus reshni* Hort. Ex Tan.) (Cleo), 'Volkamer' lemon (*Citrus volkameriana* Ten. and Pasq.) (VL), 'Swingle' citromelo [(*Citrus paradisi* (L.) × *Ponicrus trifoliate* (L.) Raf.] (SC), 'Carrizo' citrange [(*Citrus sinensis* (L.) Osbeck × *Ponicrus trifoliate* (L.) Raf.] (CC), Sour orange (*Citrus aurantium* L.) (SO), and 'Troyer' citrange [(*Citrus sinensis* (L.) Osbeck × *Ponicrus trifoliate* (L.) Raf.] (TC). Seeds of all rootstocks were locally obtained from selected healthy trees of citrus rootstock collection by the Safiabad Agricultural Research Centre in Iran. The trees were fertilized with 3.0 kg N/yr (as urea, 1.5kg in first of October and 1.5kg in middle of March), 1.0 kg P_2O_5 (as superphosphate, end of January) and 1.0 kg K_20/yr (as potassium sulphate, middle of February). Foliar applications of iron and zinc were also conducted at the rate of 200 g per tree at the end of March. Trees were irrigated once a week from mid-April to end of September. Shoots of rootstocks were removed regularly and pests and diseases were controlled using suitable management procedures. Mungbeans were grown as a cover crop in the space between trees as green manure and at the same time to reduce heat, and increase air humidity in the summer.

Data collection

Trees were grown for 10 years (1998-2007) and data were collected for the last 5 years of that mentioned period. The canopy volume (three trees/ plot) was measured and calculated according to the equation previously used by Wutscher and Hill (1995), i.e. Volume = (Tree diameter^2 - Tree height)/4. To determine cumulative yield, fruits from three trees/ plot were harvested and weighed beginning from 1st of December each year for five consecutive years from 2003– 2007. The size of the fruit was determined by measuring the fruit diameter at the equator with a digital calliper (Mitutoyo CD-15CPX). The rind thickness of the same fruits was also measured after cutting the fruit into half (Forner-Giner et al., 2003). For fruit quality analysis, random samples of 30 fruits from each plot (10 fruits/ tree from three trees/ plot) were taken and analyzed for percent juice content, TSS and acid content. These parameters were determined according to methods approved for Florida citrus quality tests (Wardowski et al., 1995).

Statistical analysis

The study was conducted in a complete randomized block design and consisted of three trees per plot with four replications. Data were collected and analyzed using MSTAT-C software and the means compared by the Duncan's multiple range tests (DMRT) at the ≤ 0.05% level of probability.

Conclusion

The study revealed that rootstocks produced marked effects on most of the parameters measured; suggesting that tree size, yield, and fruit quality of ‘Queen’ orange can be controlled by proper selection of rootstock. Trees budded on VL produced the highest fruit yield and largest fruits while Cleo and SO induced the highest percentage of juice and soluble solids, respectively. On the other hand, rind thickness and acid content were not affected by the rootstocks. Therefore, it was found that VL is a good rootstock for ‘Queen’ orange.

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